Commonsense Reasoning about Processes: A Study of Ideas About Reversibility

by

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Abstract

In recent years, research in students' conceptions about the physical world has revealed that when children reach the age of schooling they have already developed their own knowledge about the physical world which is sometimes rather different from the accepted scientific knowledge taught in schools. This thesis aims at investigating possible structures of commonsense reasoning about reversibility related to processes of interest to Science presented by students from two age-groups, 13/14 year old and 16/17 year old.

The study has a theoretical framework based upon the scientific view of reversibility mainly related to Thermodynamics. It is also related to a conceptual, commonsense and developmental perspective taken from the literature, where reversibility is connected with different concepts such as causation, action, and conservation. Therefore, based upon this framework some very basic questions were asked to students about a selected number of phenomena.

The empirical data was collected with the use of questionnaires. The sample consisted of two different age/instructional groups of students from England, Chile and Brazil. Factor Analysis was used to analyse the quantitative data. The qualitative data was analysed using a systemic network in which students' answers could be categorised.

The main result of the quantitative analysis was a common three dimensional factor space of explanation for all groups with the dimensions relating to the ways in which the processes could be seen. They are respectively the contrast between 'can happen and cannot happen', 'needs an action and happens by itself', and 'has a goal and has no goal'. Phenomena can be located in this common space, but their position may vary for different age/instructional groups and for groups from different countries. The results of the qualitative analysis give a more detailed description of the way students see the reversibility of the processes and lend support to the quantitative results.

The concepts initially formed by abstraction from particular situations or experimental complexes acquire a life of their own.

Werner Heisenberg

To my father, for his determination (*in memorium*),
To my mother, for her perseverance,
To my brother, for his passion for life,
To my sister, for her love.

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Introduction

1.1 The Context of the Research

In recent years, many studies have dealt with the content of students' ideas in science. A number of studies have demonstrated that when children reach school age they have already developed their own knowledge about the physical world, and often this knowledge is rather different from the accepted scientific knowledge taught at school (e.g. Driver and Easley, 1978). Therefore, when asked to explain any phenomenon in nature, students use this knowledge to construct their own explanation about the world.

At the beginning these studies had mainly a descriptive perspective, in which conceptions were detected and reported under different labels such as 'misconceptions' (e.g. Doran, 1972), 'preconceptions' (e.g. Novak, 1977). Such results connected with the increasing trend towards a constructivist view of the learning process, which led the studies to regard the everyday experience of the student, as what underlies 'misconceptions' (e.g. Driver and Erickson, 1983; Gilbert and Watts, 1983). The focus has recently shifted to examining how people reason using their own knowledge to explain a phenomenon, or how they explain a phenomenon, trying to make sense of how they make sense of their own ideas (Ogborn, 1985, Guidoni, 1985, di Sessa, 1988).

Within this view, a specific focus is on the understanding of people's knowledge about things in Science, in terms of commonsense forms of reasoning, to attempt to look at fundamental categories of thought. In this context, commonsense reasoning is understood as ordinary, everyday, unreflective, practical reasoning about things which are mostly seen as obvious (Ogborn, 1989).

The objective of these studies is to understand processes or modes of reasoning about entities and events, which also happen to have a different description in Science. Some focused on relating peoples' knowledge of the physical world to underlying forms of commonsense reasoning about objects and events in this world (Whitelock, 1991; Mariani and Ogborn 1991, 1993). Commonsense knowledge of the physical world is characterised as essentially the way one experiences and senses this world and supported by forms of reasoning which are seen as able to be described in terms of some fundamental dimensions of commonsense reasoning.

The present research is carried out within this last perspective. This research does not concern students' understanding of specific scientific concepts, rather it focuses on the way they reason about processes in terms of their commonsense knowledge about the physical world. The focus is on commonsense reasoning about processes and the way they are thought of as reversible or not.

In contrast to the commonsense perspective, in the scientific view processes (and their reversibility) are explained in terms of clear definitions delimiting in which way any phenomenon in nature can happen. From the thermodynamic account, through the statement of the Second Law of Thermodynamics, any process regarded as natural or spontaneous is irreversible; that is, the reverse of a natural process does not happen naturally. Thus the two accounts of reversibility need to be understood in relation to one another, identifying their differences and similarities, and seeking to understand the origin of the commonsense view.

Another source for understanding the commonsense view is to look at the way people conceive scientific concepts (see for example Pfundt and Duit, 1989), because this is related to how they explain phenomena in nature, and therefore may influence the way they reason about the reversibility of these phenomena . Looking at 'how' they explain a phenomenon in terms of forms of reasoning related to concepts such as necessity, contingency, causation, action, and teleology, which can also be related to a Piagetian developmental psychology view, could also help in analysing their ideas (see for example Ogborn, 1992b).

Therefore, taking into account these four views, the basic proposal of this research is to investigate whether it is possible to find a description of the basic elements which students use in their everyday life, to reason about processes and their reversibility and to try to give an account of the relationship between commonsense reasoning and scientific reasoning in this area. If this description is possible, another aspect will be to see what would be its implications for the teaching of the scientific ideas about reversibility.

1.2 The Organisation of the Thesis

The thesis is presented in ten chapters as described below.

Chapter 2 gives an account of reversibility from a scientific view. The emphasis is on equilibrium thermodynamics, with a short discussion of non-equilibrium thermodynamics, which is required for a discussion of the reasons why commonsense and scientific reasoning about reversibility differ.

Chapter 3 presents a review of literature focusing on studies about students' conceptions within three different views: a descriptive perspective, where instances of specific conceptions held by students are reported; a commonsense forms of reasoning perspective, where studies also focus attention on attempting to explain regularities presented in students' responses in terms of underlying commonsense forms of reasoning; and a developmental psychology perspective, where the results are discussed within this view.

Chapter 4 describes the conception of the research, in terms of the four different foci outlined in Chapter 2 and Chapter 3: thermodynamic, conceptual, commonsense and developmental, from which the research questions have arisen. This chapter also describes the design of the empirical work for an exploratory pilot study.

In Chapters 5 and 6 the results of the exploratory pilot study are presented. In Chapter 5 the quantitative analysis is described, and Chapter 6 presents the qualitative analysis.

The main study, whose design is influenced by the results of the pilot study is described in Chapter 7. The main study was carried out with five different age/instructional/cultural groups: 13/14 year old and 16/17 year old students from England and Chile and 16/17 year old students from Brazil.

Chatters 8 and 9 describe the results of the main study following a similar procedure used for describing the pilot study in Chapters 5 and 6.

Finally, in Chapter 10 the conclusions of this research are presented and discussed in terms of the broader context set by Chapters 2 and 3.

2

Reversibility: A Scientific Perspective

The purpose of this chapter is to give a scientific account of the concept of reversibility. The focus is mainly on the equilibrium thermodynamics standpoint, including a short discussion of non-equilibrium thermodynamics.

2.1 System, Surrounding, Universe

The study of thermodynamics or mechanical phenomena starts with a separation of the region of interest in order to have a clear idea of what is to be analysed. That part which is set aside in the imagination and on which the attention is focused is called the *system* and everything outside this region which has a direct connection or influence on its behaviour is known as the *surroundings*. The system and its surroundings together are called the *universe*. Once a system has been chosen the next step is to describe it in terms of quantities that will be helpful in discussing the behaviour of the system or its interactions with the surroundings or both, and these quantities need to be chosen according to the kind of analysis to be made. In general there are two points of view that may be adopted: the macroscopic and the microscopic point of view.

In the macroscopic view the quantities chosen refer to the gross, or large-scale properties of the system and usually have the following characteristics:

• They do not involve any special assumptions concerning the structure of matter;
• Only a few quantities are needed;
• They are suggested more or less by some of our sense perceptions;
• They can in general be directly measured.

That is, the macroscopic description of a system involves the specification of a few fundamental measurable properties of the system.

On the other hand, on the microscopic view the quantities chosen refer to properties of individual elements that make up the system and involve the following characteristics:

• Assumptions are made concerning the structure of matter;
• Many quantities must be specified;
• The quantities specified are not directly suggested by our sense perception;
• These quantities cannot in general be directly measured.

These two points of view are related in the sense that when both are applied to the same system, they must agree in the end. The relation between them lies in the fact that the few directly measurable properties whose specification constitutes the macroscopic description are really averages over a period of time of a large number of microscopic characteristics.

Consider the macroscopic quantity pressure for instance: pressure is a property that is perceived by our senses; we can feel the effects of pressure. And besides, pressure was experienced, measured and used long before physicists had reason to believe in the existence of molecular impacts which explain pressure as the average rate of change of momentum due to all the molecular collisions made on a unit of area. If, by any chance, the molecular theory changes in the future, the phenomenon of pressure will still remain to be accounted for, though it may at some level change its meaning[1].

Herein lies the important distinction between the macroscopic and microscopic points of view: the microscopic view goes further than our senses, it postulates the existence of molecules, their motion, collisions, etc. We can never be sure that the assumptions are justified until we have compared some deduction based on these assumptions with observations or deductions based on the macroscopic view.

[1] As for example the General Theory of Relativity changes the meaning of mass or of space.

2.2 Macroscopic Views of Mechanics and Thermodynamics

In the macroscopic views of mechanics and thermodynamics, there is a fundamental difference in relation to the aspects on which the attention is focused. In the mechanics of a rigid body, only the external aspects of the rigid body are considered. The position of its centre of mass is specified with reference to coordinate axes at a particular time. Position and time and a combination of both, velocity, constitute some of the macroscopic quantities used in mechanics and are called *mechanical coordinates*. The mechanical coordinates serve to determine the *external or mechanical energy* of the rigid body with reference to the coordinate axes. It is the purpose of mechanics to find such relations between these coordinates and the time as are consistent with some basic laws of motion. The equations of motion, in classical mechanics, are symmetrical with respect to time. If the sign of 't' is reversed, the equations still hold. Thus a purely mechanical system is perfectly reversible (strictly speaking, when all the forces derive from potentials).

In Thermodynamics, however, attention is directed to the interior of a system. A macroscopic point of view is adopted, but only those macroscopic quantities which are related to the internal state of a system are considered. It is the function of experiment to determine the quantities that are necessary and sufficient for such a purpose. Macroscopic quantities related to the internal state of a system are called *thermodynamic coordinates*. Such coordinates serve to determine the *internal energy* of a system. It is the purpose of thermodynamics to find general relations among the thermodynamic coordinates that are consistent with the fundamental laws of thermodynamics. Thermodynamic processes are not in general reversible.

2.3 Thermodynamic Equilibrium

When a system is left to itself its properties will, in general, change with time. For instance, if there are variations in pressure or elastic stress within the system, parts of the system may move, or may expand or contract. If there is dissipation, then eventually these motions, expansions, or contractions will cease and when this has happened we say that the system is in *mechanical equilibrium.*

However, if we are dealing with thermodynamics, it is necessary to consider more than the purely mechanical equilibrium of a system. When a system in mechanical equilibrium does not tend to undergo a spontaneous change of internal structure, such as a chemical reaction, or a transfer of matter from one part of the system to another, such as diffusion or solution, then it is said to be in a state of *chemical equilibrium.* However, such approaches to equilibrium may be very slow; if so the system is in a *meta-stable* state.

Thermal equilibrium exists when there is no spontaneous change in the coordinates of a system in mechanical and chemical equilibrium. In thermal equilibrium, all parts of a system are at the same temperature, and if it is in thermal contact with the surroundings, then its temperature is the same as that of the surroundings.

When the conditions for all these three types of equilibrium are satisfied, the system is said to be in a state of *thermodynamic equilibrium* and can be described in terms of thermodynamics coordinates referring to the system as a whole. By definition, there is no tendency for any change of state of the system to occur.

States of thermodynamic equilibrium can be described in terms of macroscopic coordinates that do not involve time. Thermodynamics tells us about some characteristics of the system and how they are related to various of its properties, but it does not explicitly state anything about the time variation of these properties (in contrast to the equations of mechanics and electromagnetism).

2.4 Process and Quasi-static Process

When the state of a system changes, either spontaneously or through interaction with the surroundings, in general the system will pass through non-equilibrium states. However, if it is desired during a process to describe every state of a system by means of thermodynamic coordinates referring to the system as a whole, the process must not be brought about by great variations from equilibrium. We have to conceive an ideal situation in which at every instant the system departs only infinitesimally from a equilibrium state. A process performed in this ideal way is said to be *quasi-static*. Such a process is reversible, in the thermodynamic sense. An infinitesimal departure from equilibrium can just as well be in one direction as the opposite.

2.5 The First Law: Energy, Heat and Work

The comprehension of the nature of heat and work as *processes*, not *entities* is the basis of the First Law of Thermodynamics, which lays down that energy is always conserved in a physical process. That it is energy which is conserved, not heat, was the essential result of the work of Mayer, Joule and Kelvin in the last century.

Heat and work are terms relating to the transfer of energy. *To heat* an object means to transfer energy to it in a special way, making use of a temperature difference between the object to be heated and a hotter one. *To cool* an object is the negative of heating it: energy is transferred out of the object under the influence of a difference in temperature between it and something colder. So, it is important to realise that heat is not a form of energy: *heat is the name given to energy being transferred under a temperature gradient.*

The same is true of work. Work is what is done when it is needed to change the energy of an object by means that do not involve temperature differences. Thus, lifting a weight from the floor and moving a car to the top of a hill involve work. Like heat, work is not a form of energy: *work is the name given to energy being transferred other than under a temperature gradient.*

Therefore, when it is said 'heat is converted into work', in a steam engine, for example, it has to be understood that this is an informal way of saying 'energy is transferred from a source by heating and some is then transferred by doing work', with work simply meaning a more useful and organised mode of transferring energy.

2.6 The Second Law: The Statement of Nature's Asymmetry

From the standpoint of the First Law, the consequences of a flow of energy into a system from a hot reservoir may be identical with those of the performance of the same quantity of work done on the system. In both cases, the internal energy of the system is increased by the same amount. However, there is law which discriminates these cases by stating a distinction between these two kinds of energy transfer: the Second Law of Thermodynamics.

There are different ways of stating this law. One formal statement, known as the Kelvin-Planck statement of the Second Law, says:

> *No process is possible in which the sole result is the absorption of heat from a reservoir and its complete conversion into work*

This is the recognition of an asymmetry of Nature. In other words it states that *it is impossible to 'convert heat completely into work'*, but it says nothing about the conversion of work into heat. There is no constraint on the latter process: work may be completely *'converted into heat'* without there being any other discernible change. That is, energy transferred by working can raise the temperature of a body, and an equal amount of energy can then be removed from the body by thermal flow under a temperature difference, with no other change taking place. Thus, Nature's asymmetry is revealed, inasmuch as although work and heat are equivalent in the sense that each is a manner of transferring energy, they are not equivalent in the manner in which they may be interchanged. Figure 2.1 shows a pictorial representation of the Kelvin-Plank statement.

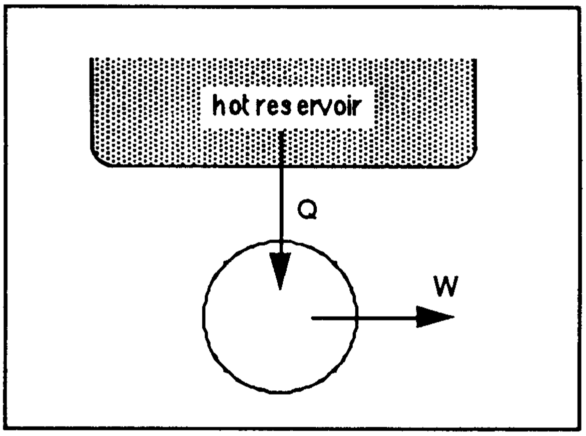


Figure 2.1 - *The Kelvin-Plank statement denies the possibility of converting a given quantity of heat completely into work without other changes occurring else where*

Another way of stating the Second Law known as the Clausius statement is:

No process is possible in which the sole result is the transfer of energy from a cooler to a hotter body

That is, the natural direction of heat flow is always from the higher to the lower temperature. The law does not prevent us from causing such a flow in the 'unnatural' direction if changes take place elsewhere in the Universe. Therefore, the Second Law specifies the *unnatural*, but does not forbid us to bring about the unnatural by means of a *natural* change elsewhere. Figure 2.2 shows a graphical representation of the Clausius statement.

Thus the two statements affirm a fundamental asymmetry in Nature, but in different ways. In the Kelvin statement the asymmetry is between work and heat, while the Clausius statement implies an asymmetry in the direction of natural change. Either statement is the basis for describing all natural changes.

Therefore, the combination of the first and the second laws says that although the total *quantity* of energy must be conserved in any process, the *distribution* of that energy changes in a irreversible way, or in other words, the First Law denies the possibility of creating or destroying energy while the Second Law denies the possibility of redistributing it in certain ways without other consequences.

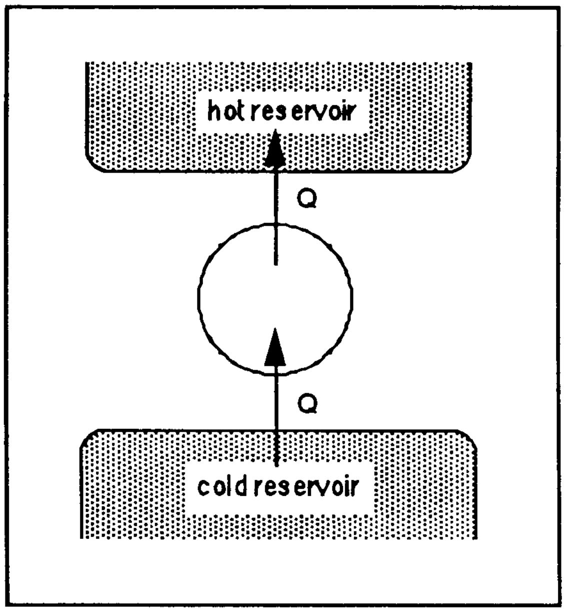


Figure 2.2 - *The Clausius statement denies the possibility of heat flowing spontaneously from a cold body to a hotter one*

2.7 Reversibility and Irreversibility

Regarding what has already been said, a reversible process is one that is performed in such a way that, at the conclusion of the process, both the system and the surroundings may be restored to their initial states, without producing any changes in the rest of the universe.

In general, natural processes do not satisfy this condition because firstly thermodynamic equilibrium is not satisfied, and secondly dissipative effects are present.

The Second Law allows reversible natural processes, but the existence of these features means that this is an ideal case only, because except in the ideal case the exact amounts of work and/or heat involved during the process are undefined due to the fact that the exact path followed to reach the final state is not known.

The ideal case, as mentioned before, is a quasi-static process. If the process is quasi-static, the system passes through states of thermodynamic equilibrium, which may be traversed just as well in one direction as in the opposite direction; and if there are no dissipative effects, all the work done by the system during the performance of a process in one direction can be returned to the system during the reverse process.

Therefore, it can be stated that a process will be reversible when it is performed quasi-statically and is not accompanied by any dissipative effects. In other words, *reversibility* *implies equilibrium and reversible processes are defined as constituting a continuous series of equilibrium states.*

The concept of a reversible process in thermodynamics resembles the idealising assumptions made so often in mechanics, such as weightless strings, frictionless pulleys and point masses (Zemansky, 1968).

2.8 Spontaneity, Equilibrium, and Reversibility

Explosions are examples of rapid, spontaneous process. However a process need not be as rapid as an explosion to be spontaneous. A spontaneous process is one that will proceed on its own without interaction with the rest of the universe. In a strict sense spontaneity has nothing to do with time. A thermodynamically spontaneous reaction is one that will occur on its own, even if requires virtually forever to do so. Thermodynamics answers the question, 'Will the process occur, eventually?', while to answer the question 'How soon will it occur?' we must turn to kinetics.

If a system undergoes a spontaneous change in its internal structure, such as a chemical reaction, there might exist a situation when the process has a tendency to occur in one direction and in the reverse, and eventually the synthesis is produced exactly as fast as the decomposition giving the appearance of change having ceased, although the processes still occur at the molecular level. This condition of balance between two opposing reactions is called chemical equilibrium. Moreover, a reaction that is at equilibrium is a *reversible reaction*. Therefore, chemical equilibrium emerges as a *dynamic concept* in contrast with the mechanical static concept.

In a system such as N_2-H_2-NH_3 [2] at equilibrium, the change in pressure, temperature, or concentration of one component required to alter the relative rate of reactions in one direction and in the reverse are infinitesimally small. Just as the lightest weight can tip a balance in mechanical equilibrium, so the smallest change can affect a system in chemical equilibrium. This is why the term 'reversible' is applied to such situations. As Dickerson et al. say 'a fingertip touch cannot halt a falling boulder, and an infinitesimal change in pressure, temperature, concentration, or any other variable cannot halt the explosion of H_2

[2] That is the reaction synthesising ammonia from H_2 and N_2. This reaction can be represented by the equation $N_2 + 3H_2$ <-=-> $2NH_3$. The synthesising reaction has a greater initial tendency to occur than the decomposition reaction. But as more NH_3 accumulates, and as less H_2 and N_2 are left, the first reaction becomes slower and the second accelerates. At some concentration of N_2, H_2 and NH_3 both reactions proceed at the same rate. Ammonia is produced exactly as fast as it is broken down.

and Cl_2 or the less spectacular reaction of N_2 and H_2 before the equilibrium is reached'[3]. Such chemical systems are not at equilibrium, their processes are *irreversible.*

In summary, an equilibrium process is reversible, and a non-equilibrium or spontaneous process is irreversible.

2.9 Entropy

Just as the First Law leads to the introduction of a property of systems, energy, which determines what states a system can reach, the Second Law also has an associated quantity, entropy, related not to whether one state of a system is accessible from another, but whether it is *spontaneously* accessible.

Entropy is defined so that its value never decreases. The direction of *spontaneous* change is from a state with low entropy to a state of high entropy. This idea can be expressed through the Entropy Principle, which is also another statement of the Second Law:

natural changes occur in the direction of increasing total entropy

The difference of entropy between two states is defined as:

Difference of Entropy = (heat transferred reversibly) / temperature

Heating is an energy transfer in which atoms increase their chaotic thermal motion; if a lot of energy is transferred as heat a lot of chaos is generated. This is consistent with heat transferred appearing in the numerator of this expression. Energy can also be transferred reversibly as work, but this has no effect on the entropy because it creates no turmoil, hence the entropy change is defined in terms of energy transferred as heat, not as work. The temperature appears in the denominator because there will be a greater proportionate increase of chaotic turmoil when the same quantity of energy is transferred at low temperatures - when there is little thermal motion present - than at high - when there is already much thermal turmoil. As Atkins says, 'a sneeze in a library creates much more additional turmoil than a sneeze in a busy street'[4].

Thus, the introduction of the concept of entropy gives a convenient way of expressing the

[3] R. Dickerson, H. Gray & G. Haight (1978) *Chemical Principles*. London: W.A.Benjamin. p.113.
[4] P. W. Atkins (1989) Time and Dispersal: The Second Law. in Flood,R. & Lockwood,M. (Eds.) *The Nature of Time*. Oxford: Basil Blackwell. p.87.

asymmetry in Nature, with its underlying tendency towards chaos and energy dispersion.

2.10 Entropy and 'Quality of Energy'

Because the total entropy never decreases, a system with low entropy is valuable, because in passing to a state of higher entropy, it can be made to produce desirable changes - such as driving machinery. This is sometimes expressed by saying that a system with low entropy has a high 'quality of energy'.

Thus, when fossil fuels, such as coal, are burnt, the supply of energy does not decrease. In this sense, there can be never a energy crisis, because the energy of the world is forever the same. We are on the verge of an entropy crisis, rather, because every time that a lump of coal is burnt the entropy of the world increases, which means energy is becoming less available (Ogborn, 1990).

So, in this sense, what it is necessary to do is not to conserve energy, for Nature does that automatically, but to care about its quality. In other words, we have to find better ways of using energy so as to avoid a large production of entropy.

2.11 Entropy and the Direction of Time

Thermodynamics gives us some insight into the nature of time, even though its equations contain no reference to time as a variable.

The phenomena described by the equations of thermodynamics are inescapably part of the temporal flow of natural process and thermodynamics gives conditions for how the states of a system must succeed each other. By taking the succession of states of a system to be the same as the temporal sequence of nature, we gain a relation between time and natural processes. Therefore, we can elucidate the parallelism between the temporal flow of our everyday experience and the particular succession of states that is prescribed in terms of thermodynamics.

Regarding the Entropy Principle, the increase of entropy is a signpost indicating the direction of time: entropy increases in direction of the future, not of the past. This is the recognition of another aspect of the asymmetry of Nature: *asymmetry in time*.

This was pointed out by Sir Arthur Eddington (1882-1944), who described increasing entropy as giving us a direction of "time's arrow"[5]. He used this expression to express the one-way property of time, which has no analogue in space, and indicates the direction of the progressive increase of the random element in Nature.

2.12 Time-Reversible Processes

In systems that contain only a relatively small number of elements, in some cases only one, their description is given in relation to the behaviour of every entity of the system. An oscillating pendulum, an electromagnetic wave, or the planets of the solar system would be examples of such a system.

Some of the basic equations which describe individual entities are Laws of Motion, in either their relativistic or non relativistic form, Maxwell's equations for electromagnetic fields, and Schrödinger's equation for the wave-amplitude of individual particles. These and other of the basic physical equations, have the property of being 'time-reversible'. This means they describe phenomena in a way that they may equally well occur either in one direction or in reverse, depending on the reversing of the initial conditions. These time reversible equations describe behaviour which is physically possible for either positive or increasingly negative values of the variable time.

In contrast, Thermodynamics deals with macroscopic large-scale systems which are constituted of many particles. The basic observables like temperature and pressure, result from average effects of many millions of particles, that is, thermodynamic properties are defined only in relation to aggregates of many particles. Moreover, the Second Law says that natural changes occur in the direction of increasing total entropy or declining quality of energy, which means, as has been said before, an asymmetry in time. Therefore, the Second Law states that natural changes are not time-reversible: heat must always flow from hot bodies to cold bodies, even when we reverse time in the equations that control the motion and behaviour of individual particles.

For the sake of illustration, if heat is considered as an agitation of particles, when energy is transferred from a hot body to a cooler one, the hotter the particles, the more agitated is their motion. The agitation itself is governed by the laws of particle physics and is in principle time-reversible, but the diffusion and spread of agitation, from hot to cold regions is governed by the Second Law, which is not time-reversible. Single particles are time-reversible, but systems of particles are not. It is like hanging a picture on a wall: 'if you

[5]A. Eddington (1928) *The Nature of the Physical World.* London: Cambridge Press. p.69.

look only at the dabs of paint, you will not know which way to hang it; you have to look at large areas of a picture to determine whether it is right way up'[6].

Thus, the Entropy Principle provides us with an arrow of time, whereas the behaviour of individual particles has no arrow of time. This fact produces a paradox, seen among others by Poincaré. A macroscopic thermodynamic system, whose change is irreversible, is composed of particles whose detailed motions are to be understood as perfectly reversible.

A first level of solution of this paradox was provided by Ludwig E. Boltzmann (1844-1906) who attempted to recover the arrow of time in terms of atomic and molecular behaviour.

2.13 Entropy and Disorder: a Microscopic View of Thermodynamics

Following in Maxwell's footsteps, Boltzmann was the first to give a fundamental physical law - the Second Law - a statistical interpretation, using probability theory.

Boltzmann realised that the asymmetry in time imposed by the Entropy Principle could be interpreted as the expression of a growing molecular disorder, and proposed a definition for entropy in terms of the degree of order of the particles of the system, which is equivalent to that obtained from the thermal definition. The equation $S = k \ln W$ expresses this idea in a quantitative form, where the proportionality factor k is a universal constant, known as Boltzmann's constant, and W the 'thermodynamic probability'.

On the left side of this equation, we have the entropy which is the classical signpost of spontaneous changes. On the right side, we have a quantity which is related to order, because its meaning can be interpreted as the answer to the question: 'in how many ways can the inside of a system be arranged without an external observer being aware that arrangements have occurred?'[7]. Thus, S stands firmly in the world of classical thermodynamics, the world of experience, while W stands in the world of atoms, the world of underlying mechanisms.

In order to understand W, we can think of a gas composed of a large number of particles, in a flask. At thermodynamic equilibrium the temperature and the pressure are uniform for any macroscopic volume of the gas. However, there are lots of different microstates, arrangements, or "complexions", of the individual gas molecules which would give the

[6] E. Harrison (1989) *Cosmology, the Science of the Universe*. Cambridge: Cambridge Press. p.141.
[7] P. W. Atkins (1984) *The Second Law*. New York: W.H. Freeman. p.66.

same macrostate. In other words, there are lots of different combinations of position and motion for the molecules that would give the same values of the thermodynamic coordinates, and the number of these possibilities, for a given macrostate, is the thermodynamic probability W. Moreover, the larger the number of particles, the greater the possible number of complexions corresponding to different distributions, and in general, the lower the value of W, the higher the degree of ordering.

Therefore, in this interpretation the increase of entropy becomes a statement about increase of disorder. An increase in entropy is an increase in the thermodynamic probability - W. Thus we can say that, the natural tendency of a system is toward disorder, and the equilibrium state is the state of maximum W.

Difference in entropy now appears as a measure of the probability of a system being in a specific macrostate, with respect to a different macrostate of the same system.

However, although the equilibrium state is overwhelmingly the most probable, as compared with any state substantially far from equilibrium, there is nevertheless a nonvanishing probability for any possible macrostate. This means that although we can expect changes in the system to be towards the equilibrium state, they do not have to be, because the possibility for fluctuations in an opposite direction remains.

Large fluctuations, which could lead an isolated macrosystem to a decreasing entropy, have only theoretical interest, due to their extremely small probability. But, if we consider microsystems composed of a few particles, fluctuations from the most probable state become physically important. It may even be that fluctuations of this kind play an important role in biological phenomena, as sources of mutations and hence of species variation and evolution. These are not inconsistent with the Entropy principle, indeed they rely on its very mechanism.

2.14 Order Out of Disorder

The remarks so far belong to the theory of *equilibrium thermodynamics* - i.e. to processes analysed as quasi-static. From this perspective, it appears to be difficult to account for the *creation of order,* which visibly occurs, in processes of life, but also in, for instance, thunderstorms. This is the realm of *non-equilibrium thermodynamics*. Only the briefest account of it will be given here.

That order *can* be created is not difficult to see. The second law only requires that, *overall,* the entropy of a system must increase. Nothing prevents a decrease in entropy of one part, at the expense of a larger increase elsewhere. Such an effect occurs every time ice cubes are frozen in a refrigerator.

New phenomena appear when a system is far from equilibrium. An example is a pan of water on a stove. Convection currents in the water will appear when the flow of energy through the system is large enough. Such convection currents are a form of macroscopic order, created by the (larger) generation of entropy due to the flame below the water. A storm is of course in essence a similar phenomenon (Ogborn, 1990).

Nature however creates order in even more spectacular ways. The Earth receives photons of sunlight at about 6000K, and re-radiates them as infra-red photons at about 300K, thus providing a continual and large increase of entropy at its surface. This increase is used to 'pay for' the decrease in entropy involved in many biological processes. Perhaps the most important of these is photo-synthesis, in which carbon dioxide and water are used to manufacture carbohydrates such as sugar and cellulose (Atkins, 1987). Thus plants appear to defy the Second Law, whereas in fact they exploit it.

Finally, and (as it will turn out) most relevantly for this thesis, we need to account for the ability of human (and other animals) to make *actions*. To a person, it appears that actions, such as lifting a weight, can be spontaneously achieved. Thus human action seems to lie outside the world as described by thermodynamics. Indeed many science books present it as such: the initial conditions of a system are presented implicitly as being able to be set as required, without thermodynamic constraints.

So, how is human action achieved? Nature has evolved a system in which the molecule adenosine tri-phosphate (ATP) is synthesised from low entropy foods. By losing one phosphate group, which becomes tightly bonded to other molecules, energy is released, in a mechanism which enables muscle fibres to contract (Atkins, 1987). The metabolism of low entropy food creates enough entropy for the reformation of the ATP molecules, a process which itself decreases entropy. Thus, because our bodies maintain themselves in a *steady state* (including a supply of ATP) far from equilibrium, by the continual processing of food, we gain the psychological impression of being 'ready for anything'.

Action seems always available to us, and making actions does not appear to deplete the power to act, except temporarily. It appears to us that we recover spontaneously from fatigue. Underlying these appearances is a continuous process of the creation of order from larger increase of disorder. The ultimate source of this increase of disorder is the continual increase of entropy due to sunlight falling on the Earth and being re-radiated. We eat the plants (and animals that ate plants) which previously 'ate' sunlight. What our food gives us is negative entropy or free energy, as was first clearly recognised by Schrödinger in his 1944 book "What is Life?".

2.15 Time's Arrow

These facts give "time's arrow" a psychological dimension. We are aware of the growth of plants and of animals, and of ageing. But these are slow processes, and on short time scales, the world and ourselves appear rather constant, maintaining themselves rather than changing. Thus we simultaneously have a feeling of the direction of time, and tend to see it as not affecting us.

Also, because we can act, we can often restore something to its original state after it has changed. This presents the world to us as *reversible* in this special sense. Our actions are capable of reducing disorder, and we are unaware of the compensating additional disorder they create.

The purpose of this scientific account is to establish one part of the context of the study, which itself does *not* concern students' understanding of this scientific account. It will be seen that students' everyday, non-scientific ideas can be partially understood from the scientific perspective. In particular, their ideas have a strong relationship to the *possibility of action*, a basic feature of living organisms (amongst whom students belong), as discussed in this chapter.

3

Review of Literature

The purpose of this review is not only to give an account of the most relevant studies and researches about students' conceptions which have the concept of reversibility as the main topic, but also to trace the indirect relationship of reversibility to studies which do not have it as an explicit object of study.

3.1 Introduction

The present research has its origin in the study of the concept of reversibility within a thermodynamic view linked to the Second Law of Thermodynamics, but takes a commonsense perspective, where the focus is on the way people think of the reversing of processes in terms of their commonsense knowledge about the physical world characterised essentially as based upon their own everyday experience. The idea is to study people's commonsense reasoning about processes and the way they are thought of as reversible or not.

A review of literature on students' conceptions shows that there is no study with such a focus and just a few which have the concept of reversibility as their main theme, though some report findings related to this concept as secondary results. Were only these studies be considered, the review would be very restrictive.

Therefore, in order to broaden this review of literature, studies about different concepts which have any sort of connection with the concept of reversibility are also included. In addition studies about students' conceptions with a focus on forms of reasoning are included to provide material for thinking about how to analyse commonsense reasoning.

The studies reviewed are analysed according to the scheme shown in Figure 3.1.

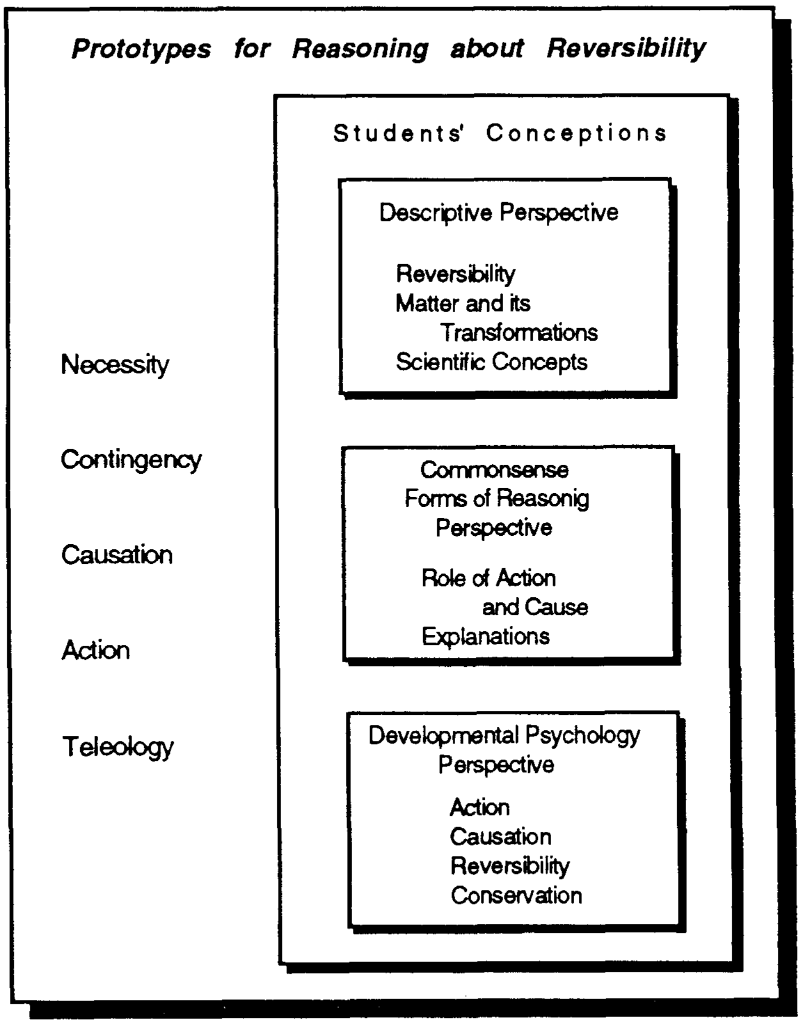


Figure 3.1 - *Scheme for the Literature Review*

In this scheme studies of students' conceptions are classified in three main categories:

- studies carried out in a descriptive perspective, where instances of specific conceptions held by students are reported;

- studies carried out at a different level of investigation, where the studies focus attention on trying to explain the regularities which seem to be present in students' responses in terms of underlying commonsense forms of reasoning;

- studies carried out on a psychological basis, where the results are discussed within a developmental psychology perspective.

These three categories together concern different aspects of students' conceptions within which we can seek forms of reasoning relevant to thinking about reversibility, labelled in figure 3.1 'prototypes for reasoning about reversibility'. These prototypes are possible ways people may use, consciously or not, to understand the reversing of a process.

The basic idea of these prototypes comes from the way that any event can be thought of as happening in nature, and they are connected with the ideas of *necessity* and *contingency*. Necessity is related to the idea that an event can be thought of as *unavoidable*, i.e., something that either *must* happen or *must not* happen. Contingency is related to the idea that an event can be thought of as *possible* to happen, i.e., something that *might* or *might not* happen.

Taking into account these two basic prototypes, and studies focusing on underlying forms of reasoning and developmental psychology, some other prototypes are considered: *causation*, *action*, and *teleology*. Causation refers both to regular causes, as opposed to chance, and the presence of some agent of cause. Action refers to the way the agency of causation may be modelled on human actions. Teleology is related to the idea that an event may happen due to some purpose.

These are no more than broad categories to guide the collection and analysis of data.

3.2 Studies in a Descriptive Perspective

The studies included in this section are classified under three headings representing different kinds of results:

- reversibility;
- matter and its transformations;
- scientific concepts.

The category reversibility comprises studies which describe results explicitly related to the concept of reversibility; the category matter and its transformations includes studies related to students' conceptions of the nature of matter and its transformations; the category scientific concepts is concerned with studies of students' conceptions about scientific concepts such as energy, which have connections to reversibility.

3.2.1 Reversibility

Duit and Kesidou (1988) aimed to find out whether several years of physics instruction had provided students with the necessary conceptions to understand irreversibility and whether ideas of irreversibility had formed through 'traditional' instruction. Therefore, clinical interviews based on the discussion of equalisation of temperature through a heat exchange process were carried out with sixteen year old students who had already studied Physics for four years in a traditional way. They report that 'if our preliminary findings are confirmed we have to conclude that students very often do not achieve a sound physics framework to understand irreversibility during several years of physics instruction'. This conclusion was based on the outcome that a remarkable number of students thought that a certain temperature difference may arise after temperature equalisation.

Johnstone et al. (1977b) describe a study on misconceptions in school thermodynamics with pupils (16-17 year old) who had just completed studies related to chemical equilibrium. They report that students confused the descriptive (rates) and prescriptive (thermodynamics) meanings of reversibility: most students could understand that a reaction may proceed forwards or backwards although the simultaneous occurrence of forward and reverse reactions at equal rates was not very well understood, 'while the significance of thermodynamic reversibility in that it prescribes how a reaction is to be operated is lost to most students'. Moreover, the concept of entropy is confounded with the concept of kinetic energy and is described in terms of disorder.

Stavridou and Solomonidou (1989) describe a study of how Greek students aged from 8 to 17 years classify a set of physical and chemical phenomena according to their own understanding. They report that students used reversibility as one of the criteria, although they did not explicitly mention the words reversible or irreversible. Students focused their attention on the material change and on the reversibility of the change undergone by the substances which took part in the phenomena. Therefore, physical changes were characterised as reversible phenomena because 'the changed substance is able to return to its initial condition', or 'they have the possibility to go back to their initial condition'; while chemical changes were described as irreversible phenomena because 'these substances are now destroyed, they can't return to their initial form', or 'there is a change and what comes out of this change can't return to the initial condition'.

Stavy (1990a) describes the acquisition of conservation of matter by students aged from 9 to 15. Students were tested for their ability to recognise weight conservation as well as reversibility of physical processes. She reports that until the age of 12 specific perceptual input from the task dramatically influences students' responses to the conservation of weight tasks but not to the reversibility of the process tasks. Moreover, students who recognised weight conservation were not always aware of the reversibility of the process, a outcome that contradicts some piagetian findings.

As mentioned before, the review of literature on students' thinking about physical processes showed that few articles report explicit results related to the concept of reversibility. However, from the few articles described in this section, it is possible to see that there are studies of reversibility connected with different areas such as chemical processes and cognitive processes. This provides a reason for broadening this review, with specific sections on such themes.

3.2.2 Matter and its Transformations

A comprehensive way of analysing these articles is to have in mind a macroscopic and a microscopic view of the nature of matter. The way students conceive matter should relate to how they explain some phenomena, because it relates to very basic ontological questions about the world around us, such as, 'What is the nature of matter?, 'What is a substance?, 'What is the nature of space?'. Consequently, one could believe that it influences the way the students think about reversibility of phenomena.

When thinking about the nature of matter, one can consider its transformations - physical and chemical changes - and the possibilities of reversing such transformations. From a scientific standpoint these ideas are related to the particulate theory of matter and encompass concepts such as state of matter, change of the state of matter, conservation of matter, chemical reaction, chemical equilibrium, which in fact are the concepts usually investigated.

3.2.2.1 Nature of Matter

Andersson (1990) gives a general account of pupils' conceptions of matter and its transformation both at the macroscopic and atomic level. The basic structure of this paper comes from his study on chemical reactions (Andersson, 1984, 1986b), and is a review of studies recently published. He reports that matter is conceived as continuous and static, leaving no room for the idea that two substances in contact can react with each other so that the original substances cease to exist and new ones are formed. The original substances simply exist in contact, but each one separately. Therefore, according to him, when explaining changes, pupils use models that imply that each substance is changed under the influence of an *external agent*, and he proposes five categories of explanation or 'transformation models' - disappearance, displacement, modification, transmutation, and chemical interaction - into which the students' answers can be classified. The two main issues to be noted are that, underlying these categories are the ideas of *action* and *conservation*: conservation of properties/identity, conservation of amount of matter, conservation of weight. In the category of disappearance, conservation is not considered at all, while the others express a conservation reasoning. Yet, in all of them the necessity of an external action to cause the transformation is observed, although in some cases no comment is made upon the idea of who or what takes this action.

Another attribute of the conception of matter reported is that macro-properties are projected onto the micro-world, such as, that atoms and molecules have the same properties as those of the substances - 'phosphorus is yellow, so phosphorus atoms are yellow', 'a soft substances cannot be made of hard molecules'. In this case, conservation also seems to be a relevant issue because after a transformation has occurred, substances are modified with respect to certain properties, but that the identity of the substance is conserved, such as the case of rust, which is perceived as iron with some of its properties altered.

Although no comment was made upon reversibility, it is clear that it is a consequential issue to be investigated. When Andersson mentions 'scientific thinking' about the formation of mercury oxide, 'which in its turn can be decomposed', indirectly he is talking about the possibility of reversing transformations occurring with matter. Even when he writes about everyday thinking, 'conservation of mass should be so firmly fixed in the mind of every citizen that no person can believe that it is possible to get rid of refuse simply by burning it...', reversibility is an implicit issue: this conception that the environment will not be changed, involves a form of 'natural reversal' in the sense that nature will always provide a mechanism which will be able to reverse any transformation caused by human beings, such that in the end everything will stay the same. Therefore, starting from the students' conceptions about transformation of matter, a study of how they understand and explain the possible reversibility of such transformations, should be carried out.

3.2.2.2 State of Matter

Séré (1985, 1986) describes an investigation of conceptions of the gaseous state held by French children aged from 11 to 13. She reports that most pupils establish a direct relationship between the presence of air and movement, as if it was necessary to have movement for the existence of air. Their conception of hot and cold air make explicit a sort of dissymmetry in their reasoning, given that 'they know that hot air rises, but they never refer to cold air sinking', which can also be observed in the way they describe hot and cold air.

Séré also reports that the idea that air has a mass is not obvious to children, and when she tried to find out if 'more air means more mass', pupils answered that the more air there is, the lighter it would be, because 'when full of air, a floating object floats better'. In view of this results, the investigation was focused on the problem of conservation of a quantity of air, and students were asked what happens to the amount of air in a syringe when its volume is changed. Half of the children said that the amount of air would remain the same, and there were two main reasons, namely, 'nothing gets in, nothing gets out', and 'if the piston is allowed to move backwards, it will come back to its original place again'.

Regarding the first reason, the idea of conservation is apparent and she connects it to the 'idea of identity' identified in children's reasoning by Piaget in the study about the development of physics quantities (1974). The second reason, can be related to the idea of reversibility in the sense that if the original configuration is restored, nothing has changed, thus the process could be characterised as reversible; she also connects this reason to the notion of reversibility identified by Piaget in the same study.

Conservation is also an issue when students were asked what would happen with the mass of air in a closed container when heated. There were answers such as, 'there is more air because it expands', 'more air is produced', 'air is heavier', 'air is lighter'. Reversibility could have been an important issue if she had asked pupils who thought that air is produced if they thought that it would also disappear.

Stavy (1988) describes a study of the conception of a gas in children aged from 9 to 15 years, and also reports that students' knowledge and understanding of the particulate theory of matter is very fragmentary. For instance, they have difficult in understanding that a gas is material in nature and weighs something, that there are different gases with different properties, and that air is mixture of gases. Similar results had been reported in Stavy et al. (1987).

Stavy and Stachel (1985a) report a study of the development of the concepts of solid and liquid in children aged from 5 to 12 years. Among the findings they report that the definitions used by children for solids and liquids related only to the physical behaviour of the material, having no connection with terms from the scientific particulate theory: from the age of five they are able to classify liquids, liquid meaning that it pours; a solid is understood as a rigid material, the shape of which it is difficult to change. Non-rigid material such as powders are classified neither as solid nor as liquid by almost half the population at all ages. While water serves as an exemplar for liquid, there is no similar exemplar for solids. Some similar outcomes are reported by Ryan (1990).

These last two studies by Ruth Stavy had the purpose of giving a basis for her studies of change of state of matter, in which the concepts of conservation and reversibility are investigated on a psychological basis, and are described later in this review (section 3.4.1).

3.2.2.3 Transformation of Matter

This section reports research which investigate changes in a more elaborate way than those discussed in the last two sections.

From a scientific viewpoint, physical and chemical changes are referred either to identity of a substance, if a macroscopic manifestation is considered, or to the particulate theory of matter, if the microscopic manifestation is focused on. Therefore, in a physical transformation of matter, the identity of the substances taking part in the process is conserved, given that at the microscopic level matter remains intact. Yet, in a chemical transformation, the identity of the substances is modified, given that the change happens at the microscopic level with an alteration of their basic structure.

However, this view is often not shared by non-scientists, especially but not exclusively, children, and even by teachers. This has already been pointed out by de Vos and Verdonk (1985) in a theoretical article about chemical reactions, and by Vogelezang (1987) in a article about the concept of chemical substance.

Stavridou and Solomonidou (1989) describe a study of how pupils aged from 8 to 17 years categorise a set of physical and chemical transformations of matter. They presented a list of eighteen phenomena - nine involving chemical change and nine involving physical changes -, and asked students to group them according to their own criteria. The results are that students tend to form categories based upon the phenomenology of the changes, using criteria such as change of form, destruction or disappearance of matter, number of substances taking part in the phenomenon.

BouJaoude (1991) studying students' understanding about the concept of burning, reports that most of the students used phrases such as 'chemical change' and 'physical change' without any consideration of their scientific meaning, and that their explanations were cued by the visible aspects of the events. Similar results are reported by Abraham et al. (1992).

Kruger and Summers (1989) investigating primary teachers' understanding of change in materials, asked them what was happening during some physical and chemical changes. They report that the majority of the teachers explained changes 'in terms of a non-molecular particulate theory which was a mixture of intuitive beliefs and half-remembered textbook science', and that some of the teachers explained the changes only at the perceptual level, based on observable entities.

These outcomes make clear the contrast between reasoning based on perceptual changes and reasoning based on conceptual aspects, where despite appearances students are able to distinguish what is really important when discussing transformations of matter. This relates to the question of what it is that remains unchanged through all the transformation, which in its turn is connected to the concept of conservation - of matter, of weight -, and to the concept of reversibility. Thus in the next sections the analysis is narrowed down with the inspection of some studies of specific changes in order to scrutinise these aspects.

3.2.2.4 Chemical Changes

3.2.2.4.1 The process of Burning. Driver (1985) reviewing a study by J. Knox on students' (11-12 year old) ideas about the process of burning, proposes a 'prototypic view' of this phenomenon, based on children's' observation of fires, matches, splints burning. The general features in this view are:

- burning involves things going red and a flame appearing;
- oxygen (or air) is needed (its function may not be clear, it may even be seen as being 'burnt away' in the process;
- things get lighter when they are burnt;
- burning drives off the smoke or parts of the material are driven off as smoke; and
- solid residues or ash are the incombustible bits left behind.

A careful look at these features shows that their structure is based upon the idea of non-conservation. Students explain the process of burning based upon perceptual changes and do not take into account the conservational aspects of the process. BouJaoude (1991) reports a study of the conception of burning whose results could fit in this prototypic view.

Reversibility was not a issue in these studies. If it had been, the work could have led to a better comprehension of the interconnection between reversibility and conservation. If conservation is considered all through a process, it may facilitate the emergence of a discussion of reversibility, in the sense that, despite the process, something remains unchanged, thus the process itself does not matter, because if reversed everything will be the same.

This aspect is raised by Méheut et al. (1985) in a study of pupils' (11-12 year old) conceptions of combustion. They report two categories of transformations: (a) transformations containing notions of the permanent nature of substances, (b) transformations not doing so. In the first case some properties of the substances are said to be conserved, such as colour and smell. Pupils use the same name to characterise the substances at the beginning and at the end of the transformation. Solids undergoing this sort of transformation 'melt', such as wax in the candle and metals, and liquids 'evaporate', such as alcohol, and water. In the second category no conservation of any property is mentioned, and the name used to characterise the result of the transformation is different from that used to characterise the initial substances. Such a transformation is often described by the verb to burn. In this case, the reversibility of the transformation is not in question. However, in the first case it is sometimes mentioned:

> 'You'd have thought that it was a liquid, but it's melted wax. When the flame goes out, the liquid turns into the candle wax because it's already the same colour'

In this case the permanent nature of the substance is justified by the permanence of one property, the colour, and the reversibility of the transformation emerges naturally, as if supported by the conservation reasoning.

Similarly, Pfundt (1982) reporting a study of substances and transformation of substances describes some general conceptions of change of substances:

- the conception of an irreversible destruction of substances;
- the conception of an irreversible changing of properties of lasting substances;
- the conception of a reversible changing of properties of lasting substances;

- the conception that substances with all their properties continue to exist, that they are merely distributed or mixed or separated.

It seems that there is a gradation from non-conservation to conservation reasoning which underlies the conception of reversibility, inasmuch as the destruction of the substance characterises the irreversibility of the process which brought it about, and the persistence of the properties, which cause it just to mix or be distributed, these being seen as processes which can be reversed.

3.2.2.4.2 The process of Rusting. Driver (1985) describes a survey of English 15 year old students, when they were asked to say how the mass of some nails would change when they became rusty. She reports three kinds of answers:

- the mass would increase because the weight of the rust is added to the weight of the nail, although there is no indication that the iron from the nail is involved in producing the rust;
- the mass is the same as before, because 'nothing has been added or taken away';
- the mass would decrease because the rust eats away the nails.

Similarly to the process of burning, these kinds of answers are related to the idea of conservation, inasmuch as it appears that students do not conserve mass. It seems likely that these differences could have affected students' ideas about the reversibility of rusting, if that had been part of the research.

3.2.2.5 Physical Changes

3.2.2.5.1 The process of Dissolving. Andersson (1984) describes a study where 15 year old students were asked what the mass of a sugar solution would be after the sugar had been dissolved. He reports that over a half predicted the solution would have less mass than the constituents, supported by reasons such as, sugar disappears when dissolved, sugar is still there but is lighter. Driver (1985) also reports similar results from a investigation with English students aged from 9 to 14, where the same question was asked. Prieto et al. (1989) in a study of how Spanish students aged 11-14 explain the process of dissolution, report that most of them describe the change undergone by the solute using the terms 'to disappear', which implies that 'when a substance dissolves, it disappears from sight'.

These outcomes make it clear that matter is not here considered as a conserved quantity, perhaps because changes seem to be modelled in terms of perceptual aspects, which conflict with the concept of conservation. It would be important to know if students who thought that the sugar vanishes thought that it can re-appear. It seems unlikely that they would do so.

3.2.2.5.2 Change of State of Water. Osborne and Cosgrove (1983) report an extensive study of children's (8-17 year old) conceptions about familiar phenomena associated with water: evaporation, condensation, boiling, and the melting of ice. The results are presented in a descriptive way within categories of children's views about:

- boiling;
- steam, and condensation from steam;
- evaporation;
- water condensing on a cold surface;
- ice melting.

Each category is divided in sub-categories describing a variety of different conceptions. A detailed description of the results does not have particular relevance to the present study. However, it is clear that the results give grounds and point to the development of further research focusing on concepts such as spontaneity, conservation, reversibility. Similar to the review of some studies described so far, this consideration is supported by results such as that when some children explained the evaporation of water as 'it has just gone...' or even when only two of them regarded condensation as the reverse process of boiling. These points can be extended to all the phenomena considered in this investigation.

Although being a psychologically oriented study, Beveridge (1985) reports similar results when describing a study of the development of children's understanding of the process of evaporation.

3.2.2.6 Bio-Chemical Phenomena

There are some processes that cross the disciplinary boundaries of chemistry and biology and are treated here as Bio-chemical processes.

3.2.2.6.1 The process of Diffusion. Westbrook and Marek (1991) describe a cross-age study of student understanding of diffusion. They asked students to explain what would happen to several drops of dye after dropping them into a gallon of water. They report that students had misconceptions about what happened with the dye during the diffusion process:

- dye changes colour in water;
- dye disappears over time;
- dye breaks up, splits, disintegrates or changes form.

These results are similar to those described for the process of dissolving, and likewise non-conservation is also an issue, perhaps in a broader sense, given that it includes not only non-conservation of matter, but also non-conservation of colour, form, and molecular nature. In the same way it would be important to know how students would think about the reversal of these features of the change.

They also report results related to the way students explained the distribution of the dye in the water. Students considered that:

(a) dye will be unevenly distributed;
(b) dye drops to the bottom and then spreads out;
(c) dye won't stay mixed, but eventually will go to the surface of the water or to the bottom of the container.

It seems that the issue here is related to ideas of contingency and causation, inasmuch as students could have been asked to explain their ideas in order to find out whether the event could have just happened or there was any causal origin. Another consequential aspect that could have been investigated is reversibility, because in asking pupils to explain answers such as (c), it would have been possible to understand how they would explain this event - which in a sense can be considered the reversal of the diffusion - and what sort of connection could be made between reversibility and contingency.

Séré (1985) describing images that twenty French children aged 12 associate with air reports that over half of them thought that two gases closed in a large container do not mix. They said that the gases would mix only at the boundary between them.

3.2.2.6.2 The process of Photosynthesis. Stavy et al. (1987) describe a study of how students aged 13-15 understand photosynthesis. Among a variety of results they report that students considered photosynthesis as a type of respiration which was reversed during the night:

> 'during the day plants absorb carbon dioxide and discharge oxygen and this is their respiration, at night the process is reversed'.

Although reversibility is not an issue in this study, from this sort of answer it is possible to make some comment related to the way that the reversal of a process can be seen. It appears clear that in this case, to reverse the process of photosynthesis means to have the output - oxygen - and the input - carbon dioxide - of the forward process as the input and output of the backward process, as if there were a symmetry in relation to it. No comment is made in relation to the process itself; what seems to matter is just the outcome of the process.

They also report that when asking students whether sunlight was a material, most of them said that it was not, however the authors say that 'our impression from what they said was that the students thought that sunlight is absorbed by the plants and is then transformed into matter'. If the authors are correct in their interpretation, this outcome appears to be related to the idea of conservation of energy and/or matter. It would be significant to know if students who thought that sunlight transforms into matter thought the reverse process to be possible.

3.2.3 Scientific Concepts

The studies included in this category are concerned with students' conceptions about different scientific concepts which have connections to reversibility. Although there are great number of studies that could be included here, just some of the most significant will be discussed.

3.2.3.1 Energy

There are a large number of researches about the concept of energy in the literature, however only a few will be discussed because the results are often similar.

Watts (1983) describing a study about alternative views of energy held by English students aged 14-18, reports seven alternative frameworks to describe their explanations:

- 'anthropocentric/anthropomorphic' framework: energy is associated with human beings or objects thought of as having human attributes, therefore being able to act and cause something;

- 'depository' model where energy is seen as a causal agent, a source of activities based or stored within certain objects;

- 'energy as an ingredient' where energy is a dormant ingredient within objects that needs to be triggered to release it, thereafter causing something;
- 'energy as an "obvious" activity' where energy is identified with an outward overt display of activity, not seen as the cause of the action, but as the occurrence itself;
- 'energy as a product' where energy is treated as a by-product of a situation that is generated, active and disappearing;
- 'energy as functional' where energy is seen as a very general kind of fuel, and has a built-in kind of causality, where energy makes an object do something;
- 'flow-transfer' model where energy is seen as a kind of fluid or substance, which might cause something.

From these results, children see energy as a causal agent, a source of activity or stored within certain objects. In addition, many researchers have reported students' lack of differentiation between energy and other physical concepts such as the concept of force (Viennot, 1979; Watts and Gilbert, 1983; Duit, 1984), or the concept of electric current (Tiberghien, 1894b).

Ogborn (1986) sheds light upon the conception of energy as 'the go of things' or energy as what makes things happen, by discussing the concept of free energy. After comparing the everyday use of the word energy with the concept of free energy, and connecting free energy to disequilibrium, for example 'petrol and oxygen mixture are a long way from equilibrium, and given the right conditions they can release a lot of free energy, and things happen as a result', he states that it is important to differentiate two concepts: energy as what takes part in changes and is conserved, and free energy as what decides if the change can happen, and, given the right conditions, is used up, and is the real 'go of things'.

3.2.3.2 Heat and Temperature

It seems that the most widespread conceptions are that heat and temperature are seen as undifferentiated and that heat is seen as a 'substance' with specific nuances described in each study. Albert (1978) reports that young children talk of heat in static terms as residing in objects, while older children describe heat in spatial and dynamic terms. Erickson (1979, 1980) reports a tendency to talk about heat as if it were a 'substantive fluid', as also described by Tiberghien (1984a). It seems that the problem is related to the fact that heat (and work) is not understood by its very nature as a *process* but rather as entity, as described in section 2.5. This misunderstanding also explains the situation when students refer to internal energy as heat (Ferracioli-da-Silva, 1986).

3.2.3.3 Second Law of Thermodynamics and Entropy

These topics are known for being difficult, and although there are theoretical studies (e.g. Marx, 1983), there are very few studies focusing on students' conceptions of entropy. Studies of heat such as Erickson (1979) reveal little about notions of the second law.

Johnstone et al. (1977a) report that most of the 16-17 year old students taking part in their study think that entropy is a measure of disorder, and that general knowledge about it is superficial. They also confound entropy with kinetic energy.

One of the central ideas of the second law, energy degradation, is the focus of some controversy among some researchers. The question is related to the commonsense meaning of energy: is the idea of energy degradation contained in the everyday meaning of energy? Some researchers such as Solomon (1982) think it is and mention expressions like 'energy consumption' or 'useless energy' as evidence. However Duit (1983) points out that studies of the meaning of the word energy in everyday German gave no helpful clues.

3.2.3.4 Chemical Equilibrium

Johnstone et al. (1977a) describe a study of the conceptual difficulties of chemical equilibrium carried out with Scottish secondary students. Among several results they report that four out of five students present the conception 'left and right sideness', which means that students visualise equilibrium systems as consisting of two independent and separate compartments rather the one whole. In a question to assess the pupil's interpretation of the reversed arrow symbol in an instance where the forward and reversed arrows are of unequal length, they report that the vast majority had a superficial understanding of the equilibrium situation, where students say that the longer the arrow the greater the rate of reaction at equilibrium, which contradicts the very concept of chemical equilibrium. However, the most important result is presented in another paper on misconceptions in thermodynamics (Johnstone et al., 1977b). They describe how most students could understand that a reaction may proceed forwards or backwards, although the simultaneous occurrence of forward and reverse reactions at equal rates was not very well understood, i.e., students failed to conceive the dynamic nature of the system at chemical equilibrium, perhaps because of the conflict with the static nature of mechanical equilibrium. Moreover, students tended to think that slowness is the criterion of reversibility, therefore asserting that a mixture of hydrogen and oxygen is reacting reversible at room temperature simply because the reaction is occurring slowly. Regarding the dynamic nature of chemical equilibrium, Friedler et al. (1987) in a study of students' (9-12 year old) difficulties in understanding osmosis, detected similar results in answers such as 'when equal concentrations are reached, water movement will stop'.

Similar and additional results are reported by different studies of chemical equilibrium. Hackling and Garnett (1985) report that many students failed to discriminate clearly between the characteristics of completion reactions and reversible reactions, and conclude that it might be because 'very few reactions are encountered by students which could illustrate the reversible nature of chemical reactions'.

Gorodetsky and Gussarsky (1986), Gussarsky and Gorodetsky (1988), and Gussarsky and Gorodetsky (1990) after studying how some chemical equilibrium concepts are related and grouped by students, conclude in the last article that the concept of chemical equilibrium is liable to be misconceptualised because of the other uses of the word 'equilibrium', that is "it arises probably from mixing of attributes of the concepts 'physical mechanical equilibrium' and/or 'everyday life equilibrium' with those of 'chemical equilibrium'".

3.3 Studies in the Commonsense Forms of Reasoning Perspective

The studies included in this section are classified under two headings:

- role of action and cause;
- explanation.

The first category comprises studies which describe results concerning pupils' conceptions but also discuss, explicitly or not, results related to the role played by action and cause. The category explanation includes studies connected with underlying forms of reasoning.

3.3.1 The Role of Action and Cause

When something happens or a change occurs, it seems natural to search for causes: why did it happen? How did it happen? Did it happen naturally, spontaneously, or was an action taken to make it happen? If there was an action, the next question might be: who or what took this action?

Stavridou and Solomonidou (1989) in a study of how Greek students classify a set of physical and chemical phenomena, describe that they gave three reasons expressing causes of phenomena:

- human action on objects;
- causes associated with entities such as 'heat', 'fire', warmth';
- the existence of necessary conditions required for a phenomena.

In the first case the subject (human being) is the agent which takes the action to cause the phenomena. It seems that in the second case, causes are modelled on action which are projected onto entities such as 'heat', 'fire', i.e. when causes are associated with these entities, they are seen as able to act to cause the phenomena. In the last case, the conditions were seen as already existing, with no subject's intervention to set them, such as 'It happens because of the air' or 'Such phenomena need time'.

Russell et al. (1989) describe a study of children's (5-11 year old) ideas about evaporation. Although focusing on the conservational aspects of children's explanations about the evaporation of water from a tank, the way they describe it gives an overview about the way action might be taken into account. One category of explanation is named 'Change of location with no physical change in the nature of the water', and is described as involving three kinds of answers:

- relocation of water by human or animal agent - when it is clear that a person, known or unknown, has removed some of the water, e.g. 'Mrs Stewart drank it';

- relocation of water to the site of the agent - when it is suggested that a non-animal physical agent was responsible for the relocation. For example, the sun might be identified as the agent, e.g. 'The sun sucks the water';

- relocation of water to a site other than that of the agent - similar to the previous but with answers such as 'The water from the puddle goes to the clouds. The *sun acts* as a magnet and brings the water up drop by drop'.

We see that when explaining the evaporation of water these students give special attention to action: in the first case action is attributed to a subject while in the others action is projected onto an entity - the sun -, which is seen as having the power to act and cause the evaporation.

In the study of views about energy by Watts (1983), analysed in section 3.2.3.1, all frameworks have to a certain extent an implicit link to actions and cause. It seems that in some cases energy is seen as the cause for changes, in some it is related to the idea of energy as the cause of actions, and in the fourth framework is seen as the action itself.

Shultz and Coddington (1981) in a study about the development of the concepts of energy, make a connection to the development of causal reasoning in children. They report that research in this area indicates that from the age of 3 years physical causality is interpreted in terms of generative transmission, that is, *'an effect is actually produced or generated by virtue of some transmission emanating from the causal event'*. They also say that within the field of physics, the production or generation of physical events is understood mostly in terms of the transmission of energy from one system - *causal* - to another - *effect*, and that psychological experimentation reveals that 'children as young as 3 years appreciate the idea that something must travel from the cause to the effect in order for the effect to be produced'. Moreover, it seems that if the transmission from a possible cause is somehow blocked or misdirected or never occurs at all, 'the child readily attributes the effect to another possible cause which is capable of transmitting to the effect'. Therefore, they justify their study of the development of energy concepts saying that apart from the fact that young children seem to possess at least a rudimentary understanding of energy transmission, such understanding also plays a central role in reasoning about causation. They report that although young children interpret causation in terms of a transmission between objects or events, the findings confirmed that they cannot say that 'children possess anything more than a rudimentary appreciation of the concept of energy' and that the intuitive grasp of the principles of energy rarely emerges before the age of 15 years.

Nicholls and Ogborn (1993) describe a study of underlying structures in children's thinking about energy where pupils aged 11 and 13 are asked a number of basic questions about a range of relevant entities such as foods and fuels, living things, natural phenomena. Apart from reporting the detection of a main structure based on the distinction between sources and users or consumers of energy, they conclude saying that 'it seems that the strongest basic notion of energy is that it is a source of action'.

Proverbio and Lai (1989) describe a study of spontaneous models for the representation of the concepts of physical time and weather with pupils from 7 to 11 year old. They report that the perception of time connected with the observation or perception of continuous changes is shown by images or verbal expressions indicating 'change' or 'evolution' which in the presence of spatial shifts are translated into 'movement'. In this representation the idea of 'passing time' is associated with different categories such as:

- time as action: this is identified with actions carried out by the subject, 'time for doing home work'

- objective time: this refers to the existence of 'passing of time' independent of any action taken by the subject, 'time can even change the earth'

Therefore, it seems that time is conceived not only through the awareness that it is "when" an action can be taken by the subject but also through the conception that time can act on its own, "when" it causes change.

The importance of an action taken by the subject is reported in at least two studies. Prieto et al. (1989) in a study of ideas about solutions held by students aged 11-14 report that most of students 'attach a good deal of importance to the mechanical actions and manipulations (taken by the subject) involved in dissolving the substances (e.g. stirring, shaking, etc.)'. Thus even in phenomena where action would not necessarily play an important role, it is still considered as manifest.

Sciarretta et al. (1990) in a study of commonsense knowledge about thermal properties of materials held by Italian students aged 13-18 and teachers (older than 25) report that although they do not know the details of the processes of cooling/heating of a pure substance, 'they do know that mechanical action may produce an increase in temperature as if heat had been given to the system'.

Yet, Anderson (1990) in a study of students conceptions of chemical reactions reports that an external action is required to cause the change, although the external agent is not always mentioned or made explicit.

A different way of analysing the role played by action in the explanation of events is to look at the way students classify phenomena. Ribeiro et al. (1990) describe a study of the influence of meaning from everyday language on interpretations of some chemical phenomena given by undergraduate chemistry students. They report that when explaining the idea of spontaneity, they adopt a criterion very close to the ordinary meaning of the word spontaneous: 'if it is observable that the reaction occurs under certain conditions without external interference then it is spontaneous'.

Stavridou and Solomonidou (1989) report that students oppose 'natural change' to 'artificial change' in the sense that natural phenomena occur without intervention, while artificial changes are connected to human beings 'who possess a technical way to bring about or provoke changes which they want and when they want them'.

3.3.2 Explanation

The studies described in this category are at a different level of investigation, where the focus is on trying to explain the regularities that seem to be present in students' responses in terms of underlying forms of reasoning, i.e., categorising instances of types of explanations developed by students, in an attempt either to generate a 'grammar' of explanations (Ogborn, 1992a) or to describe them in terms of known forms of explanations.

3.3.2.1 Ontology, Causation and Explanation

Ogborn (1989, 1992b, 1993) presents an overview of the way some of his empirical and theoretical research fits within a common theoretical framework concerned with the study of explanation and commonsense reasoning. As he says, these researches are not essentially concerned with the social and linguistic act of 'giving an explanation', but with the 'content and nature' of explanations, i.e., with the elements and structure of an explanation. They also have in common a position about the nature of explanation, which can be outlined as 'explanation rests on ontology'. The perspective relies on the assumption that 'explanations reason with reference to the nature of things, to what entities of the kind which seem to be involved can do and can have done to them', that it all depends on what entities are thought of as like.

This ontological approach belongs to the mental models tradition, where people are seen as creating explanations by constructing mental models of a situation and reasoning by manipulating the model in the mind. Within this framework a series of researches were carried out varying in nature and purpose but all with the guiding idea of getting below the surface of children's responses or forms of reasoning.

One study (Ogborn, 1985; Bliss, Ogborn and Whitelock; Whitelock, 1991), tested a theory of fundamental naive structure of understanding motion and force. The theory was based on an analysis of possible causal structures from which nine prototypes of motion such as walking, flying, being pushed and being carried were constructed. These prototypes were represented by cartoon images and proved to give reasonable account of ways students, whether taught physics or not, talk about motions. This led to the identification of a small number of stereotypical models for describing motions such as 'walk or run', 'push or pull', 'fall', 'carried'.

Gutierrez and Ogborn (1992) investigated the use of causal models in reasoning about force and motion, analysing protocols from students who were asked to describe and account for motions, also presented as cartoon images. The reasoning could be accounted for in de Kleer and Brown's (1983, 1985) terms, and although initially tending to follow Rozier's (1991) scheme of linear causal reasoning, later tended to become more complex, involving circles of causality. Also reported is the invention of mythical causes to account for discrepancies, and that students tended to look first for dynamic causal agents, and only later for structural causes.

In a series of studies Mariani and Ogborn (1990, 1991, 1993) studied some fundamental dimensions of commonsense reasoning about physical objects and events, starting from a Piagetian framework. An initial tentative study (Mariani and Ogborn, 1990) investigated conservation in relation to action, or how students imagined things which are conserved or not. They report two dimensions of commonsense reasoning about conservation - conserved vs. non-conserved and source of change vs. not a source of change: the sun and a person are seen as non-conserved sources of change; everyday objects were mainly non-conserved and not sources of change. Energy was the main entity which was both conserved and a source. Analysis of written responses suggests that to be conserved is seen as to be unable to be affected by actions.

In the following studies the investigation was about basic ontologies. In Mariani and Ogborn (1991) a study of the ontology of entities such as matter, time, light, described these entities in terms of four underlying dimensions interpreted as static vs. dynamic, place-like vs. localised, cause vs. effect and discrete vs. continuous. Therefore causation appears as one fundamental dimension of the ontology. In the last study (Mariani and

Ogborn, 1993) the investigation is about the ontology of events rather than of entities. There were again four underlying dimensions, now with causality playing an even more important role. The dimensions were: place-like vs. localised, action-like vs. event-like, static vs. dynamic and internal cause vs. external cause. The conclusion is that the dimensions for entities and events are closely related. They have the dimension localised vs. place in common although its meaning is rather more abstract in the case of events. The dimension cause vs. effect for entities seems very close to the dimension action-like vs. event-like for events. Also in common is the dimension static vs. dynamic.

A significant aspect shared is that all these studies give primacy to *object* and to *action*, where actions are seen as the source of a notion of cause, and objects are understood 'as a package of knowledge and expectations about their nature and behaviour', this leading to considering imagery as centrally important.

All these attributes are connected with the viewpoint that explanation is an abductive process, where conjectures are made about the world based upon the way it is imagined. If the world were really like the model proposed, what actually happens would be a natural consequence of the nature of the world as specified in the model. As Ogborn says, 'from an ontological perspective, in explanation we reach towards what we currently see as the essential nature of things, so that what happens does so because that is just how things are' (Ogborn, 1992b).

3.3.2.2 The Experiential Gestalt of Causation.

In order to achieve a deeper psychological understanding of pupils' reasoning, Andersson (1986a) attempts to demonstrate that there is a common core to pupils' explanations and predictions in a wide range of areas. This common core he called the experiential gestalt of causation, which is based on Lakoff and Johnson's (1980) work on language and metaphor. According to them, a given gestalt is viewed as a cluster of components that occurring together establish a complex of properties which is more basic to our experience than their separate occurrence, and characterise a prototype of causation.

Causation is an experiential gestalt which starts to be constructed at very early age, through the recurrence of actions in our experiences, as we go through our daily lives. Common to many experiences and actions is that there is an *agent*, which directly with its body, or indirectly, with the help of an instrument, affects an *object*. Therefore, testing and investigating our world, our experiential gestalt is enlarged by means of generalisations such as:

- the greater the effort by the agent, the bigger the effect on the object;
- the agent does not have to be a person; it can be an object in motion;
- different objects resist to different degrees;
- several agents have a greater effect than just one;
- the nearer the agent, the greater the effect;
- without contact there is no causation;
- causation has a particular direction;
- causes and effect can form causal chains.

Andersson analyses data related to alternative frameworks from different areas in science, such as, temperature, heat, electricity, optics, and mechanics, and tries to demonstrate that they can be explained using the experiential gestalt of causation.

3.3.2.3 Linear Causal Reasoning

Rozier and Viennot (1991) illustrate in the domain of thermodynamics, how students commonly reduce the intrinsic complexity of multi-variable problems, when a physical quantity which depends on several others is treated as if it were dependent on only one. These tendencies towards 'functional reduction' in common reasoning, may be obtained by 'forgetting some of them' or 'combining some of them, as if they were two facets of the same variable'. This results in a linear shape of argument, the 'linear causal reasoning', that constitute a temporal linear chain such as:

$$\mu_1 \rightarrow \mu_2 \rightarrow \mu_3 \rightarrow \dots \rightarrow \mu_n$$

Each phenomenon μ_n evoked is specified by only one physical quantity or more generally correspond to a single action. In another words, the links can be described as 'one cause -> one effect', even if other causes have an important contribution, as also mentioned by Gutierrez and Ogborn (1992). This kind of reasoning has two noticeable features: the first is a lack of symmetry in implications; each specific implication $\mu_n \rightarrow \mu_{n+1}$ does not imply that the reverse implication would be accepted by the same student. Another aspect is that some apparent contradictions in students' responses may be understood if it is admitted that there is a 'chronological connotation in the argument where "an arrow" or a "then" means not only "therefore" but also "later"'. This temporal connotation accounts for the lack of symmetry inasmuch as unlike scientific reasoning, where all the changing physical variables are supposed to change simultaneously under the permanent constraint of one or several relationships, this way of reasoning enables variables to be dealt with two by two, and to say different things about one of them at different stages of the argument.

A simpler causal model is proposed by Tiberghien (1984b) based upon results from a review about researches on electric circuits. All results showed that students established a causal connection between the battery and the bulb and consider that 'there is "something" that moves between the battery and the light bulb', which is considered as the causal agent. It is reported that this causal model does not imply that there is a closing of the circuit, yet it does not exclude it.

3.3.2.4 Symbolic Knowledge and Life-World Knowledge: The 'Two Domain' Theory

Solomon (1983a) proposed the 'Two Domains of Knowledge' theory, based upon the ideas of Schutz and Luckmann (1973) and Berger and Luckmann (1966), and upon her previous studies on children's ideas about energy (Solomon, 1982; Solomon, 1983b; Solomon, 1983c). According to this, when children reach at the age of schooling, they have already constructed a life-world knowledge based upon their own experience, which has both social value and great persistence. During the schooling process other interpretative systems of knowledge may be learnt, which seek to explain their experience in another province of meaning, forming what is called symbolic knowledge. As she points out:

> 'These two coexisting spheres - everyday notions and scientific explanations - are very dissimilar both in their genesis and in their mode of operation ... The primary life-world structures are not eradicated by such learning since it forms an overarching system with a radically shifted perspective of interpretation which is foreign to the natural attitude and considerable fragile. Its social currency is also much weaker since it is restricted to a small specialised group, or to certain periods of time within the school timetable.' (Solomon, 1985)

These ideas are schematised in Figure 3.2, where the relationship between the two domains is shown. The crossing over from one domain of meanings to another is not a smooth process of thinking, emphasising that ease of movement between these two domains is not symmetrical for the two directions.

In a study of children's views on the uses of energy, Solomon (1985) reports that according to the two domains theory, the more able pupils, judged by school tests, not only remembered better what they had been taught, but also had greater flexibility of thought, which enabled them to move from the everyday context of the problem to the domain of abstract symbolic thought in which a problem can be tackled by the methods of physics, while the less able needed help, or strong clues to use symbolic knowledge. And she concludes: 'what gave all pupils most trouble was the transition from the life world to an appropriate place in the formal knowledge domain, a feat which the less able only rarely attempted'.

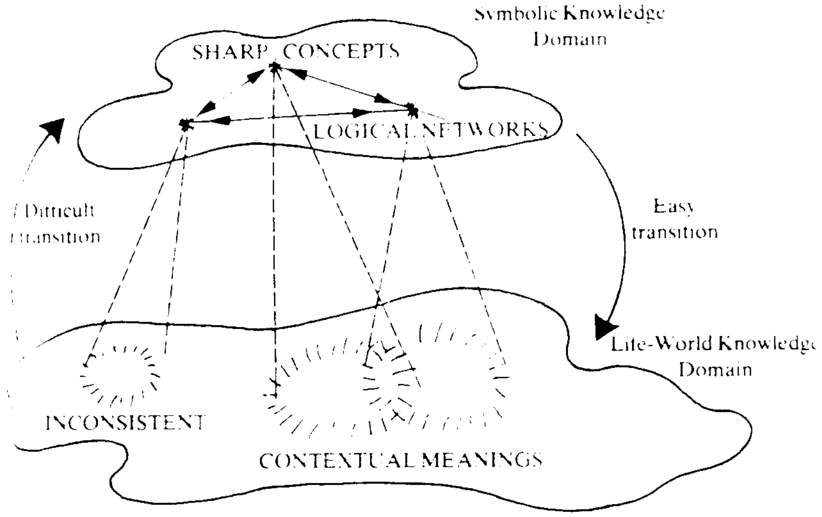


Figure 3.2 - *Relationship between the Two Domains (Solomon, 1985, p.347)*

3.3.2.5 Teleological and Anthropomorphic Reasoning (Explanations).

The use of teleology and anthropomorphism in reasoning about biological phenomena has been addressed in many studies. Engel Clough and Wood-Robinson (1985), reporting a study on pupil's understanding of biological adaptation, describe how many secondary students explain adaptation in teleological and anthropomorphic terms. Teleological interpretations are common and are used to express the belief that adaptations are due to some grand, overall purpose or design, often referred to 'inner needs', to some undefined internal unconscious drive. Yet, anthropomorphic explanations are also common, and adaptation is described as a conscious process with reference to an animal's needs or want.

Similar results are reported in studies in different areas: Westbrook and Marek (1992) in a study of students' understanding of homeostasis, e.g. 'blood needs to...'; Friedler et al. (1987) in a study of students' understanding about osmosis, e.g. 'it is a desire or drive of water molecules towards equalising concentrations'; Séré (1985, 1986) when investigating children's conceptions of the gaseous state, e.g., 'air trying to...', Driver (1985) when reviewing a study by J. Knox of students ideas about the process of burning, e.g. 'the fire likes air'; and Watts (1983) in a study of alternative views of energy, e.g. '... the bulb needs it (energy) ...'.

As suggested by Hempel (1965), teleology may be considered as a special case of anthropomorphism, since teleological explanations make us feel that we really understand the event because the explanation is given in terms of purposes and intentions which fit the way we are used to dealing with our own intentional behaviour.

Bartov (1978), focusing on the process of explaining, considers that teleological explanations indicate a means-end relationship and are peculiar to biological science, whereas physics and chemistry deal with causal explanations, i.e., explanations indicating a cause-effect relationship. However, he points out that the use of such a kind of explanation in biology is controversial because teleological explanations imply conscious, intelligent purposes, a competence which cannot be attributed to non human beings, and that they entail the identification of purposes with causes, which can mislead the student to understand biological processes as being brought about by their ends, and not by specific causal mechanisms. Therefore, Bartov (1981) proposes a methodology of teaching to help students to discriminate teleological and anthropomorphic explanations from causal ones, an ability related to analysis; and to distinguish teleological and anthropomorphic formulations from factual ones, this ability related to comprehension. The development of these two abilities was expected to help students in their reasoning about a phenomenon, and this is reported to have been achieved to a reasonable extent.

Tamir (1985) studying 17 year old biology students' capability of distinguishing between causal and teleological explanations, reports that students showed that their ability to make such a distinction was contingent upon their knowledge of biology. In Tamir and Zohar (1991), the objective was to study if there existed a developmental trend related to anthropomorphic and teleological reasoning. The results reported were that there appear to be two kinds of teleological reasoning: one closely associated with anthropomorphism and another one independent of it. The second is based on a belief in the functionality of the behaviours of living organisms, which is illustrated by major principles, such as the adaptability of organisms to their environment and the complementarity between structure and function. Moreover, students do not attribute human purposeful behaviour to plants, while they do to animals.

3.3.2.6 Tautological Explanations.

Jungwirth (1986) analyses the 'problem of tautological explanations', that is the commitment of, or agreement with, this logical fallacy. A tautology can be either the formulation of a statement and/or the use of a synonym, without adding additional information. It is reported that in opposition to what could be expected, tautological explanation is largely accepted among school pupils, undergraduates, teacher-college, when an explanation is called for. The author suggests that the respondents' failure to reject tautological explanations would seem to stem from a lack of knowledge rather than from an incapacity to grasp the concept.

3.4 Studies in the Developmental Psychology Perspective

The objective of this section is to present studies related to students' conceptions about scientific concepts, but which are also psychologically oriented. Therefore, they do not only deal with pupils' views about concepts related to the present study, but also include a discussion of these concepts within a developmental psychology perspective.

3.4.1 Stavy's Studies

Since 1985, Ruth Stavy has been investigating children's ideas about the nature of matter (Stavy and Stachel, 1985a, Stavy et al, 1987, Stavy, 1988), and its change of state (Stavy and Stachel, 1985b, Stavy, 1990b). Her interest is two fold: on the one hand it is connected to the planning and developing of science programmes for children, and on the other hand it is theoretical and connected to developmental psychology (Stavy and Stachel, 1985a), which has its main focus on the concepts of reversibility and conservation. Both interest are kept throughout her subsequent studies, to the extent that in a recent paper (Stavy, 1991), she examines the use of analogical instruction to overcome misconceptions about conservation of matter, concluding that teaching by analogy can be effective in science.

Regarding the particulate nature of matter, her studies of the concepts of solid and liquid (Stavy and Stachel, 1985a) and gas (Stavy, 1988; Stavy et al., 1987).) have already been reported in section 3.2.2.2.

The papers connected with changes in the state of matter (Stavy and Stachel, 1985b, Stavy, 1990b) are strongly psychologically based. Apart from investigating ideas of children aged from 5 to 15 years, the studies were designed to scrutinise the concepts of conservation and reversibility in relation to some of Piaget's findings. According to Piaget and Inhelder (1974), when qualitative conservation (identity, property) is compared with quantitative conservation (matter, weight), it lacks the latter's crucial property of operational reversibility. In other words, Piaget considers identity (qualitative conservation) and reversibility to be essential to the acquisition of recognising conservation, possible at the concrete operational stage.

From this perspective, Stavy and Stachel (1985b) investigating children's conceptions of melting, report that no relationship could be observed between conservation of weight and reversibility, after asking children about the invariance of material, invariance of weight and reversibility of two identical candles when one of them is melted. Some children recognised the conservation of weight but were not aware of reversibility, while some failed to recognise the conservation of weight despite their awareness of reversibility. Moreover, 'our findings suggest that identity is not a prerequisite for recognising weight conservation as might be expected from Piaget's theory'.

In respect of the task related to the reversibility of the process, a comment must be made concerning the object/substance dilemma (Jones and Lynch, 1989). The description of this task was: 'Two identical candles were given to the child. One of the candles was melted and the child was asked about the reversibility of the process (i.e. could the melted material be reversed back into a solid one) and to justify his judgement'. Depending on the way the interview is carried out, this statement might be interpreted as 'could the melted *substance* be reversed back into a solid one?' or alternatively 'could the melted *object* be reversed back to a solid one?'. Therefore, this very fact could explain the result that 'some children do not recognise that the reverse process is spontaneous (as was the melting process)', and their justifications seem to corroborate this analysis when it is said that 'they believe that if it can be done, it can be done only with magic or by a machine', which appears to be expressing the difficulty of reversing the process to get the *object* candle again.

Another point worth discussing is the assumption made in the analysis of answers to the invariance of weight question. The authors report that when asking children about the equality of weight between the two candles, after one of them had been melted, some of the children gave incorrect answers saying that a change in state means a change of weight, 'and some of them might believe that in addition to the change in state there was also some evaporation of the liquid wax'. The authors are assuming that no wax is evaporated in the process of burning a candle, which is not true at all. Therefore a doubt could be raised about the way the answers were analysed: based on this assumption, the analysis could have been misleading, and perhaps children might have been 'correct' in their view.

Stavy (1990b) reports a study of children's conceptions of changes in the state of matter from liquid or solid to gas, when their ability to conserve matter, its identity, and its weight in tasks using evaporation and sublimation was tested. Similar results to the previous study analysed are reported. The understanding of reversibility was not found to be pre-requisite for weight conservation awareness. There were cases in which children perceived weight conservation without understanding the reversibility of the process (melting of a candle, iodine sublimation), and rare cases in which the children understood the reversibility of the process but did not perceive weight conservation. Children who recognised weight conservation in one of the tasks did not necessarily recognise the same in the other. In the case of the evaporation process, for most children conservation and reversibility go together, although approximately 12% of the sample perceived weight conservation without being aware of the reversibility of the process, and in this case the conservation of weight was explained by additivity - 'the container is closed, nothing left or entered'. A similar percentage did not perceive conservation of weight despite being aware of the reversibility of the process, and in this case the explanation was the incorrect intuitive knowledge that 'liquid always weighs more than gas'. A common explanation regarding irreversibility was that 'the matter was no longer present and therefore it was not possible to retrieve it or simply that the gas cannot be changed back into liquid'. In the case of the sublimation process, it is reported that the results confirm that qualitative property conservation is not essential for conservation of matter and its weight, which is contrary to what is suggested by Piaget. In addition the conservation of properties is coincidental and specific to each material and property.

Stavy et al. (1987) describing a study on how students aged from 13 to 15 years understand photosynthesis report that "apparently, students at this age tend to consider man as the 'centre of creation' and assume that man has full control over his environment". Moreover, they say that it is difficult for children to accept the fact that human life depends on the existence of plants, for they think of plants as dependent on man. It is interesting to point out that although this is a feature of very young children's thought according to Piaget (1979), it is attuned with the view taken in the present study, when it was noted in chapter 2 that to a person it seems that actions can be spontaneously achieved at no expense.

3.4.2 Bar's Studies

Bar (1989) describes a study concerning children's ideas about the water cycle, from which it is possible to have a general view of the evolution of her research. Although having interest in children's views about phenomena such as free fall (Bar & Goldmuenz, 1987), phase changes (Bar & Travis, 1991), evaporation (Bar & Galili, 1992), her studies have a strong connection with developmental psychology, which can be seen in a study concerning the development of ratio concepts in children (Bar, 1987).

From this point of view, her main interest is in the development of the concept of conservation in children aged from 5 to 14. In Bar (1989), she writes that 'a structure can be found within the children's ideas' concerning the water cycle, which combines their "*level of understanding* concerning the *conservation* of the amount of liquid and air, the views about phase changes, and the 'theory' concerning the water cycle". It is said that a general understanding of conservation is not a necessary condition for the development of water cycle ideas, excepting for views concerning evaporation, and it is suggested that there are three levels in the understanding of conservation in this cycle:

- neither water nor air are conserved
- water is conserved, but not air
- both water and air are conserved

In a preceding study about phase changes (Bar & Travis, 1991, submitted in 1987), the main purpose is to establish the nature of the development of the concepts concerning phase changes from liquid to gas, in children aged 6 to 14 years. It is reported that the development of views concerning evaporation and nature of matter in the bubbles, follows certain stages. Changes in views can be attributed to the ability to conceive the existence of air. Regarding the concept of evaporation, the view changed from one that water penetrates solid objects to one that water evaporates, while the identification of the matter within the bubbles changed from water to air.

Although reversibility is not an issue in this paper, a relevant remark can be made in relation to the result of a factor analysis of the students' answers to a written test. The test consisted of nine items as shown in Table 3.1 and the result of the factor analysis is shown in Table 3.2.

Table 3.1 - *Problems description according to the concepts investigated (Bar, 1991)*

CONCEPT	Nº	PROBLEM DESCRIPTION
Evaporation	1	the drying of the floor
	4	the drying of the laundry
	7	the drying of the saucer
Boiling	6	the nature of the matter inside the bubbles
	2	the nature of vapour
Condensation	8	the condensation of vapour from air on a cold vessel
	9	the condensation of vapour from boiling water
	5	the possibility of a change from vapour to water
Vapour permanent existence	3	the permanent existence of vapour in the air

The factor loadings can be interpreted to describe an inner structure underlying the children's answers. In this case factor 2 groups problem 5 with problems 2 and 6. The former related to the concept of condensation and the two latter to the concept of boiling, which are, in a sense, the reverse process of each other. Similar comments can be made concerning factor 3, which groups problem 3 - related to the concept of permanent existence of vapour - with problems 8 and 9 - related to the concept of condensation, which can be seen as the process that reverses vapour into water, which in turn can become vapour again due to its permanent existence. Therefore one aspect that could be analysed in further studies is whether this result means that the students are aware of this fact and to what extent they understand it. This proposition finds some ground in the result reported that 'children who understand that water changes into vapour also say that vapour can be changed into water'.

Table 3.2 - *Result of the Factor Analysis (Bar, 1991)*

Nº	FACTOR 1	FACTOR 2	FACTOR 3
1	.5		
2	....	.34	
3	....	....	.41
4	.71		
5	....	.50	
6	....	.25	
7	.78		
8	....	....	.24
9	....	....	.34

Narrowing down the inquiry to phase changes, in Bar and Galili (1992), the aim was to investigate children's views of the process of evaporation, how it evolves with age, and the possible connection to the use of the conservation principle. This paper is quite significant for the present purpose because the author makes explicit comments connecting the students' views and the concepts of *reversibility, conservation,* and *action*. Regarding their conceptions about evaporation, a sequence of four views, which appears over the age span of 5 to 14, is described:

A - water disappears
B - water was absorbed in the floor (or/and ground)
C - water "evaporates", meaning it is now unseen and being transferred into an alternative location or media
D -water changes into vapour, which proffers small (commonly unseen) droplets, dispersed in the air, or water is transformed into air.

Although children make use of view A mainly up to age of 7, this view does not vanish completely at older ages. The authors interpreted this fact by suggesting that 'disappear' at this age could mean 'cannot be retrieved', (the water just changes into air and disappears), and that when children use it, they would be expressing their idea of the irreversibility of water evaporation.

The sequence of views A => B => C => D which develops with age is analysed. The move from view A to view B is related to the upsurging of conservation ideas. The next transition, from view B to views C and D presumes a change of the moving of the water in a downward direction to moving in an upward direction. From this analysis, the conception of water vapour as a mixture of 'water with heat' is interpreted. The change of water movement from downwards to upwards may be seen as 'unnatural' by the students, in an Aristotelian sense. Therefore, this transition could lead children to search for a 'mover' or 'agent' which would take the action to cause this 'unnatural' upward movement: they might have considered heat as such agent, and the observation of the evaporation of water boiling could possibly be the origins of such a view.

Concerning the employment of conservation, children were presented with the Piagetian task with two identical beakers with equal amounts of water in which the water of one beakers is transferred into a longer and narrower one. Children's answers could be classified into three groups:

- 'conservers' - subjects using conservation considerations during the whole interview;
- 'non-conservers' - those who did not use any conservation idea;
- 'transitionalist' - those who were not consistent, from a scientific standpoint in their responses.

It is reported that the most of the 'conserver' subjects held a view about evaporation described as 'water absorbed', while most of the 'non-conservers' chose a view described as 'water disappeared'.

3.4.3 Shultz and Coddington's Study

Shultz and Coddington (1981) describe an extensive study of the development of the concepts of energy conservation and entropy in children between 5 and 15 year old. Although this study is related to students' conceptions, it is also connected with the developmental perspective. They selected two experiments from Piaget's work which deal with each of these concepts in turn, 'not in the sense of refined scientific or mathematical expression, but rather in terms of the child's developing intuitions about the physical world'. The first experiment was to investigate the concept of conservation of energy and they selected the so-called double pendulum described in Piaget (1974), where children of different ages are asked to predict the motion of the pendulums: they declare that the experiment was designed to correct some problems and limitations intrinsic in Piaget's experiment, and, 'as well, to investigate the phenomenon on a second apparatus - the colliding pendulum'. The results show that children at each age produced some conservation judgements although data 'suggest that conservation of energy was rarely conceptualised before about 15 years old of age'. Moreover, that the emergence of this concept may not be based only upon perceptual experience, but that 'it appears that such experience must be integrated into an existing conceptual framework in order to yield a conservation judgement'.

The purpose of the second experiment was to investigate the development of the concept of entropy based upon the experiment about the notion of random mixture and irreversibility described in Piaget and Inhelder (1975), where children were asked to predict the result of the progressive mixing of balls of two different colours and the trajectories of individual balls. They say that although Piaget did not discuss this task in the context of entropy, 'it can be easily be viewed as a concrete illustration of that principle'. Therefore they conducted a similar experiment but using in addition, an apparatus showing the gradual equalisation of water levels in two interconnected containers. They report that children from

9 years old understood the operation of entropy in the marble apparatus, but not before 15 years old did they understand entropy in the context of the water levels problem. They suggest the presence of apparatus or task effects: recent researches have been finding that the conservation of discrete materials such as counters or chips typically emerges before conservation of continuous materials such as liquids, a fact already argued by Piaget and Inhelder (1941) in which the mastery of material conservation is based in part upon an atomistic approach. Therefore a situation dealing with discrete elements and causal forces generated by the experimenter such as in the marble apparatus would probably be more familiar to children than would a situation with continuous substances and the impersonal and invisible causal force of gravity.

4

The Conception of the Study

In this chapter it is intended to give an account of the way in which the scientific account of reversibility and the review of literature were used to develop the conception of the study and to generate the design of the empirical research.

4.1 The Choice of Problem

4.1.1 The Context of the Study

Since the early 70's research on students' conceptions has been carried out to investigate the ways in which students make sense of scientific concepts (for an extensive catalogue of research see Pfundt and Duit, 1991). The approach has been mainly descriptive with most of the researches trying to describe the ways in which different scientific concepts are understood by students at different age and/or instructional levels. More recently this approach has been moving to a perspective in which the researchers seek to explain the apparent regularities shown by students' responses in terms of underlying structures of reasoning.

Different labels have been used to refer to students' conceptions, such as misconceptions, (Doran, 1972), preconceptions (Novak, 1977), alternative frameworks (Driver and Easley, 1978), 'spontaneous reasoning' (Viennot, 1979), 'children's science' (Gilbert et al, 1982), 'natural thinking' (Guidoni, 1985), 'commonsense reasoning' (Ogborn, 1985), each one reflecting a different view of their nature.

The terms misconceptions or preconceptions are used in a context where they are seen as mistakes made by students when trying to use scientific concepts learnt in Science classes, and therefore needing to be corrected by teaching. The term alternative frameworks indicates that these ideas have the status of a different body of knowledge about the physical world which is not thought of as 'right' or 'wrong' but is still considered as something which differs from what students are expected to learn, and therefore needs to be changed. The remainder are connected with the idea that it is possible to find forms of reasoning or thinking about events from students' responses which are considered either as differing from those used in Science (Viennot, 1979; Gilbert et al, 1982) or as giving grounds for the construction of a 'theory of natural thinking' (Guidoni, 1985) or 'a theory of commonsense reasoning' (Ogborn, 1985).

In the last perspective it seems that whether the natural way of reasoning may or should be substituted by scientific reasoning is not the main issue. The issue becomes one of understanding processes of reasoning or modes of thinking about entities and events, which happen also to have a different description in Science. Research focuses on looking for forms of reasoning which may underlie particular responses of individuals, and be common to a group. What 'forms of reasoning' are looked for depends on how the research is conceptualised in the first place. Most such work has focused mainly on group tendencies, not on individual differences.

These researches have drawn on developmental theories (mainly Piagetian) as a way of conceptualising 'forms of reasoning' within a commonsense perspective, where commonsense reasoning about the physical world is considered as giving support to commonsense knowledge of the physical world, which is characterised fundamentally as the way one experiences and senses this world. One such focused on causes of motion (Whitelock, 1991) and another on reasoning about entities in Science, e.g. force, energy, space, time (Mariani and Ogborn 1990, 1991). In the latter work, in addition, a novel methodology was developed, where very simple and direct questions are asked to individuals and patterns of thought are searched for in the data gathered from groups of individuals through the use of multivariate exploratory techniques.

The present research belongs to this broad framework, and adopts the methodology mentioned, but makes only general use of ideas derived from developmental theories.

4.1.2 Possible Kinds of Questions to be Raised

In order to investigate people's commonsense reasoning about processes and the way they are thought of as reversible, four related perspectives help to systematise the way the problem will be focused: thermodynamic, conceptual, commonsense and developmental.

From the thermodynamic account in chapter 2, we have the concept of reversibility with a sharp definition delimiting the way in which any phenomena in nature can happen, through the statement of the Second Law of Thermodynamics. It has long been recognised and reported that the understanding and the teaching of the Second Law and related concepts are very difficult (see for example Marx, 1983). From this perspective it is important to know in what ways students' commonsense ideas about reversibility relate to or are very different from the thermodynamic account.

From the conceptual perspective the concept of reversibility is related to different concepts from different areas such as heat, evaporation etc. As described in Chapter 3, students have different views about these concepts, as well as holding different views about reversibility. Their understanding of concepts may well influence how they think about reversibility.

From a commonsense perspective, reversibility differs from the scientific view and relates to ideas of 'going back': it has a shading from simply going back in any way, to the undoing of something that happened. It can be thought of as happening either naturally or through an action. Taking into account that reasoning about the physical world requires reasoning about kinds of changes that occur and the effects they produce, and that in everyday commonsense thinking people and objects are thought of as having the power to cause events (Harré, 1988), it is possible to investigate the way causation is conceived and to better understand the connection between action, cause and effect. Evidence given in chapter 3 indicates the prevalence of linear causal reasoning. Reversibility then becomes a matter of closed causal chains. Therefore the question arises whether it is possible to find a description of the basic causal elements which people use in their everyday life, to reason about reversibility.

From a developmental perspective reversibility is connected with mental operations which are nothing but internalised actions that are mentally reversible, in opposition to actual actions. Through actions and visible movements the child becomes aware that the physical world has a before and an after, which orders cause and effect, leading him to a structuring of thought at the unconscious level, in which he gradually reaches the stage when possibility is no longer an extension of actions actually performed, but rather an internal construction in which reality becomes subject to possibility (Piaget, 1979). This raises questions related to the connection between mental reversibility and internalised actions, and perceived reversibility and actual actions, and about how this perspective might help to understand the commonsense perspective.

4.1.3 Relationship Between Different Ways of Thinking about Reversibility

It is convenient first to consider the scientific (thermodynamic) account as a basic framework, to help look for indications of likely differences between this account and the commonsense account .

From the scientific standpoint reversibility can be accounted for in two ways: in the Thermodynamic viewpoint reversibility is connected with equilibrium and concerns processes happening as a continuous series of equilibrium states, while in the Mechanics standpoint reversibility is not connected with tendency to equilibrium but rather with processes happening with no dissipation of energy, for which time reversal is perfectly consistent with the description of the process. The scientific account through the Second Law of Thermodynamics gives a rationale for explaining natural changes: all processes regarded as natural or spontaneous are considered as irreversible, because they move towards equilibrium at which point all possible differences have smoothed out leaving no possibilities for further changes. That is, the reverse of a spontaneous process does not happen naturally or with no intervention.

However, what is spontaneous or natural depends on conditions: an ice-cream will naturally melt *if* the surrounding temperature is above 0° C, and the melted ice-cream will naturally freeze *if* the surrounding temperature is below 0° C. The point is that the scientific account does not include in the process the establishing of the conditions to be set to cause the event, but regards them as 'outside' the process. Commonsense reasoning may differ in considering the process of setting conditions as part of the event itself.

If setting the conditions is thought of as part of the event this may be done through actions of a person. It seems likely that commonsense thinking about actions will treat them as having a source in intention, as opposed to a scientific analysis of the biology of actions, which gives no place to intention. As already noted in chapter 2, actions seems always available to us and taking actions does not necessarily appear to deplete our power to act, and even if temporally we think so, it appears to us that we recover spontaneously.

Actions can appear to us to be freely available because in our daily life we are not usually aware of the fact that we maintain ourselves in a steady state far from equilibrium by the continual processing of food, when we are keeping ourselves 'in order' at the expense of destroying order in the form of food. Therefore we feel prepared to act to 'do whatever we want', so that we can often restore something to its original state after it has changed, which can not only lead us to think of a world which is 'reversible', but also to build up a 'commonsense' way of reasoning about the world around us based upon this way of thinking.

One can also consider actions as a source of organisation in the sense that taking an action to restore the original state of a natural process can be a case of increasing order. But again this is only possible, from the scientific point of view, at the expense of creating disorder elsewhere, because when we act we are using free energy taken from the food we ate, which took free energy from the sun, etc.

It is also possible that reversibility is related to conservation. If a process would break a principle of conservation (e.g. create matter from nothing) then it is impossible, and if it is the reverse of another process, the second will be non-reversible. According to Mariani and Ogborn (1990) conservation is related to inaccessibility to action: something stays the same if it cannot be acted on. This suggests that it would be desirable to know what subjects think of as staying the same or not, and why, when asking them whether processes are reversible.

Therefore this contrast between the scientific and everyday commonsense perspectives provides some basic features to look at more carefully. These features can be summarised as related to the ideas described below:

• *actions* - the analysis of the role played by action in the happening of an event forwards and backwards: is action considered as necessary for an event to happen? If so, is an external action needed to make the event happen or can something within the process provide an action?

• *conditions* - the possibility of an event happening, depending upon particular conditions;

• *spontaneity* - connected with the ideas of:

- • *equilibrium* - in the scientific view processes move towards equilibrium. How does commonsense reasoning regard such 'natural' processes? How does commonsense reasoning deal with movement away from equilibrium? Is equilibrium seen as 'natural balance'?

- • *conditions modified* - spontaneity related to the necessary conditions to be set or modified to cause the event to happen forwards or backwards;

- • *mechanical reversibility* - does commonsense reasoning recognise processes that can equally well happen in either direction, that are 'the same' in both directions?

This discussion also provides a rationale for the choice of processes to be included in the research, in the sense that processes which represent classical exemplars within the scientific perspective should be taken into account and contrasted with commonsense reasoning about them.

Regarding the two other accounts, we can also consider the conceptual account which gives from the literature different ways students may think about phenomena and entities. This may give some pointers to what to look for, given that how people regard the reversibility of a process may depend on how they understand the nature of the entities involved.

As the objective of the study is to see how people reason about reversibility the idea is to ask people to imagine the reversal of some processes, and it will be necessary to consider what they say not only from the point of view of processes themselves but also of how they are manipulated in imagination. There is some relation here to the developmental account, which discusses how ideas are constructed from imagined actions and events. In particular, there may be something useful to be said about reversing a process in the imagination as opposed to it in reality. It does reinforce the need to pay attention to action, already suggested by the previous argument, so as to lead us to a better understanding of its role in the commonsense reasoning and its connection with cause and effect.

4.1.4 Research Questions

Taking all these aspects into account the problem of investigating commonsense reasoning about the reversibility of processes can be thought of as investigating whether it is possible to describe how students reason about the reversibility of processes in terms of the prototypes for explaining reversibility described in Chapter 3: necessity, contingency, action, causation and teleology. This can be expressed by the three basic questions:

- *is it possible to find a description of the basic elements which students use in their everyday life, to reason about processes and their reversibility?*

- *how can the way students reason about processes and their reversibility be related to the review of literature?*

- *if such a description is possible, what would be the implications for the teaching of scientific ideas about reversibility ?*

The first question can be raised in terms of another four secondary questions:

- *what are the different ways of reasoning about reversing a process?*

- *what is the relation between commonsense reasoning and scientific reasoning?*

- *what is the role played by action in reasoning about reversibility?*

- *what is the role played by conservation in the reasoning about reversibility: to what extent does reversibility involve something being 'conserved'?*

4.2 The Empirical Work

In Chapter 3, Review of Literature, it was seen that there are few studies specifically connected with the concept of reversibility. These studies were mainly descriptive accounts of the ideas that students had about the concept of reversibility as a scientific concept, not focusing on the way they reason about reversibility in a specific situation or process.

However, the present research has a different perspective focusing on commonsense reasoning or modes of thinking about entities and events in Science, aiming at investigating the way people think about everyday processes happening forwards and backwards. This means that this is a study of reversibility within a new perspective related to commonsense reasoning.

Therefore, as there was not much previous empirical basis for this research, the empirical work was designed to be exploratory, with a pilot study to test the conception of the research, the likelihood of getting interesting results, and to develop methods and concepts for the analysis of data, to be followed by a main study using a larger sample and refined methods.

4.2.1 The Pilot Study

The basic idea was to ask students about phenomena happening first in one direction, then in the reverse direction. The student would be asked about the possibility of such a process happening, how it could either happen or be made to happen, the reason for it, and what has changed in the end or what has stayed the same.

The design of the pilot study had two aspects to be considered: firstly which and how many events or phenomena to select, and secondly what kinds of questions to ask about them. These two aspects will be discussed in the next sections.

4.2.1.1 The Choice of Phenomena

The criteria for choosing the phenomena to include in the study were that they should be processes having scientific interest with regard to reversibility for which the commonsense account would be likely to differ, and that at the same time they should be phenomena easily found in daily life and familiar to the students.

These criteria can be satisfied by a great number of phenomena. To select them, phenomena were grouped from a scientific point of view, choosing examples from thermal changes, physical changes, chemical changes, mechanical processes, magnetic/electrical processes, biological (life) processes, plus a few of a more general nature.

The actual selection of phenomena considered a wide range of degrees of reversibility or irreversibility, covering clearly reversible phenomena such as a ball rolling down hill or a wheel turning, to extremely irreversible events such as a exploding bomb or a person ageing, with events such as evaporation in between.

Twenty phenomena were chosen. Table 4.1 shows a summary of the phenomena (each with a short name which will be used to refer to it), a short description that was used to describe the phenomenon, and the type of process within a area of Science most clearly associated with it.

Table 4.1 - *Description of the Phenomena for the Pilot Study*

SHORT NAME	DESCRIPTION	TYPE OF PROCESS
PENDULUM	a pendulum stops swinging	mechanical
WHEEL	a rotating wheel stops turning	mechanical
JACK	a 'jack in the box' jumps	mechanical
SLOPE	a ball rolls down	mechanical
ICE-CREAM	an ice-cream melts	thermal
TEA	a cup of tea becomes cold	thermal
PUDDLE	water in a puddle evaporates	physical
CHAMPAGNE	the champagne goes flat	physical
MAGNET	a magnet attracts nails	magnetic/electrical
BATTERY	a car battery runs down	magnetic/electrical
CANDLE	a candle burns away	chemical
BOMB	a bomb explodes	chemical
ALKA-SELTZER	an alka-seltzer tablet dissolves	chemical
CAR	a car rusts away	chemical
BOY/MAN	a man grows old	biological (life process)
PLANT	a plant grows	biological (life process)
PENCIL	a pencil is worn out	general
TANK	the water flows out	general
EGG	an egg is broken	general
WATCH	the time goes by	general

4.2.1.2 Methodology

Researches on students' conceptions has been mostly concerned with students' understanding of scientific concepts and the studies have been mainly carried out with questionnaires or interviews (see Pines et al., 1978; Gilbert et al., 1982) asking in some depth about students' ideas concerning a certain concept or phenomenon. The analysis is basically qualitative, with the focus on individuals' answers although there is always an attempt to describe students' answers in terms of broad categories. Statistics are used in a mainly descriptive way.

The methodology which will be used here has a starting point in previous research on commonsense reasoning in Science (Whitelock, 1991; Mariani and Ogborn, 1990, 1991), where it is assumed that students use their own commonsense knowledge of the physical world in trying to understand scientific concepts, and this commonsense knowledge is supported by commonsense forms of reasoning about objects and events. As discussed before, the methodology is based upon two fundamental assumptions: it is assumed that the way people reason in their everyday life is not normally easily available to them by reflection, but that there are regularities and similarities in forms of reasoning shared by groups of individuals and not too much affected by individual differences.

These assumptions lead to a methodology in which very simple, direct and even 'obvious' questions are asked to individuals, but in which forms of reasoning may emerge as patterns in relationship between responses. The objective is to get a broad picture of the essentials of the structure of the underlying reasoning, in terms of fundamental factors or dimensions. Such factors or dimensions can be looked for using multivariate techniques.

This methodology leads to a choice of a kind of question requiring only yes/no answers about the variety of processes selected, asking for each about a range of features related to the way these processes might be seen as happening. The form of the question is a grid consisting of a collection of phrases, each representing a different way of explaining phenomena in nature, to be considered for each phenomenon (forwards and in the reverse). As stated above, results are mainly looked for here in patterns of responses to these simple questions, not in individuals responses to individual questions.

The structure of this kind of question has proved useful in looking for dimensions of explanation through patterns of answers (Mariani and Ogborn, 1990, 1991; Nicholls and Ogborn, 1993) and the interest was to see whether it would apply to a new problem. The question is discussed below, section 4.2.1.3.2.

4.2.1.3 The Instrument

The instrument for collecting data used in this study was a questionnaire. This does not mean that interviews were dismissed. It would rather be better to have a combination of both, when the students could have been directly asked about their choices in the question in the form of a grid. However, for various reasons this was not possible. First, we wanted to ask several people from at least two different age groups, which means that we would have large samples. Secondly, it was planned for the main study to use samples from different countries, therefore making it impractical to have interviews with all of them.

The choice was to supplement the question in the form of a grid with more orthodox questions where students were asked to give extended answers which could be analysed qualitatively. These two kinds of questions are complementary inasmuch as the findings of the open-ended questions may or may not agree with the dimensions revealed by the question in the form of a grid. If they do, it may be possible to reach some conclusions about results confirmed by using two different approaches; if they do not, there may be some interesting comparisons to be understood further. Therefore, the pilot questionnaire consisted of six questions, one question in the form of a grid and another five open-ended questions, which are described in the following sections.

4.2.1.3.1 The Open-ended Questions

To know how students reason about a process and its reversibility the idea was to ask them about the possibility for this process to happen in one direction, how it could either happen or be made to happen, the reason for it, and what has changed in the end or what has stayed the same. Thereafter the same questions would be asked for the same process happening in reverse. In this way we could have a broad view about the way students reason about the process as whole.

Therefore, the open-ended questions were based upon the ideas of *possibility, action, cause, differences (changes), and sameness (no changes)* which are intrinsically related to the basic prototypes described in Chapter 3, i.e. necessity, contingency, causation, action and teleology. The questions were:

- *'Think of - or imagine - some way to go from A to B. How?'*
- *'What would you say is the cause of the change from A to B?'*
- *'In going from A to B, what things CHANGE?*
- *'In going from A to B, what things STAY THE SAME?'*
- *'Is there only one way to go from A to B?'*

The first question is related to the idea of the possibility of something happening (which involves contingency and/or necessity) and may involve action, given that it asks for thinking or imagining some way to go from one state to another, and how to do that (which might involve teleology). The second question asks for causes, while the third and the fourth questions are related to a description of what changes and what does not (which involves conservation). The fifth question is also related to possibility, in that it asks for different possible ways for this change to occur.

4.2.1.3.2 The Question in the Form of a Grid

The question in the form of a grid had the objective of examining patterns of interpretation of the phenomena and thereafter how these patterns might fit with their answers to the open-ended questions. It consisted of a collection of eighteen phrases describing different views of the way a process could be thought of as happening, where students were asked to either tick - expressing agreement - or cross - expressing disagreement - each phrase according to their own ideas, which was stated as: *Which of the following phrases describe your idea?*

The phrases represent prototypes of thinking about an event according to the structure shown by the network (Bliss, Monk & Ogborn, 1983) in Figure 4.1, and are also based upon the basic prototypes *necessity*, *contingency*, *causation*, *action*, and *teleology*, as described in Chapter 3. The network can be described starting from the leftmost terms, which give the main outlines, down to the right hand terminals.

The network represents different ways of describing a process, which is based upon the conjunction of three main attributes represented by the BRA: *base*, i.e., whether the phrase is related to the idea of either necessity or contingency, portrayed by the top BAR; *outcome*, i.e., whether the phrase translates the idea of something either happening or not happening, represented by the central BAR; and the bottom BAR representing *case*, i.e., whether the final meaning is connected with either *causation*, linked to the presence of some agent which takes an action, or *nature*, linked to the ideas of naturalness/spontaneity, goal/teleology, law-likeness, and relaxation, or *circumstance*, linked to the ideas of accident/randomness, or practicality.

From these three levels of attributes, the phrases are grouped into seven categories or cases as shown in Table 4.2. The numbers in the table show the actual, randomised, order of presentation of the phrases.

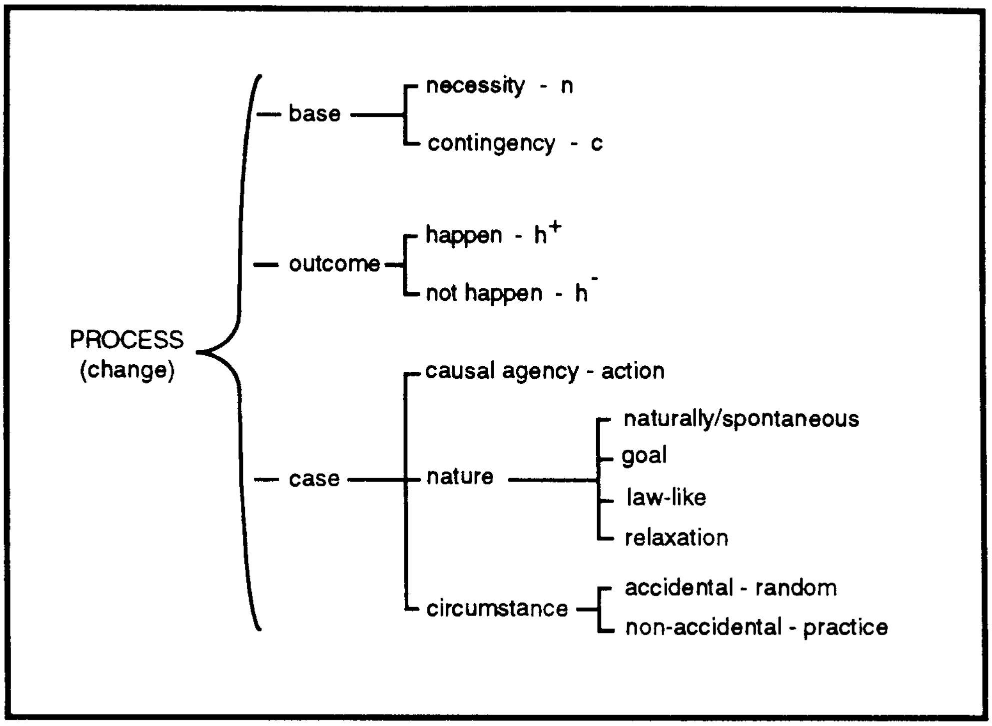


Figure 4.1 - *Network expressing the structure of phrases of the question in the form of a grid for the pilot study*

4.2.1.3.3 The Questionnaires

The final composition of the questionnaire presented a picture of each phenomenon first happening in one direction, then in the reverse direction, each time followed by the same set of questions already described. With the use of pictures, it was intended to make the students recall their own ideas about the phenomena. The questions were presented in the following sequence:

- Question 1: *'Think of - or imagine - some way to go from A to B. How?'*

- Question 2: *Which of the following phrases describe your idea?* (see Table 4.2)

- Question 3: *'What would you say is the cause of the change from A to B?'*

- Question 4: *'In going from A to B, what things CHANGE?*

- Question 5: *'In going from A to B, what things STAY THE SAME?'*

- Question 6: *'Is there only one way to go from A to B?'*

With this sequence, the question in the form of a grid, Question 2, asked students to choose the phrases which would be in agreement with their own ideas about the way they had imagined the process to happen when answering Question 1.

However, twenty phenomena, each repeated forward and in reverse, would have given an excessively long questionnaire. In order to test a good range of processes in this exploratory pilot study, it was decided to divide the processes into two questionnaires which would otherwise be similar to one another.

Table 4.2 - *Categorisation of Phrases for Questionnaires of the Pilot Study*

CATEGORISATION		Nº	PHRASE
ACTION	c, h^+	10	It needs some action to make it happen
NATURAL	c, h^+	6	There is no cause for it, it just happens
	c, h^+	7	It is something which happens naturally
	c, h^+	16	It happens spontaneously, all by itself
GOAL	n, h^+	3	It happens because the system has to go to B
	c, h^+	5	It happens because the system tends to go to B
	c, h^+	9	It happens because getting to B is the reason for the change
LAW-LIKE	n, h^-	4	There is a law which prevents it happening
	n, h^-	8	It could never happen, in principle
	n, h^+	12	It cannot be stopped from happening
	n, h^+	17	There is a law which makes it happen
RELAXATION	c, h^+	18	It was forced into state A and then just goes back to B
ACCIDENT	c, h^+	1	It happens accidentally
	c, h^+	14	It happens by some random process
PRACTICE	n, h^-	2	It cannot really happen in practice
	c, h^-	11	It is possible, but difficult to do in practice
	c, h^-	13	It is possible in theory, but not in practice
	n, h^-	15	It is possible to imagine but not to do

To attempt to produce two similar and approximately equivalent questionnaires, the phenomena were chosen in more or less matched pairs according to general features of the criteria used to select them (see 4.2.2.1). The two questionnaires had twenty two questions each (eleven related to an event happening in one direction, and eleven happening in reverse). Each event was introduced by a pair of drawings representing two different moments, with a short phrase describing what happened (as shown in Table 4.1). The idea of showing a drawing was to characterise clearly the changes happening when each direction was shown. Table 4.3 shows the phenomena chosen for each questionnaire. Two items were duplicated in both questionnaires. Each questionnaire had a front cover giving instructions about how to answer it and emphasising that the students should not be anxious about giving 'right' answers but to give their own ideas about the events. Appendix A gives the actual questionnaires with pictures.

Table 4.3 - *Phenomena selected for the two questionnaires used in the Pilot Study*

QUESTIONNAIRE 1	QUESTIONNAIRE 2
PENDULUM	WHEEL
SLOPE	JACK
TANK	EGG
PENCIL	PENCIL
TEA	ICE-CREAM
CHAMPAGNE	PUDDLE
BOMB	CANDLE
CAR	ALKA-SELTZER
BATTERY	MAGNET
PLANT	BOY/MAN
WATCH	WATCH

4.2.1.4 The Sample and Administration

The pilot study was carried out with the questionnaires being answered by sixth form students in two selective schools in Kent. The two groups were similar in age - 16/17 year old -, ability, and background.

It was intended that the two questionnaires would be given to two different but equivalent groups, hence the repetition of two items so as to check on the equivalence of the groups. However, in the event, this plan was changed and an attempt was made to give the two questionnaires to the same group, on two occasions (morning and afternoon). This has the advantage that the question of comparability of the groups does not arise. The repeated items now test whether responses to an item may show variability between two occasions.

Unfortunately, this second plan was not able to be fully implemented. 15 A-level Science students, all taking A level Physics answered questionnaire 1. There were 9 boys and 6 girls. For questionnaire 2 one girl did not attend, and two additional boys joined the group, introducing an additional source of variation, and further unbalancing the gender ratio, as shown in Table 4.4. However 14 students answered both questionnaires.

Table 4.4 - *The Sample of the Pilot Study*

QUESTIONNAIRE	BOYS	GIRLS	TOTAL
1	9	6	15
2	11	5	16

The administration of the questionnaires started with a general explanation of what the questionnaires were about. The general objective of the research was explained, and after giving them the questionnaires the instructions were read aloud to emphasise the idea that they should not be anxious about giving correct answers. Students took, on average, 50 minutes to answer the questionnaires.

The analysis of the data collected in this pilot study and the results are described in Chapters 5 and 6. This exploratory study in the form of a pilot study gave grounds for improving the questionnaires, which were applied to larger samples from three different countries. The alterations, improvements and the description of the main study are presented in Chapter 7, and the analysis of data and description of results of the main study in Chapter 8 and 9.

5

Pilot Study - Factor Analysis: A Space of Explanation

The data analysed consisted of:

- responses to the statements about the way each process can be explained;
- accounts of how each process is seen as happening and the reason for that;
- responses to the questions about changes and samenesses.

The analysis of the first set of data is described in this chapter. The analysis of the two others is presented in the next chapter.

5.1 Introduction

In this chapter the solution produced from the analysis of question 2 of the questionnaire is described. In this question, students were asked to agree or disagree with each of the seventeen statements about processes. Initially there were eighteen phrases, but phrase 13 - 'it is possible in theory, but not in practice' - was not considered in this analysis because the students found its meaning unclear. Therefore we took this phrase out of the whole analysis but kept the original index numbers of the phrases, this being the reason for the 'missing phrase 13' in Table 5.1.

The analysis is based upon the search for similarities of patterns of responses to the seventeen statements about the processes happening forwards and backwards. This involves the exploration of data in an attempt to recognise any non-random pattern or structure requiring explanation, and methods are sought which allow possible unanticipated patterns in the data to be detected, opening up a wide range of alternative explanations. (Everitt and Dunn, 1983).

Thus it was expected that some patterns of responses would emerge for a group of students which would identify ways of reasoning about processes. This means analysing correlations between the statements, across all processes, and looking for a smaller number of fundamental factors or dimensions.

A way to look for patterns in the answers gathered is the use of multivariate techniques and at the present exploratory stage, two ways of doing that were tried: Factor Analysis (see for example Child, 1978) and Multidimensional Scaling - MDS (see for example Everitt and Dunn, 1983). The best approach turned out to be Factor Analysis with an oblique solution, since the factors were correlated. MDS was tried but the interpretation was difficult, as by definition MDS gives orthogonal dimensions.

5.2 Factor Analysis

To conduct the analysis, the unit of analysis was taken as the group, not the individual, so that the results reflect tendencies of a group, not necessarily perceptions of individuals as previously mentioned in section 4.2.1.2. Therefore the data were organised as a 44x17 matrix of the proportion of 'yes' responses to the seventeen statements for the eleven forward events and the eleven backwards events for both questionnaires together, treating the situations in the two questionnaires as different even when replicated.

This matrix was then factor analysed, treating the seventeen statements as variables and the forty-four events as cases, and gave a strong indication that there is a factor structure: the Bartlett Sphericity test rejected the hypothesis of no structure with $p = .0001$ (see Appendix C for statistical summary for the factor analysis).

Several procedures have been proposed for determining the ideal number of factors (dimension of the space). One criterion suggests that only factors that account for variances greater than unity should be included (eigenvalues greater than unity). Factors with a variance less than unity are no better than single variable, given that each variable is standardised to have a variance equal to 1.

Therefore after extracting factors by Principal Components Method, this criterion led to the choice of four factors. The four factors jointly explained 79.9% of the variance. The factors were correlated, therefore the oblique solution was chosen. This fact means that the factor space is non-orthogonal given that the correlation between two variables can be expressed by the cosine of the angle between them.

The results are represented in the form of plots of the factor space. For simplicity the factor space is taken as three-dimensional since the fourth factor is loaded mainly by only one variable. The non-orthogonal three-dimensional factor space is shown plotted in two dimensions in turn: factor I orthogonal to factor II (Figure 5.1), factor I non-orthogonal to factor III (Figure 5.2), and factor II non-orthogonal to factor III (Figure 5.3).

In this space, events are plotted by their factor scores (see Appendix C). Events which are close together are the ones which attracted similar patterns of responses across the seventeen statements. There are also vectors representing each statement by their 'factor scores' described below. The size or magnitude of the vectors representing statements can be interpreted as the contribution of their related statement to the particular dimensions in a given two-dimensional projection. The longer a vector the more important it is for these dimensions. A small size vector can be interpreted as if its related feature has no important contribution for these particular dimensions, and so as its associated dimension being orthogonal to these dimensions.

5.2.1 Representations of Phrases in the Factor Space

The phrases can be plotted in the factor space just by using their factor loadings as coordinates for the tip of a vector drawn from the origin. Since a factor loading is the correlation of a phrase with a factor the angle between a vector representing a phrase, and the axis representing a factor, shows this correlation. However, this space has no inherent scale. Only the angles matter.

In order to plot vector for phrases on the same factor score space as the events, 'factor scores' for the phrases were constructed as follows. For a given phrase, the factor scores on each event were averaged, after being weighted by the percentage of 'yes' answers to that phrase on each event. Thus the vector points to the 'centre of gravity' of positive responses about events on that phrase. The term 'factor score' in inverted commas, will be used throughout to indicate this construct.

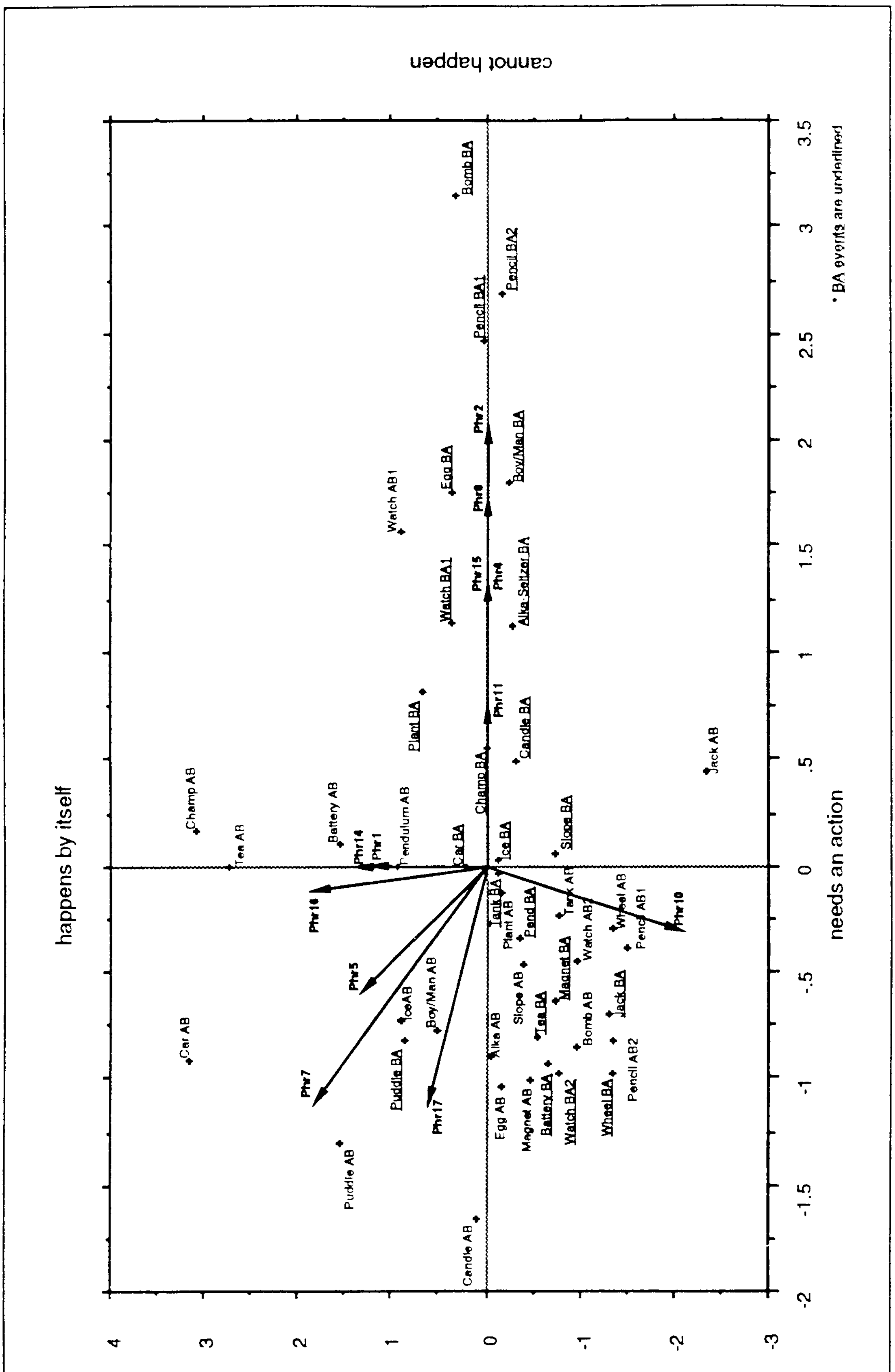


Figure 5.1 - *Factor Space of the Pilot Study: Dimension I vs Dimension II*

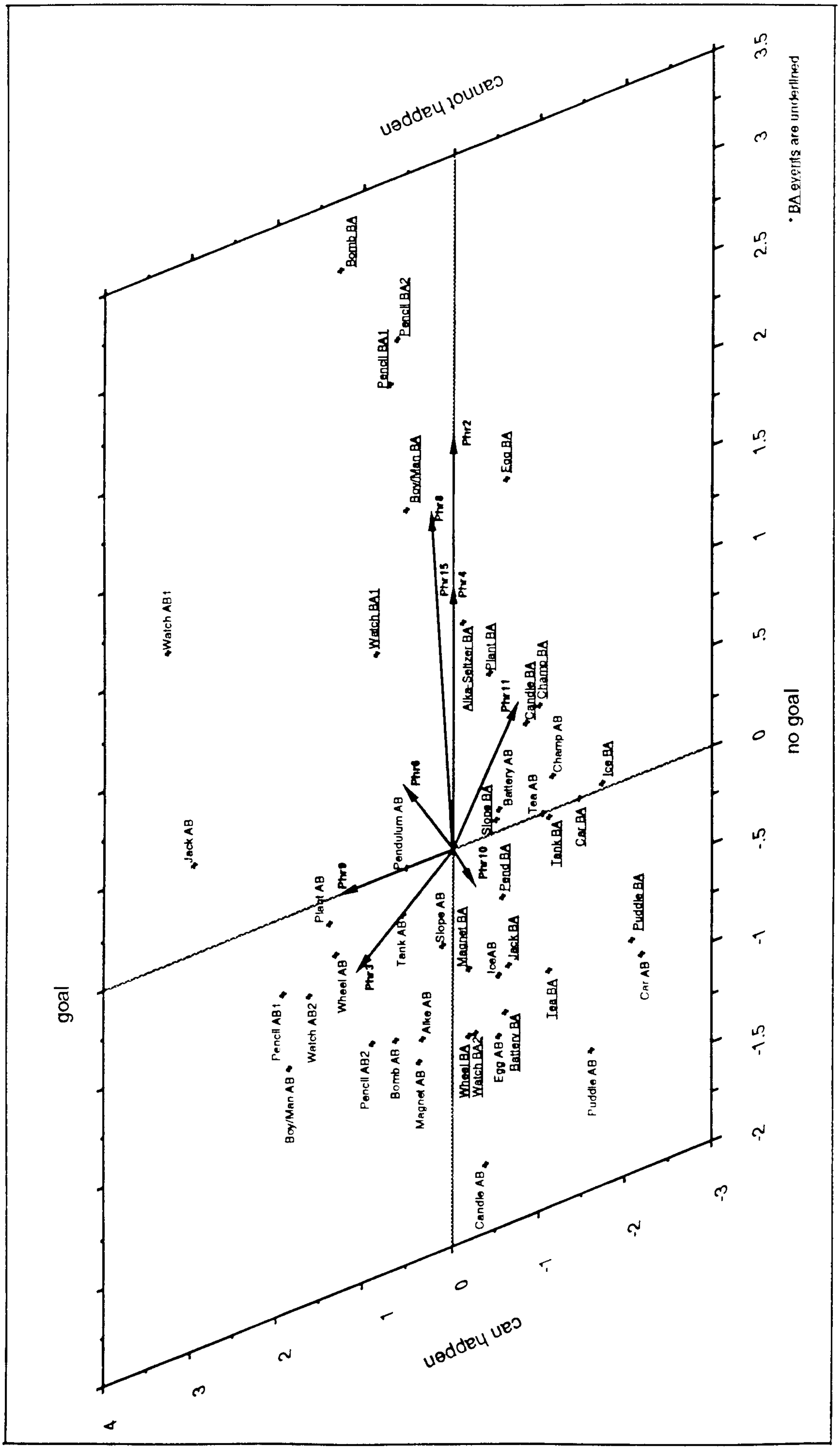


Figure 5.2 - *Factor Space of the Pilot Study: Dimension I vs Dimension III*

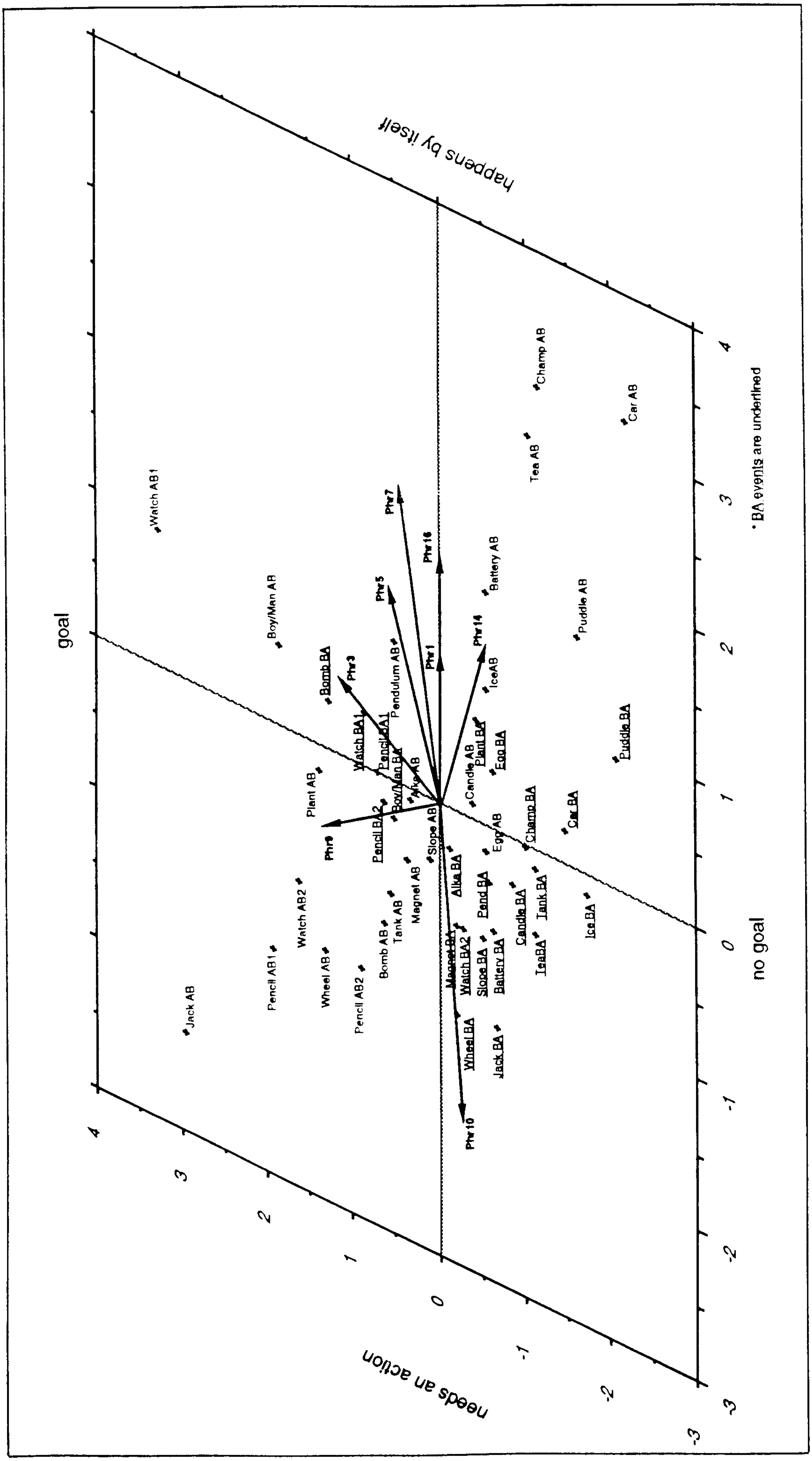


Figure 5.3 - *Factor Space of the Pilot Study: Dimension II vs Dimension III*

5.3 Interpretation of the Factors

The interpretation of the dimensions is done by combining different approaches:

- looking at the factor loadings of statements on each factor (see Table 5.1);
- observing where events fall in the space;
- observing where the vectors representing the statements fall in the space.

To characterise each factor, it is necessary to highlight significant loadings of variables (statements) which contribute to a factor. Small factor loadings can be omitted and usually no loading less than 0.5 is considered. The attempt to interpret and name the factors has to be done so that in the end it represents the essence of the variables loading on it, a process helped by the two other approaches.

When interpreting a factor solution, it is substantially easier to deal with solutions where each variable has a large loading on just one factor and low loading on most factors. However this is an ideal case, and in some cases one variable has significant loadings on more than one factor, and sometimes loadings on all less than 0.5. Thus, an interpretation of a factor solution is not to be considered as definite or 'correct', but *a* possible interpretation from a set of possibilities.

Table 5.1 - *Oblique Solution Primary Pattern Matrix-Orthotran/Varimax*

Phrases	Factor Loadings				Variable
	I	II	III	IV	Complexity
1- It happens accidentally	-0.013	**0.788**	-0.165	0.009	1.089
2- It cannot really happen in practice	**0.950**	0.017	-0.030	0.007	1.003
3- It happens because the system has to go to B	-0.209	0.259	**0.605**	0.006	1.620
4- There is a law which prevents it happening	**0.940**	-0.024	0.036	-0.015	1.005
5- It happens because the system tends to go to B	-0.295	**0.515**	0.241	0.182	2.387
6- There is no cause, it just happens	0.517	0.256	**0.640**	-0.356	2.911
7- It is something which happens naturally	-0.392	**0.646**	0.163	-0.010	1.799
8- It could never happen, in principle	**0.997**	-0.026	0.100	0.028	1.023
9- It happens because getting to B is the reason	-0.016	-0.322	**0.972**	0.082	1.234
10-It needs some action to make it happen	-0.120	**-0.891**	-0.122	0.051	1.081
11-It is possible, but difficult to do in practice	**0.413**	0.030	**-0.497**	0.074	1.994
12-It cannot be stopped from happening	-0.217	**0.512**	0.395	-0.450	3.270
14-It happens by some random process	0.090	**0.999**	-0.428	0.281	1.552
15-It is possible to imagine but not to do	**0.976**	0.073	0.008	0.028	1.013
16-It happens spontaneously, all by itself	-0.054	**0.913**	-0.001	0.067	1.018
17-There is a law which makes it happen	**-0.561**	0.325	0.125	0.307	2.358
18-It was forced into state A and then just goes back	-0.009	0.158	-0.018	**0.907**	1.061

5.3.1 Factor I: Can Happen vs. Cannot Happen

In considering the loadings in descending order of absolute magnitude in Table 5.1, it can be observed that the basic account of this factor is given by:

Phrase 8 - it could never happen in principle
Phrase 15 - it is possible to imagine but not to do
Phrase 2 - it cannot really happen in practice
Phrase 4 - there is a law which prevents it happening

They all have high positive loadings and variable complexity approximately 1, and all describe the impossibility of something happening. Thus it seems clear that this factor is related to the possibility or impossibility of something happening.

Phrase 11 - 'it is possible, but difficult to do in practice', helps to ratify this interpretation; though having a variable complexity larger than 1, it has one of its two important loadings on this factor. Likewise, the negative loading of Phrase 17 - 'there is a law which makes it happen' contributes to this factor with its reverse meaning, as also does phrase 4.

On the contrary, Phrase 6 - 'there is no cause, it just happens' is not included in this interpretation because it has a very high variable complexity, which means that this phrase loads on more than one factor, and it was taken to have its more important contribution is on factor 3.

Although not very high, the negative loadings of

Phrase 3 - it happens because the system has to go to B
Phrase 5 - it happens because the system tends to go to B
Phrase 7 - it is something which happens naturally
Phrase 12 - it cannot be stopped from happening

are consistent with the interpretation: they also express the idea of denying the happening of something.

Therefore, events having a high score on this factor seem able to be interpreted as being related to the possibility or impossibility of something happening. This factor will be associated with a dimension named CANNOT HAPPEN vs. CAN HAPPEN. Events such as Bomb BA, Pencil BA, Boy/Man BA were located on the 'cannot happen' side, while events such as Candle AB, Puddle AB, Egg AB were located on the 'can happen' side.

5.3.2 Factor II: Happens by Itself vs. Needs an Action

On this factor, the largest loadings are from

Phrase 14 - it happens by some random process
Phrase 16 - it happens spontaneously, all by itself
Phrase 1 - it happens accidentally
Phrase 10 - it needs some action to make it happen

with the loading being negative for phrase 10. All have variable complexities approximately 1. In addition,

Phrase 7 - it is something which happens naturally
Phrase 5 - it happens because the system tends to go to B
Phrase 12 - it cannot be stopped from happening

also load on this factor, though their variable complexities are larger than 1.

The underlying meaning of these phrases seems to be that events having a high score on them are events which happen randomly, spontaneously, accidentally, as against those which naturally tend to happen without the necessity of any external action being taken. The loading of phrase 12 is consistent with this interpretation because a random, spontaneous event may be difficult to stop happening, even if only because it is unpredictable.

The interpretation of this factor can be expressed in several ways. Phrase 10 being the only phrase with a negative loading suggests that the dimension could be named NEEDS NO ACTION vs. NEEDS AN ACTION.

However, regarding phrases 1, 5, 7, 12, 14, and 16, it seems there is little differentiation between an event which happens accidentally, naturally, randomly or spontaneously, thus the dimension could be described in different ways such as NATURAL/SPONTANEOUS vs. NOT NATURAL/NOT SPONTANEOUS, or ACCIDENTAL vs. INTENTIONAL, or RANDOM vs. PLANNED. Perhaps a general description of this dimension, including all these ideas, could be HAPPENS BY ITSELF vs. NEEDS AN ACTION. Examples of events which happen by themselves are Car AB, Champagne AB, Tea AB, while events which need an action to happen are Jack AB, Pencil AB, Wheel AB.

5.3.3 Factor III: Teleology - Goal vs. No Goal

This factor is mainly defined by the loadings of

Phrase 9 - it happens because getting to B is the reason for the change
Phrase 6 - there is no cause for it, it just happens
Phrase 3 - it happens because the system has to go to B.
Phrase 11 - it is possible, but difficult to do in practice

with the loading being negative for phrase 11. Phrase 9 has a high loading and variable complexity not much more than 1. Phrases 6, 3, and 11 support it because they have their largest loading on this factor, though having variable complexity larger than 1.

These phrases can perhaps be interpreted as describing events, which are possible and happen without difficulty, where the 'cause' is the goal of getting to B, perhaps because of some inner tendency.

Although not having its main contribution on this factor, phrase 14 - ‘it happens by some random process’, with a negative loading, also supports this interpretation. The reverse way of understanding phrase 14 could be that an event which has a goal cannot also happen randomly or by chance.

Therefore, events having high scores on this factor seem to be able to be interpreted as events happening because they have a kind of goal that is the reason for them to happen. This factor can be associated with a dimension named GOAL vs. NO GOAL, or DIRECTED/PLANNED vs. NON DIRECTED/RANDOMLY. Events such as Jack AB, Pencil AB, Boy/Man AB were high on the goal end of the dimension, whereas events such as Car AB, Puddle AB, Ice Cream BA were high on the non-goal or spontaneous end.

5.3.4 Factor IV: Relaxation

This factor is basically defined by phrase 18 - ‘it was forced into state A and then just goes back to B', which has a high loading and variable complexity virtually 1. Its meaning is related to the idea of relaxation, or the idea that some systems naturally return to an initial state from which they have been moved, without the need for any external action to be taken, as if they had a kind of built-in tendency to go back.

Although with only moderate loadings, there are another three phrases that also contribute to the interpretation of this factor. An event which just goes back to the initial state after being moved from it can be understood as an event happening to systems that have a kind of law ruling them in this way. This is how the positive loading of phrase 17 - 'there is a law which makes it happen' could be understood.

In relation to phrase 6 - 'there is no cause, it just happens', its negative loading can be interpreted as denying the possibility that an event with a high score on this factor has no cause. If it happens, it is because the event has a cause which is a sort of inner propensity. The negative loading of phrase 12 - 'it cannot be stopped from happening' can be interpreted that, if a system relaxes, it can be stopped or interrupted at any time.

Therefore, this factor seems to be associated with a dimension which could be named NATURAL RETURN vs. NO NATURAL RETURN, or FORCED-RELAX BACK vs. NOT FORCED-RELAX BACK. Examples of events happening as natural return are Tea AB, Champagne AB, Jack AB, whilst Boy/Man AB, Watch AB, Candle AB are examples of no natural return.

5.4 Interpretation of the Correlations between Factors

After having interpreted and named the factors, it is possible to try to give an account of the correlations between factors. The important correlations are those between factor III and factors I and II.

Concerning factor III - GOAL vs. NO GOAL - and factor I - CANNOT HAPPEN vs. CAN HAPPEN -, the negative correlation can be interpreted as the idea that events having a goal cannot usually be seen as not happening, because they were directed or planned to happen.

In relation to the positive correlation between factor III - GOAL vs. NO GOAL - and factor II - HAPPENS BY ITSELF vs. NEEDS AN ACTION -, it may be noted that events having a goal or a inner tendency, do not need any action to make them happen. The goal 'replaces' the action.

5.5 Inspecting the Interpretation of the Factor Solution

After plotting the events in the factor space and interpreting the factors, a different way of dealing with the description of each dimension was to look at the location of the events in the space of explanation and to look directly at the frequencies of replies to each phrase. The objective is to attempt to identify general features which could help to understand the way in which the events were seen and to re-examine the interpretation itself.

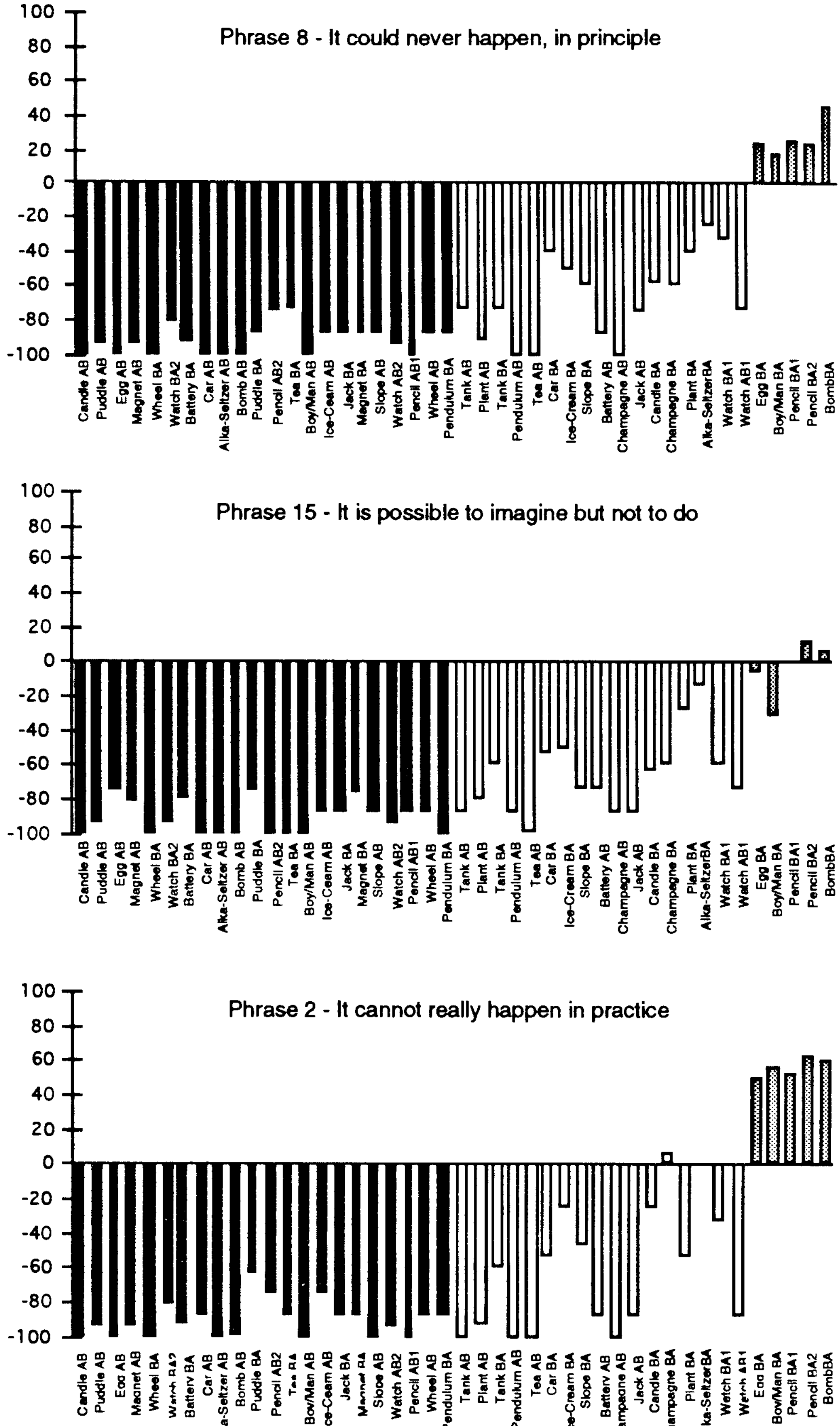
First of all, the factor scores for events on each dimension shown in Appendix C were sorted in ascending order, and then the corresponding frequencies of replies to phrases with high loadings on each dimension and clear patterns of replies were plotted. The frequencies of replies are represented on the vertical axis and show the agreement (positive numbers) or disagreement (negative numbers) with each phrase, which are represented in the horizontal axis with their description on the bottom of each chart. Zero means an equal number of 'yes' and 'no' responses. Considering *f* a fraction of students responding 'yes', the value plotted is 100 (f - [1 - f]). Thereafter the events are described according to: (1) the pictorial trend of the frequencies of replies to the significant phrases on each dimension; (2) the location of the events in relation to this trend; and (3) the location of the events in the factor space shown in Figures 5.1, 5.2 and 5.3

5.5.1 Events along the dimension I: Cannot Happen vs. Can happen

Figure 5.4 shows the frequencies of replies to each event on those phrases with high loadings on this dimension, with the events in ascending order of their factor scores on this dimension. It can be seen that from the leftmost event located on the extremity 'can happen' (Candle AB) to around the event Pendulum BA there is a persistent tendency to consider the events as possible to happen. From this event on, this tendency starts being weakened with a decisive inversion to the few rightmost events on the extremity 'cannot happen'.

In general the events AB (which happen in the 'obvious' forward direction) are located on the very extremity 'can happen'; and the events BA (in the reverse or 'unusual direction) are located towards the extremity 'cannot happen'.

A closer look at Figure 5.4 makes it clear that most events are seen as able to happen, with relatively few seen as not likely to happen, which seems to suggest that a less rigid interpretation of this dimension could be attempted. Instead of characterising this dimension with the sharp opposition between 'can happen' and 'cannot happen', it could be named as ABLE TO HAPPEN vs. LESS LIKELY TO HAPPEN.



■ - Events seen as able to happen ▒ - Events seen as very unlikely to happen

Figure 5.4 - *Frequencies of Replies to phrases with high loading on dimension I*

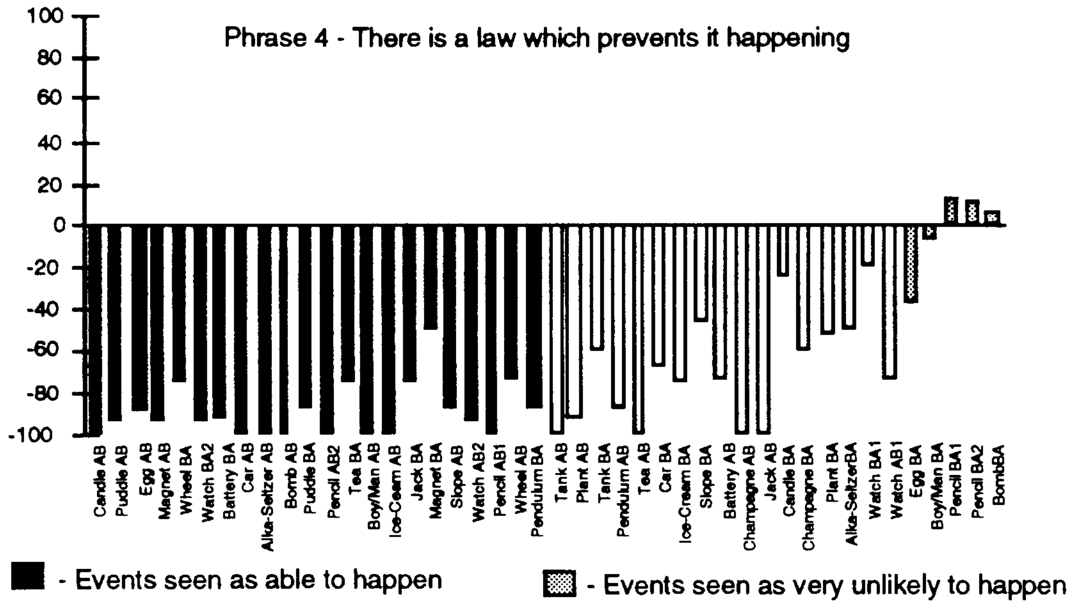


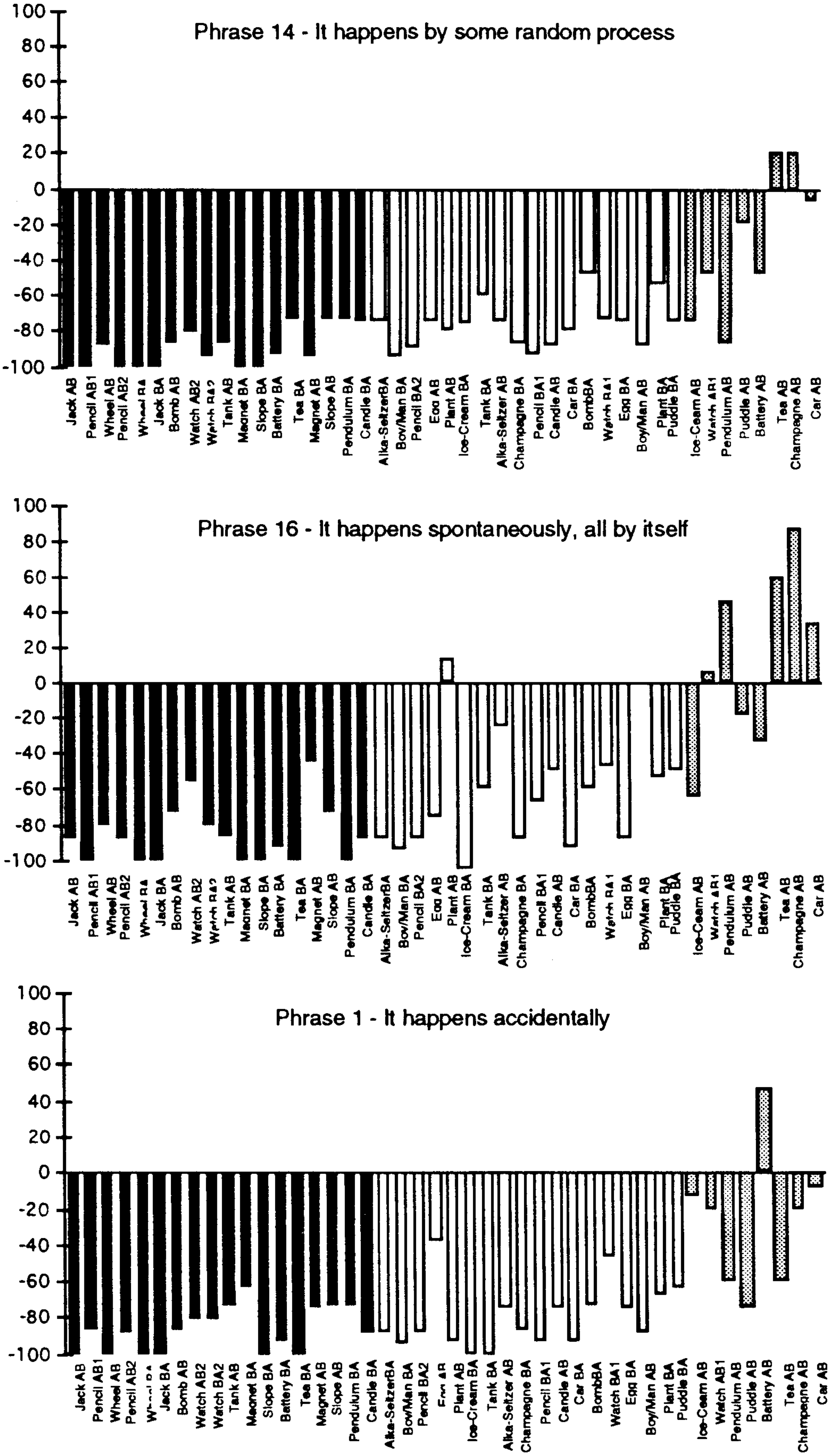
Figure 5.4 - *Frequencies of Replies for phrases with high loadings on Dimension I*

Therefore according to this view events such as Candle AB, Puddle AB, Egg AB are seen as able to happen, whereas events such as Bomb BA, Pencil BA, Boy/Man BA are seen as less likely to happen.

5.5.2 Events along the dimension II: Happens by itself vs. Needs an action

Figure 5.5 shows the frequencies of replies for events sorted in ascending order of their factor scores on the significant phrases on this dimension. There is no apparent distinction between AB and BA events on the extremity 'needs an action', although on the other extremity - 'happens by itself' - there is a concentration of AB events.

Figure 5.5 also reveals that there is a strong tendency to consider most of the events as needing an action to happen, however in a region centred on the event Egg AB the profile begins to change, with an eventual inversion near by the extremity 'happen by itself'. Therefore the events such as Jack AB, Pencil AB1, Wheel AB are clearly seen as needing an action to happen, while events such as Car AB, Champagne AB, Tea AB as clearly seen as happening by themselves.



■ - Events seen as needing an action to happen ▒ - Events seen as happening by themselves

Figure 5.5 - *Frequencies of Replies for phrases with high loading on dimension II*

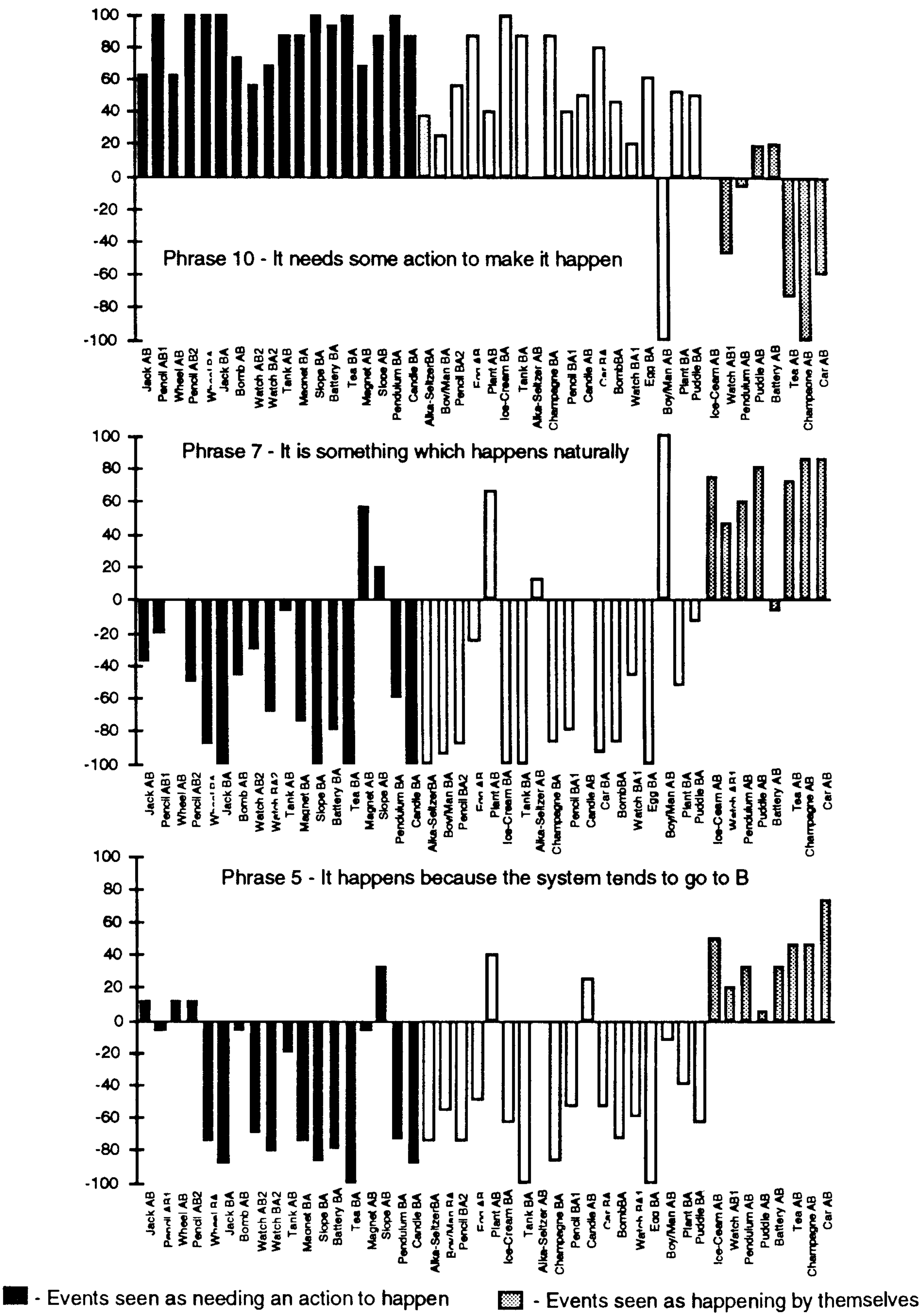


Figure 5.5 - *Frequencies of Replies for phrases with high loadings on Dimension II*

5.5.3 Events along the dimension III: Goal vs. No Goal

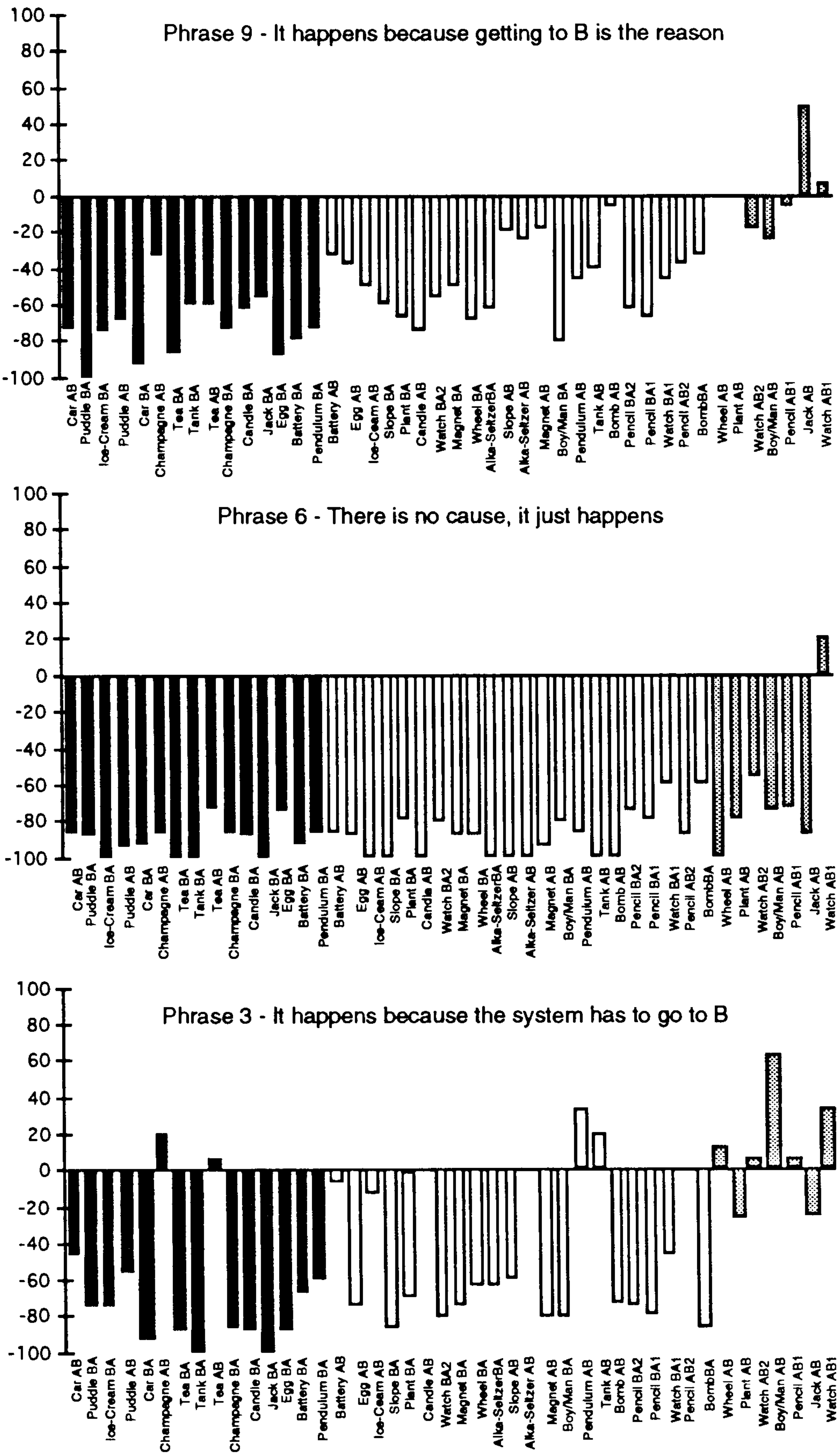
Figure 5.6 shows the events ordered on this dimension, for the phrases with high loading on it. It can be seen that there is a moderate concentration of BA events on the extremity 'no goal', although the events at the very extremity 'goal' are all AB.

For most events, many subjects deny both phrases 9 ('it happens because getting to B is the reason') and 3 ('it happens because the system has to go to B'), except for a few events located at the extreme right, showing that most events are seen as not driven by a specific goal. Phrase 6 ('there is no cause, it just happens') is denied by nearly all students for essentially all events. They evidently expect a cause in every case. Thus according to this dimension events such as Car AB, Paddle AB, Ice-Cream BA are seen as not having any goal, whereas events such as Watch AB1, Jack AB, Pencil AB1 are seen as happening due to a goal. Although the events Champagne AB and Tea AB fall on the no-goal end of this dimension their frequencies of replies to phrase 3 tend to contradict this, showing them as having a natural tendency to happen.

5.6 Characterisation of Events According to the Fourth Factor: Relaxation

Only phrase 18 - 'it was forced into state A and then just goes back to B' loads substantially on this factor. Figure 5.7 shows the events sorted in ascending order of their factor scores on this factor. There is no clear tendency on the ordering of AB and BA events. However, from the leftmost event located on the extremity 'no natural return' (Boy/Man AB), to around the event Bomb AB there is a consistent tendency to consider the events as happening not as a natural return. From this event on, this tendency starts weakening with a explicit inversion to the few rightmost events which are seen as happening as a natural return.

Considering these results and the fact that this dimension is related to the idea that some systems naturally return to an initial state from which they have been moved, without the need for any external action, perhaps there is another complementary interpretation to this dimension, related to the idea that, for some systems, there are states which are considered as the 'natural' state, which the system should be. From this perspective, this dimension could be named RETURN TO A NATURAL STATE vs. NOT A RETURN TO A NATURAL STATE.



■ - Events seen as not having a goal ▒ - Events seen as having a goal

Figure 5.6 - *Frequencies of Replies for phrases with high loading on dimension III*

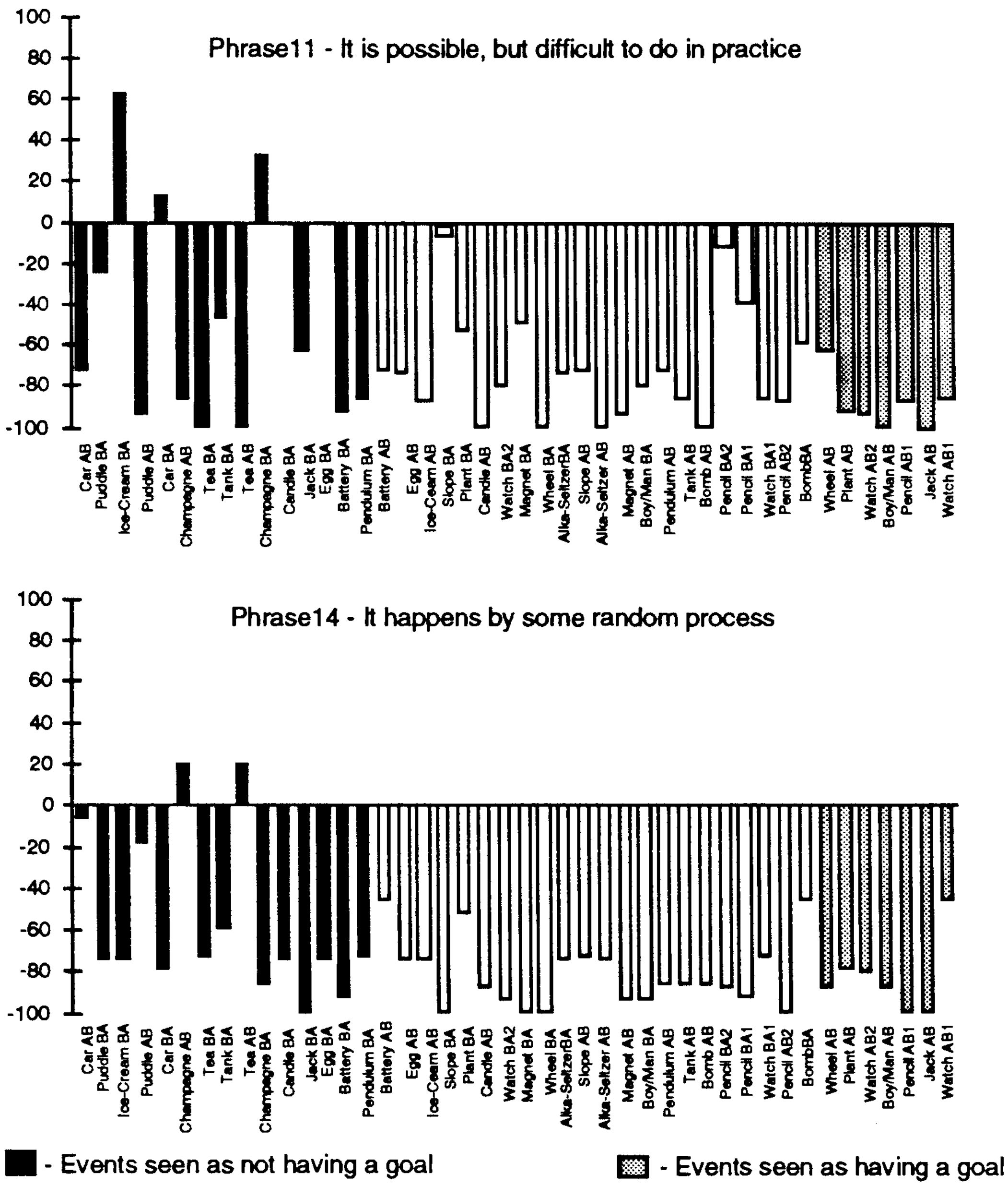


Figure 5.6 - *Frequencies of Replies for phrases with high loadings on Dimension III*

Thus events such as Tea AB, Champagne AB, Jack AB are seen as happening as a natural return, while events such as Boy/Man AB, Watch AB1, Watch AB2 are seen as happening not as a natural return.

The events Boy/Man, Watch 1, Watch 2, Magnet, Egg, and Car are considered as not happening as a natural return in the AB as well as in the BA direction.

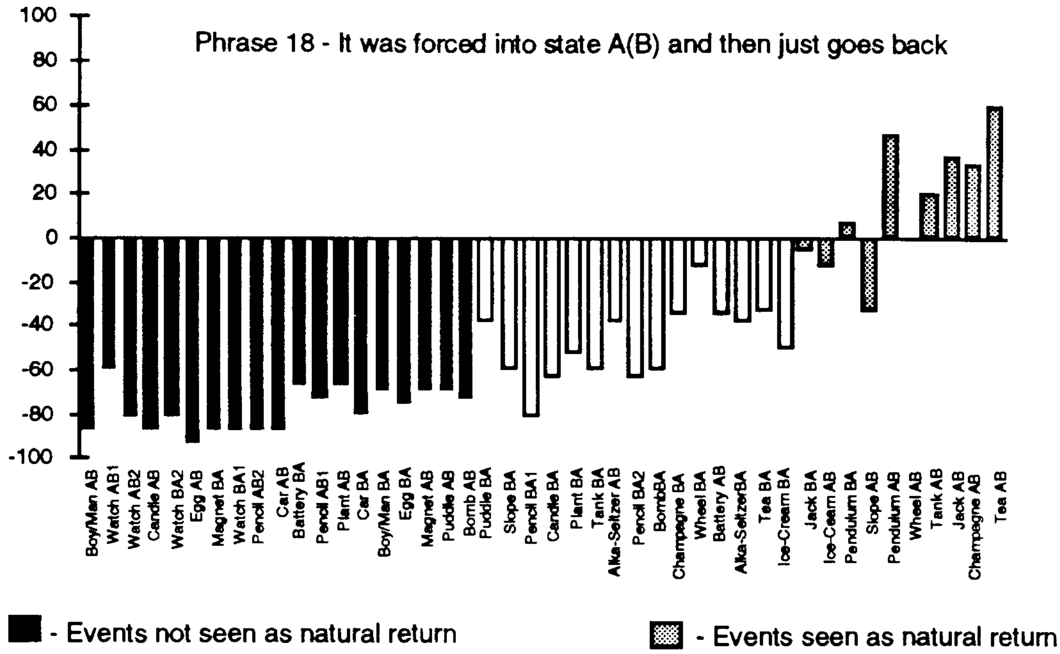


Figure 5.7 - *Frequencies of Replies for phrases with high loadings on Dimension IV*

5.7 Summary of Factor Space

Looking now at the whole factor space (Figures 5.1 - 5.3), and the responses shown in Figures 5.4 - 5.7, we can summarise the analysis in two ways, the interpretation of the factors and the placing of events in the factor space.

5.7.1 Summary of the Interpretation of the Factor Solution

The outcome of the factor analysis suggests that there is an underlying way of explaining the events, which is best described in terms of a non-orthogonal four dimensional space of explanation.

This space is defined by a first and strong dimension related to the possibility or impossibility of an event to happen, and was named CAN HAPPEN vs. CANNOT HAPPEN. The second dimension is connected with the necessity or not of an action to be taken to make the event happen and was labelled HAPPENS BY ITSELF vs. NEEDS AN ACTION. The third and more moderate dimension, negatively correlated to the first and positively correlated to the second, relates to the idea that an event happens due to a goal or an inner tendency, therefore being named GOAL vs. NO GOAL. A fourth dimension named NATURAL RETURN vs. NOT NATURAL RETURN was identified. It was however loaded by only one variable. Therefore an interpretation of these dimensions is:

CAN HAPPEN vs. CANNOT HAPPEN

HAPPENS BY ITSELF vs. NEEDS AN ACTION TO HAPPEN

HAPPENS DUE TO A GOAL vs. HAPPENS WITH NO GOAL

NATURAL RETURN vs. NOT NATURAL RETURN

5.7.2 Summary of the Results concerning the Description of Events

In relation to the way the events fall in the factor space, we see the following tendencies:

- most events are seen as able to happen, with BA events being generally the less likely to happen;
- many events are seen as needing an action, particularly but not exclusively the BA events;
- many events are seen as having a cause, and few as random;
- a few events are seen as driven by a goal;
- a few events are seen as happening as a natural return to the original state.

This explains the high density of events in the quadrant 'can happen' and 'needs an action' in Figure 5.1. Correspondingly the extreme of the opposite quadrant ('cannot happen' and happens by itself') is empty, not surprising as the two accounts contradict one another.

However, there are events which can happen, and which also either happen by themselves (top left quadrant in Figure 5.1) or which happen because of a goal (top left quadrant in Figure 5.2). They all tend to be AB events.

Finally, Figure 5.3 shows that there is a distinction between events which both have a goal and need an action (top left quadrant) contrasted with events which have no goal and happen by themselves (bottom right quadrant).

In the following chapter, the description of events emerging from the responses to the questions related to action and causes is presented.

6

Pilot Study - Description of Events

This chapter firstly presents the use of cluster analysis as a tentative way of characterising the events followed by the analysis of the written accounts of how each process is seen as happening and the reasons given (action/causes responses), with a overall description of events. The chapter ends with the analysis of the responses to the descriptions of changes and samenesses.

6.1 Introduction

In the last chapter, the factors identified by factor analysis gave grounds for the characterisation of a space of explanation in which the events were plotted and described according to the major trends.

However, given the space of explanation, the reasoning of students about the events can be investigated in greater detail by two further stages of analysis:

• looking for clusters of events in the factor space;
• examining the written answers for these clusters to questions about actions and causes.

6.2 Cluster Analysis

Because the dimensions of the factor space are correlated, it is sometimes hard to see all the underlying connections existing among the variables that explain an event, and so cluster analysis (see Appendix B) was also used to help the analysis.

Clusters were sought amongst the events plotted in the factor space. When their factor scores were cluster analysed using the complete linkage method, eight main interpretable clusters were found as shown in Appendix D.

To aid the interpretation of the clusters, the three bi-dimensional projections of the factor space were analysed in turn with the events of each cluster highlighted, and through their characterisation the clusters appear to be interpretable as:

- happens by itself, ruled by some causal law
- unlikely to happen
- possible, but difficult to reverse
- happens by itself
- non natural reversal, caused by action
- happens naturally due to a planned action
- happens with no difficult due to an action taken with a goal
- unlikely to happen or possible reversal for a purpose

The detailed description of each cluster is shown in Appendix D and Table 6.1 shows the events included in each cluster. The results of the cluster analysis are used together with the analysis of the action/causes responses later in this chapter.

Table 6.1 - *Clusters of Events based upon Factors Scores*

CLUSTERS	EVENTS
Happens by itself, ruled by some causal law	CHAMPAGNE AB - the champagne goes flat
	TEA AB - a cup of tea becomes cold
	CAR AB - a car rusts away
	PUDDLE AB - water in a puddle evaporates
	PUDDLE BA - backwards
Unlikely to happen	ALKA-SELTZER BA - backwards
	EGG BA - backwards
	PLANT BA - backwards
	WATCH BA1 - backwards
Possible, but difficult to reverse	CANDLE BA - backwards
	CHAMPAGNE BA - backwards
	ICE-CREAM BA - backwards
	CAR BA - backwards
	TANK BA - backwards
Happens by itself	ICE-CREAM AB - an ice-cream melts
	BATTERY AB - a car battery runs down
	PENDULUM AB - a pendulum stops swinging
Non natural reversal, caused by action	SLOPE BA - backwards
	PENDULUM BA - backwards
	EGG AB - an egg is broken
	TEA BA - backwards
	WATCH BA2 - backwards
	BATTERY BA - backwards
	MAGNET BA - backwards
	JACK BA - backwards
	WHEEL BA - backwards
Happens naturally due to a planned action	PENCIL AB2 - a pencil is worn out
	BOMB AB - a bomb explodes
	MAGNET AB - a magnet attracts nails
	ALKA-SELTZER AB - an alka-seltzer tablet dissolves
	TANK AB - the water flows out
	SLOPE AB - a ball rolls down
Happens with difficulty due to an action taken with a goal	WATCH AB2 - the time goes by
	WHEEL AB - a rotating wheel stops turning
	PENCIL AB - an pencil is worn out
	BOY/MAN AB - a man grows old
	PLANT AB - a plant grows
Unlikely to happen or possible reversal for a purpose	PENCIL BA2 - backwards
	PENCIL BA1 - backwards
	BOY/MAN BA - backwards
	BOMB BA - backwards
	WATCH AB1 - the time goes by
	JACK AB - a 'jack in the box' jumps

6.3 Analysis of the Action/Cause Responses

The next step is to examine the written answers to the questions about how each process is seen as happening and the reasons given in action/causes responses, to characterise the events according to the students' point of view. Afterwards this characterisation and the clusters are analysed together.

6.3.1 A systemic network for analysing the responses

Looking at the responses to all events, it was possible to devise the systemic network (Bliss, Monk & Ogborn, 1983) shown in Figure 6.1 to help the description of how the students explained the events. The network can be described starting from the leftmost terms, which give the main outlines, down through increasing levels of delicacy to the right hand terminals, which are closer to what is in the data.

The network represents students as making a choice whether the process (change) is able to happen or not, which is portrayed through the first BAR. If the process is seen as possible, it has two ways of happening: through either an intervention (which is a subject's action) or a non-intervention (naturally), which is represented by the top second BAR.

If the process is considered as caused by an intervention, represented by the capital letter (**A**), the action can be taken either directly on the object or indirectly. In the first case the action is taken on the object to make the change, and causes are related to the action itself, either as a description of the action or a description of what would happen. When acting indirectly, the action is taken on either the object or the circumstances, but only to trigger a process which will happen naturally due to different causes or reasons, which are expressed by the word THEN. In this case, after triggering the process, there are three options: it 'just happens, without any reason', or 'other agent acts to make the change, such as entities, surroundings, or different objects', or 'the object itself acts to make the change.

On the other hand, if it is understood that there is no intervention, represented by the capital letter (**N**), the process has two attributes considered in the lower BRA: one is concerned with whether it is taken for granted that the process is going to happen 'let change happen (**H**)' or it is considered that some circumstances/conditions need to be fulfilled, but are supposed to have already been set up (**C**). The second attribute is related to causes or reasons that make the process happen, as described above in the triggering case.

The other option of the first BAR is when the process is seen as not possible. In this case either it is said explicitly that the process is impossible (**I**) or although impossible, either some imaginative solution is invented (**Im**) or the object is replaced by a new one (**R** - renewal).

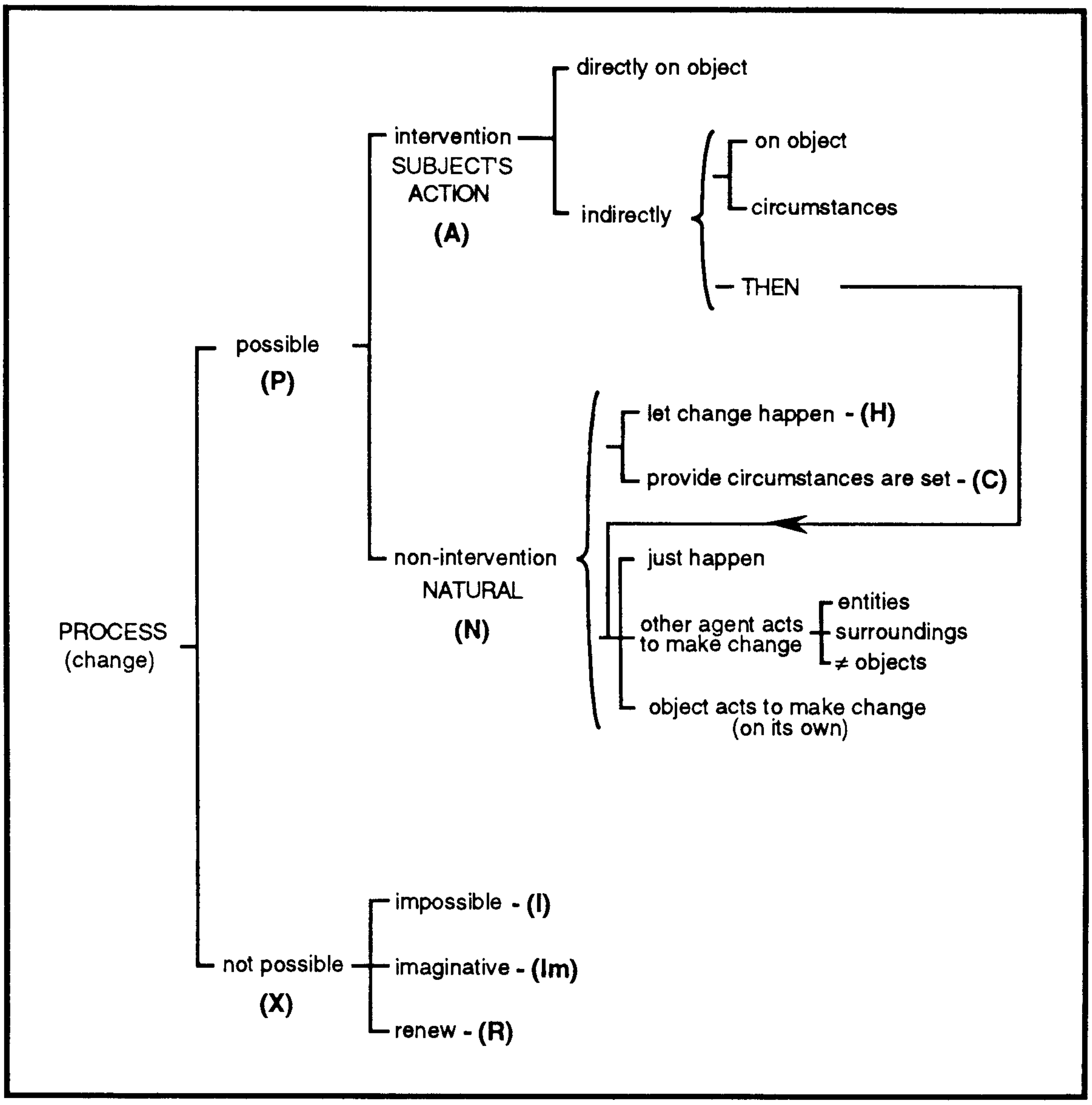


Figure 6.1 - *The network for analysing the action/cause answers*

Considering the event Wheel as an example of the use of the network, all students interpreted it as being possible: half of them said that it would be necessary to take an direct action on the object (A), e.g. 'stop the wheel with your hand' and saw the cause as being related to the action itself namely 'the force being applied'; the other half seeing it as a natural process, either just happening due to an entity such as 'friction' (NH), or started by an initial action, such as 'put the brakes on', and followed by a natural action of an entity such as 'friction between the brake and wheel' (AN).

6.3.2 The Events: how the students describe them

Each event will now be described according to the network. The events numbered from 1 to 11 belong to Questionnaire One and those numbered from 12 to 22 belong to Questionnaire Two. The notation used is: AB = responses given to the *forward* process, whereas BA = responses given to the *backwards* process.

6.3.2.1 PENDULUM - 'a pendulum stops swinging'

AB - Most answers (11) saw this as natural, just letting change happen (**NH**), for example 'just let it swing to a stop', with causes being related to entities such as 'gravity', 'air resistance'. However, a few (4) gave a direct action on the object, e.g. 'stop the pendulum with your hand'.

BA - All answers (15) were in terms of a direct action on the object (**A**), such as 'push the pendulum', the cause being the action itself, 'the pendulum is moved'.

REVERSIBILITY - This (mainly) natural process is reversed by external actions which restore the original configuration.

6.3.2.2 SLOPE - 'a ball rolls down'

AB - Most answers (10) saw this as a natural process started by an action (**AN**), with the natural process caused by an entity such as 'gravity' (8) or by the object itself (2). (One of the gravity answers only implied the previous action). Five answers mention only an direct action on the object, e.g. 'push the ball'.

BA - All answers (15) were in terms of a direct action on the object (**A**), such as 'push the ball up the slope'.

REVERSIBILITY - As for Pendulum, it is considered a mainly natural process, but one started and reversed by an external action.

6.3.2.3 TANK - 'the water flows out'

AB - As with the Slope, most answers (10) were in terms of a natural process, started by an action (**AN**). Some described external factors such as 'gravity' or 'air pressure' as the causing agent, while three saw the process as natural to the object, e.g. 'pressure of water'. Five other answers mentioned only the direct initial action on the object.

BA - All answers (15) suggested two actions (**A+A**), one to remove or reverse the initial action, e.g. 'close the tap', and one to restore the initial state, e.g. 'pour water back'.

REVERSIBILITY - Similarly to Slope, a natural process started by an action and reversed by external action, in this case a combination of two actions. There is no comment whether or not the same water has to be used again.

6.3.2.4 PENCIL - Q1 - 'a pencil is worn out'

AB - All answers (15) were in terms of a direct action on the object (**A**), e.g. 'sharpening it'.

BA - Nearly all answers (12) considered the reversal to be impossible (**X**) - being either R replies (7), 'buy a new pencil', or imaginative (3), 'pencil grew longer'. Two stated that it was impossible. The three action-type answers all concerned actions to restore the original state, e.g. 'glueing the sharpening back on'.

REVERSIBILITY - This is a case of an irreversible process, where there is no real reversible action.

6.3.2.5 TEA - 'a cup of tea becomes cold'

AB - All answers (15) were about a natural process, with the majority (10) being the most 'natural' case, with no causes, 'it just gets left' (**NH**). All the other (5) answers focused on the surroundings (circumstances) with all but one seeing the circumstances as already existing, e.g. 'leave it in a cold place'. The exception (put it in fridge) took action to set up the circumstances.

BA - All answers were very much like the exception mentioned above, an action on the circumstances (**AN**), followed by a natural process driven by the circumstances (not just happening) .

REVERSIBILITY - The process is reversible, and involves natural changes in both directions. However, in the forward direction, it mainly 'just happens' while in the reverse direction action on circumstances is necessary and they play a more active role.

6.3.2.6 CHAMPAGNE - 'the champagne goes flat'

AB - All answers (15) were in terms of a natural process just happening (**NH**). The exemplary answer was 'leave it', with causes being a description of what was happening, 'gas bubbles escaping'.

BA - The overwhelming majority of the answers (14) were in terms of an direct action on the object (**A**) to restore the original state, such as, 'bubble gas through liquid', and causes being the action itself, 're-bubbling the champagne'. One stated it was impossible.

REVERSIBILITY - This is a natural process reversed by external action which restores the original state.

6.3.2.7 BOMB - 'a bomb explodes'

AB - About half (7) the answers saw the process as just happening (**NH**). The rest (8) paid attention to an initial action , e.g., 'light the fuse' (**AN**), followed by either a natural action of the bomb itself (3), 'the reaction of chemicals in it cause the explosion', or of entities (2) such as 'enough energy is given to activate the bomb', or gave no further reason (3) . Some (3) answers also focused on the cause of the initial action.

BA - All answers saw the reverse as not possible (**X**), either stating that it was impossible (3), or proposing imaginative action such as reversing time, 'go back in time' (7), or R replies such as 'buy a new bomb' (5).

REVERSIBILITY - Natural process, or a natural process triggered by action, which cannot be reversed. Time reversal is mentioned.

6.3.2.8 CAR - 'a car rusts away'

AB - All answers (15) were about a natural process, focusing on circumstances seen as already existing (**NC**), such as 'leave the car by the sea'. Nearly all answers (13) saw the natural process caused by different objects such as 'salt water', 'rain', 'oxygen of the air'. Two answers gave no reason.

BA - Approximately half (8) answers saw the reverse as not possible (**X**), expressed through R replies, 'buy a new car', 'replace all the rusted body', whereas the rest (6) considered the process reversible by an external action on the object (**A**), such as 'clean off rusting + re-painting', which is very like R.

REVERSIBILITY - Natural process happening depending on certain circumstances, but considered as irreversible or as reversible only by an action close in its nature to renewal.

6.3.2.9 BATTERY - 'a car battery runs down'

AB - Most answers (11) saw this as a natural process, with the majority (8) focusing on circumstances seen as already existing (**NC**), e.g. 'the car lights are left on', and the others (3) being the most natural case 'car is left for several weeks and battery drains', with no specific reason. The rest (4) were in terms of an action on the object, e.g. 'use the battery', and the causes related to the action itself, 'energy stored in the battery is used up'.

BA - Nearly all answers (13) were in terms of an external action on the object (**A**), such as 'recharge the battery'. Two were R replies, 'buy a new battery'.

REVERSIBILITY - Similarly to the car rusting, it is considered a natural process depending on circumstances, but clearly reversed by an external action to restore the initial state, again with suggestion of renewal.

6.3.2.10 PLANT - 'a plant grows'

AB - All answers (15) were about a natural process, with the majority (13) seeing this as a natural process aided by an action (**AN**), e.g. 'by watering and feeding the plant' with the natural process caused by either the object itself, 'the plant takes up water and food and grows' (7), or a different object, 'the water, fertiliser + sun)' (3), or no specific reason (3). Two answers stated that it just happens.

BA - Most answers (9) were in terms of an external action on the object (**A**), such as 'cut back the plant', the cause being the action itself. Some (3) answers considering the circumstances as already existing, 'plant is not watered', saw it as natural process, 'begins to die'. Two answers saw it as not possible.

REVERSIBILITY - Natural process started by an action, and reversed by an external action to restore the original shape/appearance. Three answers considered the process of dying as a means of reversing the process. As for Bomb, time reversal was mentioned.

6.3.2.11 WATCH - Q1 - 'the time goes by'

AB - Approximately all answers (11) saw this as a natural process, 'wait', with no specific reason, 'time passes' (**NH**). Two gave a direct action on the object, 'wind clock forward', seeing the event not as time passing but as movement in an object.

BA - About half (7) answers were in terms of an external action on the object (**A**), such as 'wind hands backwards', and another two answers saw it as an action of the object (this just exploits the rotation of a clock), 'wait another 11 1/2 hours'. The rest (6) considered the reversal to be impossible (**X**), either stating it was impossible (4), or proposing an imaginative action of reversing time, 'travel back in time'.

REVERSIBILITY - As for Pendulum, it was considered a mainly natural process, but one either reversed by an action (but now on the object), or irreversible.

6.3.2.12 WHEEL - 'a rotating wheel stops turning'

AB - Around half (9) answers were in terms of an external action on the object (**A**), 'hold the wheel'. The rest (7) saw it as natural process, either started by an initial action, e.g. 'put the brakes on', followed by an natural action of an entity such as 'friction' (3), or just happening due to an entity such as 'friction' (4).

BA - All answers (16) were in terms of an external action on the object (**A**), for example 'spin the wheel', the cause being the action itself.

REVERSIBILITY - This is a process mainly seen as started by an external action, and reversed by an external action to restore the initial state.

6.3.2.13 JACK IN THE BOX - 'a "jack in the box" jumps'

AB - Most answers (12) saw this as natural process started by an action (**AN**), with the natural process caused by an entity such as 'potential energy'. Four mentioned only an direct action on the object, e.g. 'open the lid'.

BA - All answers (16) suggested two actions (**A+A**), one to arrange the elements of the system, 'push the Jack down', and one to reverse the initial action and restore the initial stage, 'shut the lid'.

REVERSIBILITY - As for Slope, a natural process started by an action and reversed by an external action, in this case a combination of two actions.

6.3.2.14 EGG - 'an egg is broken'

AB - Most answers (11) saw this as a natural process started by an action (**AN**), with the natural process caused by a different object such as 'a hard surface'. Three were in terms of only a direct action on the object, 'push it', the causes being the action itself, 'the force of pushing it'.

BA - Most answers (11) suggested two actions (**A+A**), one to collect the elements of the system, 'the contents are placed together', and one to restore the initial configuration/appearance, 'and the shell glued together'. The rest (4) considered it as not possible.

REVERSIBILITY - As for Jack in the Box, a natural process started by an action and reversed by a combination of two external actions to restore the external configuration/appearance, no matter the internal structure.

6.3.2.15 PENCIL - Q2 - 'a pencil is worn out'

AB - Almost all answers (14) were in terms of an direct action on the object (**A**), e.g. 'keep sharpening the pencil'. Two answers were an initial action followed by a natural action of an entity, 'friction'.

BA - Nearly all answers (9) considered the reversal to be impossible (**X**) - being either R replies (1), or imaginative (5), such as 'by stretching the pencil'. Three stated that it was impossible. The four action -type answers all concerned with action to restore the original state/configuration, 'stick the shaves back on'.

REVERSIBILITY - This process is considered as an action which is irreversible. Only imaginary action can be thought of as reversing the process.

6.3.2.16 ICE-CREAM - 'an ice-cream melts'

AB - All answers (16) were about a natural process focusing on circumstances, with nine considering them as already existing (**NC**), e.g. 'it is a hot day', and six took an action to set up the circumstances (**AN**), 'place the ice-cream in the sun'; in both case, the causes being different entities such as 'heat', 'energy', 'temperature'. In one case, the process would just happen, with no reason.

BA - All answers were concerned with action on the circumstances (**AN**), followed by a natural process driven by the circumstances. Five answers mentioned only this action on circumstances, e.g. 'freeze the liquid', while the rest (11) were a combination of two actions. Eight suggested an initial action on circumstances, to restore the initial state of the ice-cream, 'put in freezer', followed by another direct action on the ice-cream, to restore the initial appearance/shape; three suggested the same idea but on the other way round.

REVERSIBILITY - Similarly to Tea, the process is reversible, and involves natural changes in both directions, but with a predominant dependence on circumstances.

6.3.2.17 PUDDLE - 'water in a puddle evaporates'

AB - Nearly all answers (13) were about a natural process, with the majority (9) being the most 'natural' case (**NH**), and four focusing on circumstances considered as already existing; both cases having the causes related to entities such as 'temperature', 'heat energy'. One answer mentioned a direct action on the object.

BA - Most answers (11) were about natural process, 'it rains' (**NH**). Four answers mentioned a direct action on the system, 'pour some water into the puddle'.

REVERSIBILITY - This is a reversible process involving natural changes in both directions.

6.3.2.18 CANDLE - 'a candle burns away'

AB - All answers (16) were about a natural process, with most of them (12) seeing this as a natural process (**NH**), either with no specific causes (5), or caused by entities such as 'heat', 'temperature' (7). The rest (4) saw this process started by an action (light the candle), with the natural process caused by an entity (heat) (2) or by the object itself (the candle burns) (2).

BA - About half (8) answers were in terms of a combination of external action, such as 'take the wax around the candle, melt it and reshape it' (**A**). The rest (7) saw it as not possible (**X**), either with R replies, 'buy a new candle'(3), or imaginative answers, 'reversing time'(4).

REVERSIBILITY - Natural process mainly seen as irreversible, but sometimes seen as reversible through actions, close to renewal in nature, which re-establish the original configuration (external appearance) using either the same material or not. Time reversal is mentioned.

6.3.2.19 ALKA-SELTZER - 'an alka-seltzer tablet dissolves'

AB - Most answers (13) saw this as a natural process, with the majority (8) seeing it as just happening, mainly due to some property of the object such as 'the tablet is water soluble' (**NH**), and five paying attention to an initial action, e.g. 'drop the alka-seltzer in water', followed by a natural process either caused by some property of the object such as 'solubility of the tablet' (2), or with no specific reason (3) (**AN**). The rest were in terms of a direct action on the object, such as 'swirling the water around'.

BA - Most answers (10) were in terms of a combination of action (**A**), such as 'by evaporating the liquid and forming the tablet again', and causes being the action itself. Five saw it as not possible.

REVERSIBILITY - This is mainly a natural process reversed by an external action to restore the original configuration.

6.3.2.20 MAGNET - 'a magnet attracts nails'

AB - All answers (15) saw this as natural, with about half (7) seeing it as just happening (**NH**), due to some entities, such as 'magnetism', 'magnet field', magnetic force'. The other half (8) focusing on an initial action (**AN**), e.g. 'put the magnet close to the nails', followed by a natural process caused by either the object, 'magnet attract the nails' or some entities, 'magnetic force'. The exception just gave a direct action on the object, 'put the magnet close to the nails'.

BA - Most answers (10) were in terms of a direct action on the object (**A**), e.g. 'take the nails off', with the cause related to the action itself. The rest (6) paid attention to an initial action to set up the circumstances, such as 'another stronger magnet could be held...', followed by a natural process caused by an entity such as 'greater force'.

REVERSIBILITY - A natural process reversed by an external action which restores the initial configuration or starts a natural process.

6.3.2.21 BOY/MAN - 'a man grows old'

AB - All answers (16) saw this as an natural process, just happening with no reason (**NH**).

BA - All answers (16) considered the reversal to be impossible (**X**), either stating it was impossible (4), or giving imaginative actions such as 'reverse time'.

REVERSIBILITY - This is a natural irreversible process. Time reversal was mentioned.

6.3.2.22 WATCH - Q2 - 'the time goes by'

AB - About half (9) answers were in terms of a direct action on the object (**A**), e.g. 'move hands of the clock using the knob on side'. The rest (6) saw this as a natural process just happening (**NH**), 'wait for half an hour'.

BA - Most of answers (12) were in terms of an direct action on the object (**A**), e.g. 'the hands are moved back half an hour', and the causes being the action itself such as 'moving hands'. The rest (3) saw it as natural, just happening, such as 'wait another 11 1/2 hours', but it is clear that in these answers that the focus is mainly on the configuration or appearance of the hands, not on the concept of time.

REVERSIBILITY - As for some responses of the event Watch Q1, this natural process is considered as reversible by an action. However it is clear through the answers that the students took a mechanistic view of the event, focusing attention on the watch itself not on time.

Table 6.2 shows the summary of the description of events in both questionnaires.

Table 6.2 - *Summary of the description of events in both questionnaires*

EVENTS	DIRECTION		REVERSIBILITY	
	AB	BA	√ or x*	DESCRIPTION
PENDULUM	**NH**	**A**	√	action reverses natural process
SLOPE	**AN**	**A**	√	action reverses action+natural process
TANK	**AN**	**AA**	√	action reverses action+natural process
PENCIL-Q1	**A**	**X**	x	irreversible process/imaginative actions
TEA	**NH**	**AN**	√	action+natural reverses natural process
CHAMPAGNE	**NH**	**A**	√	action reverses natural process
BOMB	**NH/AN**	**X**	x	irreversible natural process
CAR	**NC**	**A/X**	√/x	action reverses natural process/ irreversible natural process
BATTERY	**NC**	**A**	√	action reverses natural process
PLANT	**AN**	**A**	√	action reverses action+natural process
WATCH-Q1	**NH**	**A/X**	√/x	action reverses natural process/ irreversible natural process
WHEEL	**A**	**A**	√	action reverses action process
JACK	**AN**	**AA**	√	action reverses action+natural process
EGG	**AN**	**AA**	√	action reverses action+natural process
PENCIL-Q2	**A**	**X**	x	irreversible process/imaginative actions
ICE-CREAM	**NC**	**AN**	√	action+natural reverses natural process
PUDDLE	**NH**	**NH**	√	reversible natural process
CANDLE	**NH**	**AA/X**	√/x	action reverses natural process/ irreversible natural process
ALKA-SELTZER	**NH**	**A**	√	action reverses natural process
MAGNET	**NH**	**A**	√	action reverses natural process
BOY/MAN	**NH**	**X**	x	irreversible natural process
WATCH-Q2	**A/NH**	**A**	√	action reverses action process+natural process

* √ = reversible , and x = not reversible

6.3.3 Reversibility: the description of the events

Based on the way the events were described by the students, they can be grouped according to their similarities. A first criterion to be adopted is whether or not the events are considered reversible. Within this classification a second criterion taken is whether the events are considered as natural processes, i.e., whether they happen naturally without the necessity of any external action or provide that some 'natural' circumstances are fulfilled.

By the first criterion, most of the events are considered in some way as reversible, these being:

PENDULUM	SLOPE	TANK
TEA	CHAMPAGNE	CAR
BATTERY	PLANT	WATCH-Q1
WHEEL	JACK	EGG
ICE-CREAM	PUDDLE	CANDLE
ALKA-SELTZER	MAGNET	WATCH-Q2

The events Plant, Egg, Watch-Q1 and Watch-Q2 are considered as reversible for different reasons. Concerning the former, the focus is on the external appearance, where reversibility seems to be related to the restoring of the appearance of the initial state, while in the latter the focus is on the configuration of the hands of the watch.

The events considered as irreversible are:

PENCIL-Q1	BOMB	CAR
WATCH-Q1	PENCIL-Q2	CANDLE
BOY/MAN		

Three events - Candle, Car, and Watch-Q1 - are considered reversible by some and irreversible by others.

If we consider the second criterion, a more refined classification can be given: there will be natural processes that can be either reversible or irreversible, and non natural processes classified in the same way. Therefore, for reversible processes the categories are:

6.3.3.1 Natural process reversed by an action

These processes are seen as happening forward naturally, with no intervention, but reversed through a subject's intervention.

PENDULUM	CHAMPAGNE	ALKA-SELTZER
MAGNET	CANDLE	WATCH-Q1
CAR	BATTERY	WATCH-Q2

The events Car and Battery are considered as natural processes happening depending on certain conditions or circumstances.

6.3.3.2 Natural process triggered by an action and reversed by an action

This category include processes which are considered as natural as long as there is an initial action to trigger them.

SLOPE	TANK	PLANT
JACK	EGG	

The actions thought of to reverse the process are mostly simple attainable actions. However in the case of Plant and Egg, action is thought of to restore the external appearance, no matter the internal structure.

6.3.3.3 Natural process with natural reverse

These processes are seen as happening naturally forward and backward. The events Tea and Ice-Cream are seen so, provided an initial action is taken to reverse them.

TEA	ICE-CREAM	PUDDLE

The event Puddle is the one simply reversible natural process.

6.3.3.4 Non natural process triggered by an action reversed by an action

These processes are seen as happening by means of actions in both directions. As already mentioned the event Watch-Q2 is interpreted within a mechanistic view where the focus is on the Watch itself, not on time.

WHEEL	WATCH-Q2

Regarding the irreversible processes, the categories are:

6.3.3.5 Irreversible natural processes

These events are seen as not being able to be reversed, considered as impossible to happen in reverse.

BOMB	BOY/MAN	CANDLE
CAR	WATCH-Q1	

6.3.3.6 Irreversible processes: irreversible action

These events are seen as happening forward by means of an action, but irreversible inasmuch as there is no real reversible action to reverse it.

PENCIL-Q1	PENCIL-Q2

6.4 The Clusters according to Actions and Causes

The clusters described in section 6.2 will now be characterised according to the responses to the action/causes questions as described in section 6.3. In doing so, we are seeking support in the students' responses to the open questions, for the previous description of the clusters based on the cluster analysis of the factor scores.

Therefore, Tables 6.3-6.10 show the events in each cluster described according to the summary presented in Table 6.2.

6.4.1 First Cluster: Happens by itself, ruled by some causal law

The major feature of these events is that basically no intervention is required to make them happen. Excepting Puddle BA, the other events are explained in terms of a cause which is related to an external agent such as 'temperature' (Candle AB), 'salted water' (Car AB). When analysed from the factor space the idea of cause was unclear, however from the written answers it is possible to see that causes are projected on external agents. An alternative name for this cluster could be 'happens by itself due to an external cause'

Table 6.3 - *Events in the First Cluster and Summary of Description*

EVENTS	DESCRIPTION
CHAMPAGNE AB	NH
TEA AB	NH
CAR AB	NC
CANDLE AB	NH
PUDDLE AB	NH
PUDDLE BA	NH

6.4.2 Second Cluster: Unlikely to happen

All events in this cluster are BA ones, and although the prominent feature of these events is that they are seen as being able to be reversed through an direct intervention on the object, most of the actions proposed would not really reverse the process, such as 'collect the content and glue the shell' (Egg BA), 'cut the plant' (Plant BA), 'wind the hands backwards' (Watch BA), indicating that it cannot really happen; moreover some of the answers to all of them were that it would be impossible.

Table 6.4 - *Events in the Second Cluster and Summary of Description*

EVENTS	DESCRIPTION
ALKA-SELTZER BA	A
EGG BA	AA
PLANT BA	A
WATCH BA1	A/X

6.4.3 Third Cluster: Possible, but difficult to reverse

They are all BA events considered possible to be reversed through an action, although to some of them there were a significant number of answers considering them as not possible.

Table 6.5 - *Events in the Third Cluster and Summary of Description*

EVENTS	DESCRIPTION
CANDLE BA	AA/X
CHAMPAGNE BA	A
ICE-CREAM BA	AN
CAR BA	A/X
TANK BA	AA

6.4.4 Fourth Cluster: Happens by itself

They are like the events in the first cluster, insofar as no intervention is required, but the circumstances play a important role in this case because the necessary conditions to lead them to happen need to be fulfilled. Thus, from the analysis of the extended questions it is possible to characterise this cluster better, and a meaningful name could be 'happens by itself, depending on circumstances'.

Table 6.6 - *Events in the Fourth Cluster and Summary of Description*

EVENTS	DESCRIPTION
ICE-CREAM AB	NC
BATTERY AB	NC
PENDULUM AB	NH

6.4.5 Fifth Cluster: Non natural reversal caused by action

As they are all BA events, excepting Egg AB, they are considered reversible, not naturally, but through an action. Unlike the third cluster, there is no restriction for the reversal aspect. In a broad way, the event Egg could be considered as a non natural event, which demands an action to happen.

Table 6.7 - *Events in the Fifth Cluster and Summary of Description*

EVENTS	DESCRIPTION
SLOPE BA	A
PENDULUM BA	A
EGG AB	AN
TEA BA	AN
WATCH BA2	A
BATTERY BA	A
MAGNET BA	A
JACK BA	AA
WHEEL BA	A

6.4.6 Sixth Cluster: Happens naturally due to a planned action

They are all AB events, and the main feature of this cluster is the natural way that they happen, excepting for Pencil AB2 which could be considered as being seen as natural to happen. The second main feature is that action plays a important role insofar as it can be seen as triggering the process such as 'light the fuse' for Bomb, 'push the ball' for Slope, although for Pencil a continuous action is required - 'keep sharpening the pencil'. An alternative name could be 'happens naturally when an initial action is taken'.

Table 6.8 - *Events in the Sixth Cluster and Summary of Description*

EVENTS	DESCRIPTION
PENCIL AB2	A
BOMB AB	NH/AN
MAGNET AB	NH/AN
ALKA-SELTZER AB	NH
TANK AB	AN
SLOPE AB	AN

6.4.7 Seventh Cluster: Happen with difficulty due to an action taken with a goal

As in the sixth cluster, they are all AB events which happen due to an action, but not naturally, excepting the event Boy/Man. It seems that a action has to exist along the whole process to lead it to the end, such as 'sharpening it' for Pencil AB1 or 'watering the plant' for Plant AB. A simpler name for this cluster could be 'happens with no difficulty due to an action'.

Table 6.9 - *Events in the Seventh Cluster and Summary of Description*

EVENTS	DESCRIPTION
WATCH AB2	A/NH
WHEEL AB	A
PENCIL AB1	A
BOY/MAN AB	NH
PLANT AB	AN

6.4.8 Eighth Cluster: Unlikely to happen or possible reversal for a purpose

Most events are BA ones, with the major feature of being considered as impossible to happen. Although the events Watch AB1 and Jack AB happen to fall in this cluster, from the descriptions the cluster would be better characterised as 'unlikely to happen'.

Table 6.10 - *Events in the Eighth Cluster and Summary of Description*

EVENTS	DESCRIPTION
PENCIL BA2	X
PENCIL BA1	X
BOY/MAN BA	X
BOMB BA	X
WATCH AB1	NH
JACK AB	AN

6.5 The factor space, the cluster analysis and the action/cause responses interpretation

The description of the events clustered according to their location in the factor space turns out to be broadly similar to the description based on the answers to the open questions. The few dissimilarities may have arisen from to the different levels of analysis in both interpretations and the way the students may have answered these two types of questions. With regard to the latter aspect, after looking through the answers and the location of the events in the factor space, it seems that when answering the grid question, which gives grounds for the construction of the factor space, the subjects just answer it with no great reflection. However, when answering the extended questions related to actions and causes they are more conscious and reflective and try to give more elaborated answers, which may be the source of some discrepancies between the different analyses.

Regarding the former aspect, due to the generality of the answers given to the open question, sometimes it is necessary to restrict the level of analysis (which can be understood as the levels of delicacy in the network) , otherwise it is impossible to find any general overview based on the data. In addition, there is the fact that the study was carried out with a restricted sample, which may have caused some instabilities in the process of the factor analysis, when correlations were being calculated. This may be an explanation for the fact that the factor score of the event Watch AB1 locates it on the unlikely to happen side in Figure 5.1.

On the other hand, the analysis of the written answers did help to improve and refine the whole analysis. First of all it helped in a better characterisation of the clusters previously interpreted according to the location of the events in the factor space. Secondly, it shed light on the 'odd' location of some events such as Watch BA2, Puddle AB and Puddle BA. The location of Watch BA2 on the 'likely to happen' side was understood by the mechanistic view of the event, in which the students focused on the mechanism of the watch and not on the concept of time. The closeness of the events Puddle happening forward and backward can be explained by the view that this event is seen as a natural reversible process.

6.6 Analysis of the Questions related to Changes/No Changes

From the responses to all events on the questions about what changes and what remains the same, a systemic network (Bliss, Monk and Ogborn, 1983) was devised to help describe of how the students explained what things either changed or stayed the same in the processes going forwards and backwards.

The network shown in Figure 6.2 represents students describing what they see as changes or constancy in the process, first by making a choice whether it was a general or a detailed description, which is portrayed by the first BAR. If the description is in terms of general aspects, it can be done in three different ways, represented by the top second BAR: firstly the description is related to the main element of the phenomenon, which in its turn can be referred either to the object as a whole or to its inner structure; secondly the description is related to any other component or part represented in the phenomenon; and finally when the description concerns non-specific aspects which can be in terms of either laws of physics or elements not considered in the phenomenon or vague descriptions.

On the other hand, if the description is detailed, it has two attributes considered by the BRA. The first determines whether the description is related to either specific elements or the system as a whole, and second regards what sort of features are considered in the description, either perceptual aspects or properties.

Considering the event TANK -'the water flows out' - as an example of the use of the network, when describing what changes, an answer such as 'water' is regarded as a general description of the object itself, while 'the level of water' is considered as a detailed description of an element of the phenomenon in terms of a perceptual aspect. Concerning what stays the same, an answer such as 'the tank' is regarded as general description of a component, and 'the shape of the tank' is considered as a detailed description of a element of the phenomena in terms of a perceptual aspect.

Another example is the event PENCIL - 'a pencil is worn out': an answer related to what changes such as 'the length of the pencil' is regarded as a detailed description of the system in terms of perceptual aspects, while the answer 'the ability to write' referring to what stays the same is a detailed description of the system in terms of a general property.

In the case of the event ICE-CREAM - 'an ice-cream melts', an answer concerning what stays the same such as 'chemical composition' is considered as a general description of the nature of the main element in terms of a general property, whereas the answer 'shape' related to what stays the same is a detailed description in terms of perceptual aspects.

Clearly a considerable number of features can be considered as changing or staying the same. When answering these questions students gave single word responses. Thus under the different labels related to property there are finer levels of delicacy which are close to the data itself: physical properties such as temperature, speed/velocity, pressure; physical entities such as kinetic, potential, thermal energy, charge; chemical properties such as concentration; or general: ability, ideas, taste, flavour.

However regarding the description of the aspects which could change or stay the same for all events, the main types were related to perceptual aspects - (a) configuration, (b) shape/form, (c) amount of substance, and to the object (d) identity (nature). Although these questions were not included in the questionnaire for the main study, results from them will be discussed further in Chapter 10, in connection with other results.

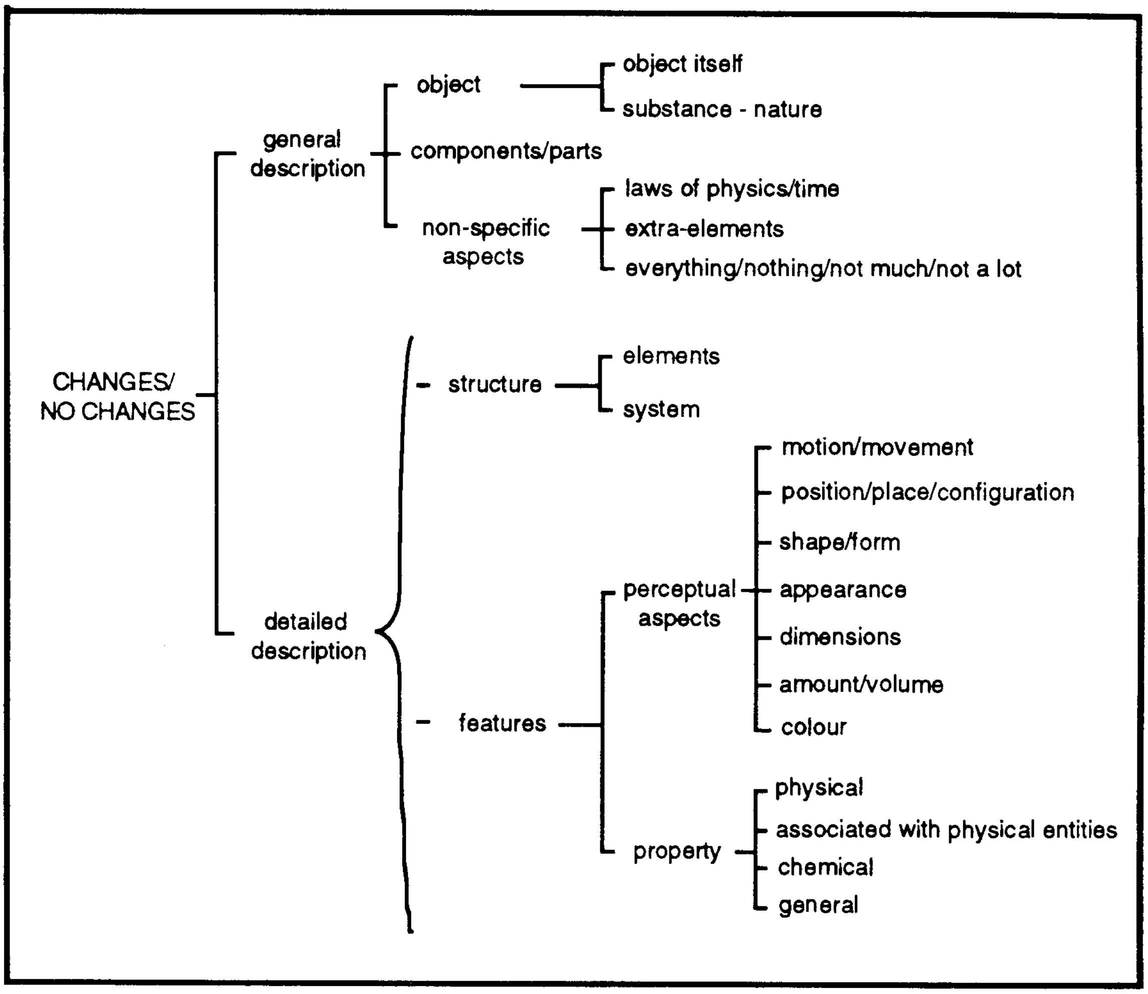


Figure 6.2 - *Network for analysing the change/no change questions*

6.7 The Analysis of the Question: 'Is there only one way to go from A to B?'

The objective of this question was to gather information about different ideas that a process could be thought of as happening or not. However, its analysis turned out to be impractical, since most students did not answer this question and even those who did, just ticked 'yes' or 'no' writing no explanations in the space left in the questionnaire.

7

The Description of the Main Study

The main study was carried out with a new version of the questionnaires used in the pilot study. The new version was basically similar to the old version, with some alterations in the number of questions, phrases and phenomena included. They are described in this chapter.

7.1 The Questions

For the main study, the questionnaire was based upon the ideas of *possibility, action, and causes*. The questions related to the ideas of differences (changes) and sameness (no changes) were left out of this version. This was done to reduce the time needed to answer the questionnaire. Therefore, the set of questions consisted of the three first questions of the pilot questionnaire: two open-ended questions - Question 1 related to the idea of possibility and action and Question 3 related to causes, and one question in the form of a grid - Question 2 consisting of a collection of fourteen statements describing different views of the processes. The questions were:

- Question 1: *Think of some way to go from A to B. How?*

- Question 2: *Which of the following phrases describe your idea?* (See Table 7.1)

- Question 3: *What, if anything, would you say is the cause of the change from A to B?*

7.1.1 The Phrases in the Question in the Form of a Grid

The phrases included in question 2 of the new version were similar to those included in the pilot study, with some minor alterations. These changes resulted from the analysis of data in the pilot study. Questions that were confusing, or contradictory, or which replicated others, were removed or modified.

7.1.1.1 The Number of Phrases

To achieve these changes, a new categorisation was devised to help to synthesise the phrases, so as to reach a simpler structure, which could be more coherent and consistent with the analysis of the results of the pilot study, and obtain a more even distribution of different kinds of questions.

When, the phrases were re-considered, the initial eighteen phrases were reduced to fourteen. Table 7.1 shows the final set of phrases with their new numbers, grouped according to the new categories.

Table 7.1 - *Classification of the phrases based on the analysis of the Pilot Study*

CATEGORY	Nº	PHRASE
MUST HAPPEN	6	It cannot be stopped from happening
	13	There is a law which makes it happen
DIFFICULT TO HAPPEN	5	It is possible but difficult to do in practice
	12	It could happen but hardly ever will
CANNOT HAPPEN	2	There is a law which prevents it happening
	8	It could never happen, in principle
ACTION	7	It happens because it is forced to go to B
	10	It needs an action to make it happen
NATURAL/SPONTANEOUS	1	It is something which happens naturally
	9	It happens spontaneously, all by itself
GOAL	4	It happens because it ought to go to B
	14	It happens because getting to B is the reason for the change
ACCIDENTAL/RANDOM	3	It happens accidentally
	11	It happens by some random process

7.1.1.2 The Changes

Eleven phrases were kept the same as in the pilot study, the alterations made comprising two kinds: some phrases were left out, some were re-written, and one was added. There were different reasons for the phrases left out:

• Phrase 2 - 'It cannot really happen in practice' and Phrase 15 - 'It is possible to imagine but not to do', because the category where they would fit - CANNOT HAPPEN - was better represented by different phrases;

• Phrase 6 - 'There is no cause for it, it just happens' because it seemed rather feeble, in that it would fit in nearly all categories;

• Phrase 13 - 'It is possible in theory but not in practice' - was not included because it had already been left out of the data analysis of the pilot study. The reason was that while applying the questionnaires, it was observed that students found it ambiguous;

• Phrase 18 - 'It was forced into state A and then just goes back to B' because it was a single item belonging to a fourth factor - RELAXATION. Thus attention was focused on the three major dimensions.

There were three other alterations. Phrase 3 - 'It happens because the system has to go to B' was re-written as 'It happens because it is forced to go to B' in order to stress the idea of the necessity of an action to make the event happen. Phrase 5 - 'It happens because the system tends to go to B' was re-written as 'It happens because it ought to go to B' to emphasise the idea of a goal. The word 'system' in both phrases were changed for 'it' for the sake of simplicity. Finally, a new phrase related to the category DIFFICULT TO HAPPEN was added: 'It could happen but hardly ever will'.

Therefore, the set of phrases presented in Question 2 for the main study is essentially the same as that presented in the pilot study. They can still be categorised according to the basic ideas expressed by the network shown in Figure 4.1, except for the elimination of the aspect related to relaxation stated by Phrase 18, and Figure 7.1 shows the new version of the network. The categorisation of the phrases according to this new network is shown in Table 7.2, providing a way complementary to that of Table 7.1, for thinking about the meaning of the phrases.

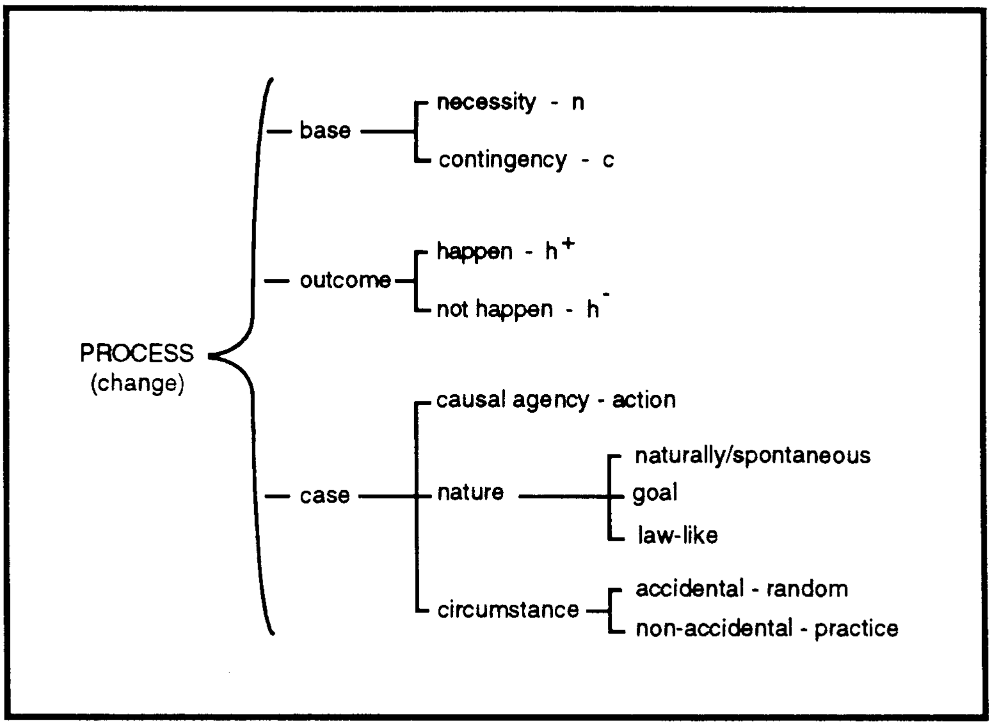


Figure 7.1 - *Network expressing the structure of phrases of Question 2 for the main study*

7.2 The Events

The events included in the new version of the questionnaire were basically the same as those included in the versions for the pilot study, but in reduced number because of the time needed to answer the questionnaires.

To reduce the number of events, the criteria used in the pilot study were re-examined. The events still should cover phenomena related to physical, chemical and biological changes, and a range of degrees of reversibility or irreversibility. As the number was to be reduced, the choice had to be more objective and strict in relation to the areas to be covered.

Therefore, looking at the distribution of events in Questionnaires 1 and 2 for the Pilot Study (Table 4.3), the four events classified as general, which were matched in pairs - Tank-Egg, Pencil-Pencil, and Watch-Watch - were removed. The same was done with the pair related to electricity/magnetism. The four events related to chemical changes were reduced to two, while the two events associated with biological changes were kept.

Mechanics and thermodynamics are the most important areas in the study of reversibility, therefore they were privileged with a more significant contribution. The two thermal events and the two physical changes related to thermodynamics were kept. Regarding the four events related to mechanics, two were kept, and another four more representative for this study were added.

Table 7.2 - *Categorisation of Phrases for the Main Study, according to the network shown in Figure 7.1*

CATEGORY		Nº	PHRASE
ACTION	n, h^+	7	It happens because it is forced to go to B
	c, h^+	10	It needs an action to make it happen
NATURAL	c, h^+	1	It is something which happens naturally
	c, h^+	9	It happens spontaneously, all by itself
GOAL	n, h^+	4	It happens because it ought to go to B
	c, h^+	14	It happens because getting to B is the reason for the change
LAW-LIKE	n, h^-	2	There is a law which prevents it happening
	n, h^-	8	It could never happen, in principle
	n, h^-	12	It could happen but hardly ever will
	n, h^+	6	It cannot be stopped from happening
	n, h^+	13	There is a law which makes it happen
ACCIDENT	c, h^+	3	It happens accidentally
	c, h^+	11	It happens by some random process
PRACTICE	c, h^-	5	It is possible but difficult to do in practice

In the end, fourteen phenomena were chosen. Table 7.3 shows a summary of the phenomena, each with a short name that will be used to refer to it, a short description that was used in the questionnaires, and the type of process within the area of Science most clearly associated with it.

7.3 The Questionnaires for the Main Study

Although the number of events was reduced, fourteen phenomena, each repeated forward and in reverse would still produce an excessively long questionnaire. Thus, the same procedure used in the pilot study was adopted, and two similar and approximately equivalent questionnaires were designed. The phenomena were chosen in approximately matched pairs according to the general features by which they were categorised, as shown in Table 7.3. In the final version each questionnaire had fourteen question (seven showing the event happening in one direction, and seven showing it happening in reverse), with a very similar form as in the version used in the pilot study. Table 7.4 shows the events chosen for each questionnaire, and in Appendix E the actual version of the questionnaire is shown with pictures.

Table 7.3 - *Description of the phenomena for the Main Study*

SHORT NAME	DESCRIPTION	TYPE OF PROCESS
PENDULUM	a pendulum stops swinging	mechanical
SLOPE	a ball rolls down	mechanical
FALLING BALL	the ball falls and bounces back up	mechanical
SWING	the swing comes back	mechanical
SEE-SAW	the see-saw is tilted a little	mechanical
SPRING	the spring is stretched a little	mechanical
ICE-CREAM	an ice-cream melts	thermal
TEA	a cup of tea becomes cold	thermal
PUDDLE	water in a puddle evaporates	physical
CHAMPAGNE	the champagne goes flat	physical
CANDLE	a candle burns away	chemical
CAR	a car rusts away	chemical
BOY/MAN	a man grows old	biological (life)
PLANT	a plant grows	biological (life)

7.3.1 The Portuguese and the Spanish Versions of the Questionnaires

The original versions of the questionnaires were written in English, and were translated into Portuguese and Spanish to produce the versions to be applied in Brazil and in Chile respectively.

The techniques used were back translation and decentering (Brislin et al., 1973). The questionnaires were translated into Portuguese and Spanish by a bilingual speaker and a second bilingual speaker of each language translated it back to English. The result was compared with the original version in English and the decentering technique was used in that the questionnaires in English were changed so that there was a smooth, natural-sounding version in Portuguese and Spanish (Brislin, 1976).

Table 7.4 - *Phenomena selected for the two questionnaires used in the Main Study*

QUESTIONNAIRE 1	QUESTIONNAIRE 2
PENDULUM	SLOPE
ICE-CREAM	TEA
PUDDLE	CHAMPAGNE
CAR	CANDLE
BOY/MAN	PLANT
FALLING BALL	SWING
SEE-SAW	SPRING

In the final versions in Portuguese and Spanish the design of Question 2 was changed. Instead of asking students to tick or cross each phrase, it was designed in such a way that in each phrase students were asked to tick whether they agreed or disagreed. This was done following the advice of native speakers in both languages that this would be better understood. Also, in Questionnaire 2 the event TEA was altered to COFFEE and in the event CHAMPAGNE was altered to COCA-COLA. This was done because it was thought that these examples would be more familiar. The Portuguese and the Spanish versions of the questionnaires are available on request.

7.4 The Sample and Administration

The main study was carried out with samples from three different countries: England, Chile and Brazil. In England and Chile the questionnaires were answered by two different age groups: there was a group of 13/14 year old students and a group of 16/17 year old students. In Brazil the questionnaires were answered by just a group of 16/17 year old students, it having proved impracticable to obtain data from younger students as had been planned to do.

The choice of two different age groups - 13/14 and 16/17 year old - was designed to examine possible effects of age and schooling. The older ones would be expected to be more familiar with basic information in Science.

As far as sampling and administration are concerned, all groups had the same basic general features:

• The questionnaires were applied on two different days, with Questionnaire 2 being applied, on average, a week later;

• It was intended to give questionnaire 2 to the same groups as questionnaire 1. However, there was some variation in the numbers of student, due to the fact that some students were missing and/or others joined the initial ones. The final total number of students in each group was the same;

• Students took, on average, 40 minutes to answer the questionnaires;

• Random selection was not possible, and the students were selected according to their willingness to participate in the study. Consequently, it was not possible to avoid an uneven distribution of gender and age.

Table 7.5 shows a summary of the samples by country.

Table 7.5 - *Summary of the Samples of the Main Study*

COUNTRY	AGE GROUP	
	13/14	16/17
England	60	42
Chile	24	29
Brazil	-	92

7.4.1 The English Samples

The 13/14 year old sample comprised students of mixed ability from three schools in the North of London. The 16/17 year old sample comprised sixth form students from the same three schools in north London plus two schools in Birmingham. The older groups were all taking at least Physics A-level. Table 7.6 and 7.7 summarise the English samples.

Table 7.6 - *English Sample - 13/14 year old*

QUESTIONNAIRE 1

AGE	BOYS	GIRLS	TOTAL
13	13	13	26
14	19	15	34
TOTAL	32	28	60

QUESTIONNAIRE 2

AGE	BOYS	GIRLS	TOTAL
13	15	12	27
14	25	8	33
TOTAL	40	20	60

Table 7.7 - *English Sample - 16/17 year old*

QUESTIONNAIRE 1

AGE	BOYS	GIRLS	TOTAL
13	8	5	13
14	11	18	29
TOTAL	19	23	42

QUESTIONNAIRE 2

AGE	BOYS	GIRLS	TOTAL
13	6	3	9
14	18	15	33
TOTAL	24	18	42

7.4.2 The Chilean Samples

The Chilean samples came from the same upper class secondary school located in Santiago city. All 13/14 year old students were from the last year of regular eight year primary course. They were all attending 4 hours per week of science lessons, these being divided into Physics, Chemistry and Biology. Syllabi cover Structure of Matter, Chemical Activity and Living World. All 16/17 year old students were from the second year of regular three year secondary course. They were all attending, on average, 5 hours per week of science lesson. These data were collected with the help of a local teacher. Table 7.8 and 7.9 describe the Chilean samples.

Table 7.8 - *Chilean Sample - 13/14 year old*

QUESTIONNAIRE 1

AGE	BOYS	GIRLS	TOTAL
13	3	9	12
14	8	4	12
TOTAL	11	13	24

QUESTIONNAIRE 2

AGE	BOYS	GIRLS	TOTAL
13	5	9	14
14	5	5	10
TOTAL	10	14	24

Table 7.9 - *Chilean Sample - 16/17 year old*

QUESTIONNAIRE 1			
AGE	BOYS	GIRLS	TOTAL
13	4	13	17
14	4	8	12
TOTAL	8	21	29

QUESTIONNAIRE 2			
AGE	BOYS	GIRLS	TOTAL
13	4	13	17
14	9	3	12
TOTAL	13	16	29

7.4.3 The Brazilian Samples

The Brazilian samples came from the same state low middle class school located in Rio de Janeiro city. All students were from the second year of a regular three year secondary course. They were all attending 9 hours per week of science lessons, these being divided into Physics, Chemistry and Biology. Syllabi for the second year cover Heat and Temperature and Waves. Table 7.10 describes the Brazilian sample.

Table 7.10 - *Brazilian Sample - 16/17 year old*

QUESTIONNAIRE 1			
AGE	BOYS	GIRLS	TOTAL
13	20	25	45
14	16	31	47
TOTAL	36	56	92

QUESTIONNAIRE 2			
AGE	BOYS	GIRLS	TOTAL
13	18	20	38
14	19	35	54
TOTAL	37	55	92

The analysis of the data collected in the main study and the results are described in Chapters 8 and 9. The conclusion and discussion of the results are presented in Chapter 10.

8

Main Study - A Common Space of Explanation

Following a similar procedure of analysis to that used in the pilot study, the data analysis of the main study is now outlined. In this chapter the factor solution is described, and in the next the qualitative data from the open-ended questions is analysed. As already mentioned in Chapter 7, the sample consisted of 5 groups from 3 different countries: England, Chile and Brazil, given that England and Chile had two different age groups - 13/14 and 16/17 year old students, while Brazil had just one group, 16/17 year old students.

8.1 Introduction

A factor analysis was used to investigate whether underlying the patterns of responses to the fourteen statements about each of the 28 events, there were a simpler set of dimensions expressing the way students were reasoning about events. Basically one is looking to see whether the pattern of correlation between responses to the statements across the range of events has a simpler interpretation in terms of a few underlying dimensions.

As the sample consisted of several groups of respondents, there are four possible outcomes of such an analysis:

- 1. responses of some, or all groups show no simpler structure;
- 2. responses show structure, but which is different in kind from group to group;
- 3. responses show similar underlying structures, but groups judge events differently with respect to common underlying dimensions;
- 4. responses show similar structures and events are also judged similarly with respect to common underlying dimensions.

To investigate these possibilities, the first approach is to analyse each group independently to consider whether differences in the underlying structures for the groups would emerge, although where there seem to be similarities, these remain at the level of the interpretation of the factors. Doing so helped to test possibility 1 and 2, which were easily eliminated. The analysis of the results from the 5 groups independently, all gave a few strong factors with a fairly similar interpretation, as described in section 8.2.

Since the analysis for the groups independently indicated the existence of similar underlying dimensions, but with some minor differences, the next step is to analyse the groups combined to see whether it is possible to find a common structure of dimensions for all groups, when differences may appear as different judgements against this common structure. The analysis of the results from the groups combined, keeping all groups' responses to statements distinct, helped to eliminate possibility 4, suggesting possibility 3 as the best solution, giving a common factor space against which it is possible to look for differences among the groups, as described in section 8.3.

Since the analysis of the combined groups turned out to be the most helpful, the main focus of this chapter is on this analysis. The analysis of groups independently is described briefly, with the main results which gave grounds for doing the combined analysis.

8.2 Factor Analysis by Groups

Factor analysis was performed for each group, considering groups as a whole, not the individual, as the unit of analysis as mentioned in section 5.2. Thus, for each group, data were organised as a 28 x 14 matrix of the proportion of 'yes' responses to the fourteen statements for the seven forward events and the seven backward events for both questionnaires together and treating the situations in the two questionnaires as different.

Each matrix was then factor analysed, treating the fourteen statements as variables and the twenty-eight events as cases, and all gave a strong indication that there is a factor structure. The statistical summary for each group is presented in Appendix F and the interpretation of the dimensions together with a representation of the factor spaces are presented in Appendix G.

The overall results common for all groups are:

• 1 - The Bartlett Test of Sphericity rejected the hypothesis of no structure with p = .0001;

• 2 - The factor analysis extracted three factors for all groups, excepting for the Chilean 16/17 year old group, in which case the third factor had an eigenvalue marginally less than unity, but its inclusion gave a simpler interpretation of the factors;

• 3 - The three factors jointly explained over 80% of the variance for all groups;

• 4 - For all groups, except the 13/14 year old Chilean Group, the oblique solution was chosen because of the significant correlation between factors;

Regarding the interpretation of the factors or dimensions, Table 8.1 presents a summary of the interpretation for all groups. Looking at this table, two main results can be described:

• 1 - Each dimension has essentially a similar basis of interpretation for all groups:

  • Dimension I is related to the idea of the possibility of something happening. Thus, the events are essentially seen as either able to happen or not happening, although the Chilean groups and the Brazilian group have an underlying account related to action.

  • Dimension II is basically related to the idea of the necessity of action to make it happen. Therefore, an event is seen either as needing an action to happen, or not needing an action or happening by itself.

  • Dimension III is associated with the idea of goal or plan. In this way, events are seen as either happening due to a goal, or accidentally.

- 2 - The interpretation of the dimensions is nearly the same between the two age groups from the same country. The two English groups and the two Chilean groups have very similar interpretations for all dimensions. The interpretation for the Brazilian group is similar to the interpretation for the Chilean groups.

Table 8.1 - *Summary of the Interpretation of the Three Dimensions for all Groups Independently*

GROUP	DIMENSION I	DIMENSION II	DIMENSION III
13/14 ENGLISH	Does Not Happen vs. Happens	Happens by Itself vs. Needs an action	Goal/Planned vs. No Goal/ Accidental
16/17 ENGLISH	Does Not Happen vs. Happens	Happens by Itself vs. Needs an Action	No Goal/ Accidental vs. Goal/Planned
13/14 CHILEAN	Happens by Itself vs. Does Not Happen	Forced/Accidental vs. Not Forced/Not Accidental	No Goal/Randomly vs. Goal/Planned
16/17 CHILEAN	Happens by Itself vs. Does Not Happen	Needs an Action vs. Does Not Needs Action	Randomly/Accidental vs. Not Randomly/Not Accidental
16/17 BRAZILIAN	Happens due to Action vs. Does Not Happen	Happens by Itself vs. Needs an Action	Randomly/Accidental vs. Not Randomly/Not Accidental

There is a further statistical reason for being cautions about the factor analysis by groups. It will be seen from the details given in Appendix F that in several cases the factorsare rather strongly correlated. This is sometimes taken to suggest that more factors should have been extracted (StatView 512+ Manual, 1986). However, in the view of the similarity of the factors extracted for each group, this suggestion does not seem very plausible. As it turns out (se below), the factor analysis for the combined groups extracts a similar set of three factors, which are not strongly correlated (0.3 for one pair, and essentially zero for the other pairs, in Appendix H). Thus it seems best to regard the analysis by groups individually as suggestive but not firmly established, and to rely mainly on the analysis with the groups combined.

Having summarised the results of the factor analysis by groups, the results of the analysis for the groups combined are described and discussed in depth.

8.3 Factor Analysis of Groups Combined

To conduct the analysis, the data were organised in a 140 x 14 matrix of the proportion of 'yes' responses to the fourteen statements for the twenty-eight events (seven forward events and seven backward events for both questionnaires together) for the five groups together, but treating the responses of each group to each event in the two questionnaires as different, thus, adding up 5 (groups) times 28 (events) 'events' for each statement.

Extracting the factors, treating the fourteen statements as variables and the 5 x 28 'events' as cases, the Bartlett Sphericity test rejected the hypothesis of no structure with $p = .0001$, leading to a solution with three factors explaining 80.1% of the total variance (see Appendix H for the statistical summary).

As occurred for most of the groups analysed independently, the factors were correlated, and the oblique solution was chosen. Thus, the factor space associated with the three factors is a non-orthogonal three dimensional space, with the dimension I associated with factor 1 non-orthogonal to the dimension II associated with factor 2. For simplicity, the smaller factor correlations have been treated as equal to zero.

Table 8.2 - *Oblique Solution Reference Structure-Orthotran/Varimax*

Phrases	Factor	Loadings		Variable
	I	II	III	Complexity
1- It is something which happens naturally	**-0.474**	**0.639**	0.016	1.829
2- There is a law which prevents it happening	**0.866**	0.000	0.075	1.014
3- It happens accidentally	0.075	**0.664**	-0.031	1.029
4- It happens because it ought to go to B	**-0.444**	**0.557**	0.186	2.121
5- It is possible, but difficult to do in practice	**0.847**	0.000	-0.104	1.028
6- It cannot be stopped from happening	-0.098	**0.772**	0.124	1.079
7- It happens because it is forced to go to B	-0.019	-0.139	**0.927**	1.050
8- It could never happen, in principle	**0.906**	0.067	-0.051	1.017
9- It happens spontaneously, all by itself	-0.368	**0.721**	-0.021	1.476
10-It needs an action to make it happen	0.334	**-0.586**	**0.481**	2.516
11-It happens by some random process	0.313	**0.741**	0.079	1.358
12-It could happen but hardly ever will	**0.899**	0.026	0.085	1.019
13-There is a law which makes it happen	-0.240	0.439	**0.557**	2.348
14-It happens because getting to B is the reason for the change	0.160	0.442	**0.705**	1.860

To interpret the factors, apart from using the factor loadings (Table 8.2), the 'factor scores' for each phrase in the factor score space (See Appendix H) were calculated, as described previously in section 5.2.1, and represented as vectors in the factor score space: the longer a vector the more important it is in a given two-dimensional projection of the factor score space. Phrases with small factor scores are omitted for clarity.

The factor space is shown in Figure 8.1 with the interpretation of each factor or dimension. As can be seen, this interpretation is very similar to the overall interpretation for the groups independently. For simplicity the space is represented by two two-dimensional projections: dimension I vs. dimension II and dimension II vs. dimension III.

8.3.1 Interpretation of the Factor Solution

This interpretation is based upon the statements with high loadings on each factor shown in table 8.2 and Figure 8.1.

8.3.1.1 Dimension I: Does Not Happen vs. Happens

This first and more important dimension, associated with the strongest factor, is explained by the positive loadings of

Phrase 2 - There is a law which prevents it happening
Phrase 5 - It is possible, but difficult to do in practice
Phrase 8 - It could never happen, in principle
Phrase 12 - It could happen but hardly ever will

and the negative loadings of

Phrase 1 - It is something which happens naturally
Phrase 4 - It happens because it ought to go to B

All positive loadings deny the possibility of an event happening, while the negative ones say that it is able to happen. The main idea of this dimension, translated by Phrases 2, 5, 8, and 12, which is indicated by the horizontally oriented vector in the upper part of Figure 8.1, is in agreement with the previous analysis, which all had a similar dimension.

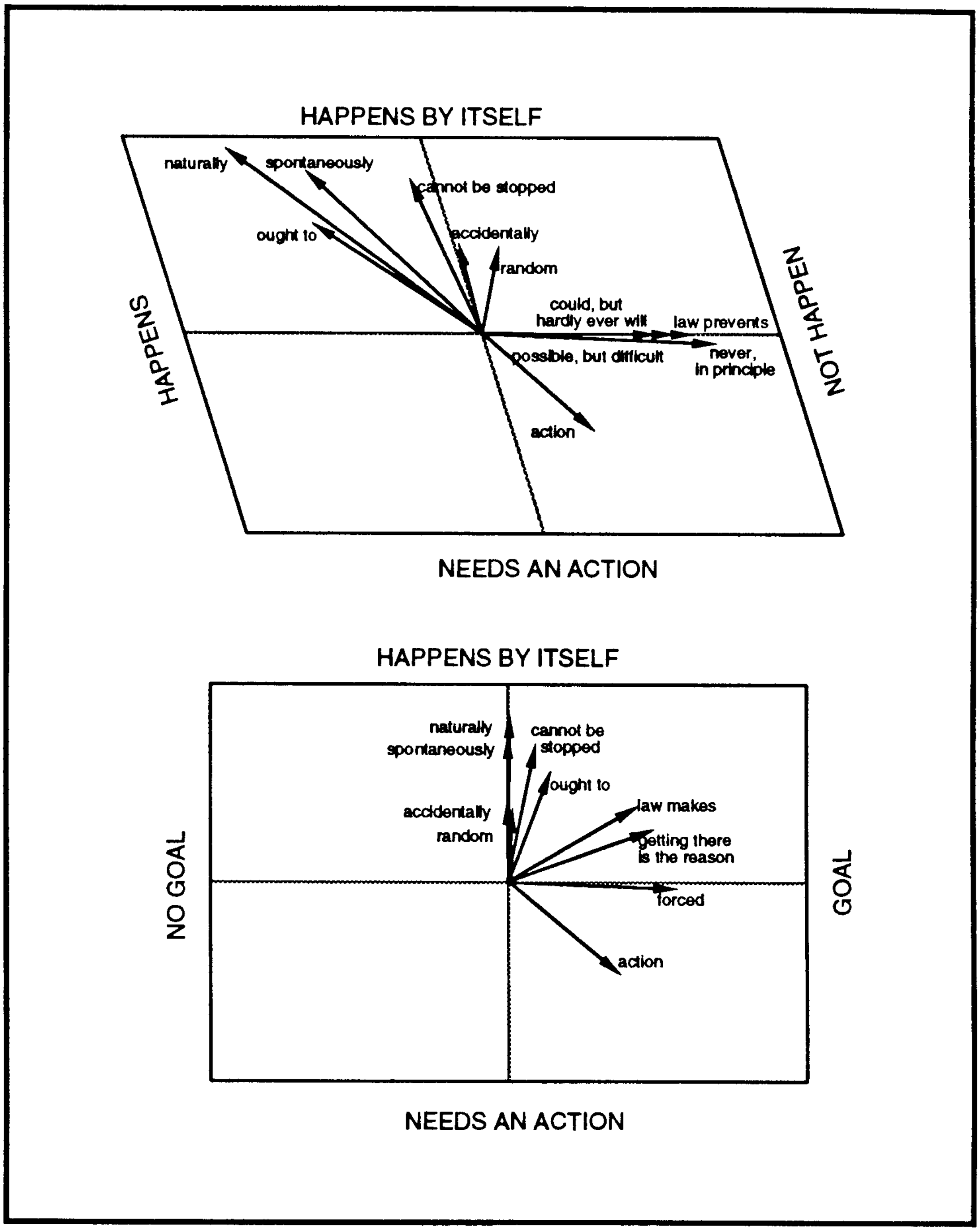


Figure 8.1 - *Factor Space with phrases represented as vectors*

8.3.1.2 Dimension II: Happens by Itself vs. Needs an Action

This second dimension is defined by the positive loadings of

Phrase 1 - It is something which happens naturally
Phrase 3 - It happens accidentally

Phrase 4 - It happens because it ought to go to B
Phrase 6 - It cannot be stopped from happening
Phrase 9 - It happens spontaneously, all by itself
Phrase 11 - It happens by some random process

and negative loading of

Phrase 10 - It needs an action to make it happen

In this dimension the idea of something happening naturally, accidentally, spontaneously, or randomly come together in opposition to the idea of something demanding an action to happen. The phrases expressing these ideas are all represented in the lower part of Figure 8.1 by their vertically oriented vectors. Yet, it seems that Phrases 4 and 6, with positive loadings, emphasise that something happening in this way, is unavoidable in the sense that it is unpredictable. Phrase 13 - 'There is a law which makes it happen' and Phrase 14 - 'It happens because getting there is the reason for the change' are not included in this dimension because they have high variable complexity, which means they load on more than one factor, and their more important contribution is on factor III.

8.3.1.3 Dimension III: Goal /Law-like vs. No Goal

This third dimension, associated with the least strong factor, is described by the positive loadings of

Phrase 7 - It happens because it was forced to go to B
Phrase 10 - It needs an action to make it happen
Phrase 13 - There is a law which makes it happen
Phrase 14 - It happens because getting to B is the reason for the change

There are no negative loadings in this case, and all phrases are related to the idea of something having to happen, either because it is forced, or due to a law which determines it, or because reaching the final state is the very reason for the event. The contributions of Phrases 7, and 10 seem to be related to the idea that an action is thought of to promote the achievement of a goal, i.e., to make the event happen, instead of being related to action itself. In Figure 8.1, these phrases are represented in the lower part by their mainly horizontally oriented vectors.

Therefore, what is in common in the underlying way of explaining the events of all groups can be described in terms of three dimensions:

HAPPENS vs. DOES NOT HAPPEN
HAPPENS BY ITSELF vs. NEEDS AN ACTION
GOAL vs. NO GOAL

8.3.2 Inspecting the Interpretation of the Factor Solution

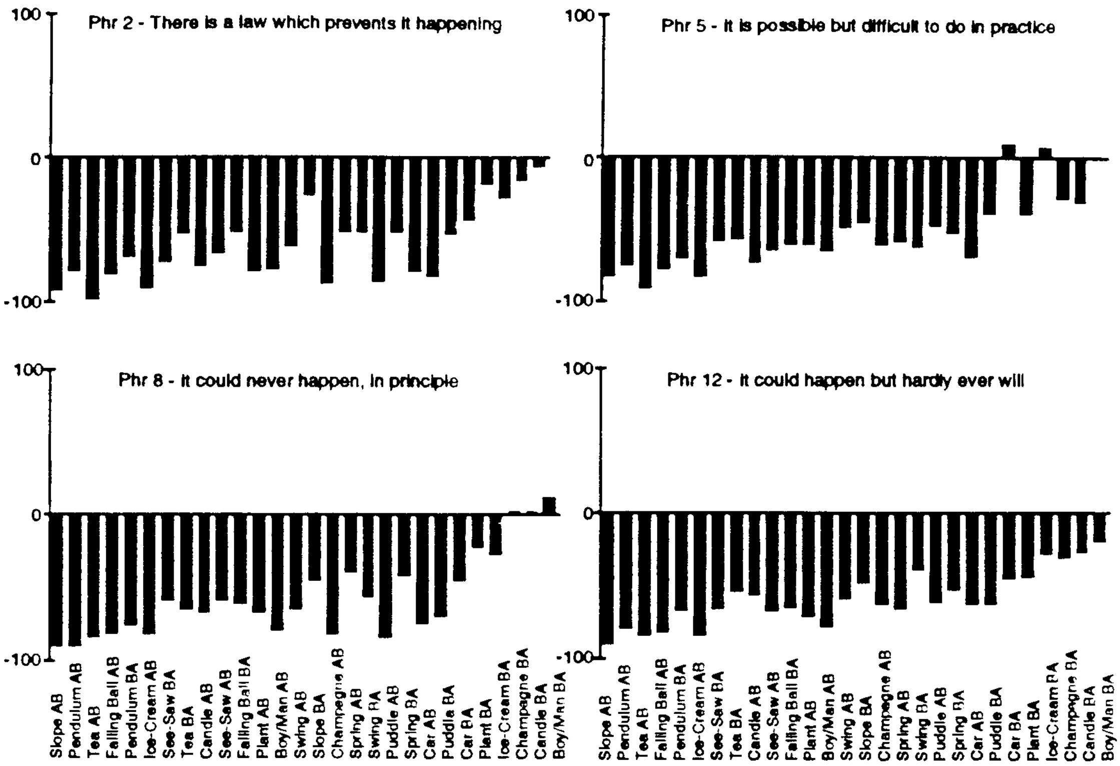
Given this interpretation of the factor solution, a different way of dealing with the characterisation of each dimension is to look at the way each group sees the events according to this interpretation, to attempt to identify general features which could help to better understand the way in which the events are seen and the interpretation itself. Therefore, the location of the events in the factor space plus the frequencies of replies to each phrase with a high loading on each dimension are analysed.

First of all, for each group, the factor scores of events on each dimension were sorted in ascending order in turn, and then the corresponding frequencies of replies to phrases with high loadings on each dimension were plotted. Events were then described according to pictorial trend of the frequencies of replies to phrases and the ordering of the events in relation to this trend, as well as their location in the factor space.

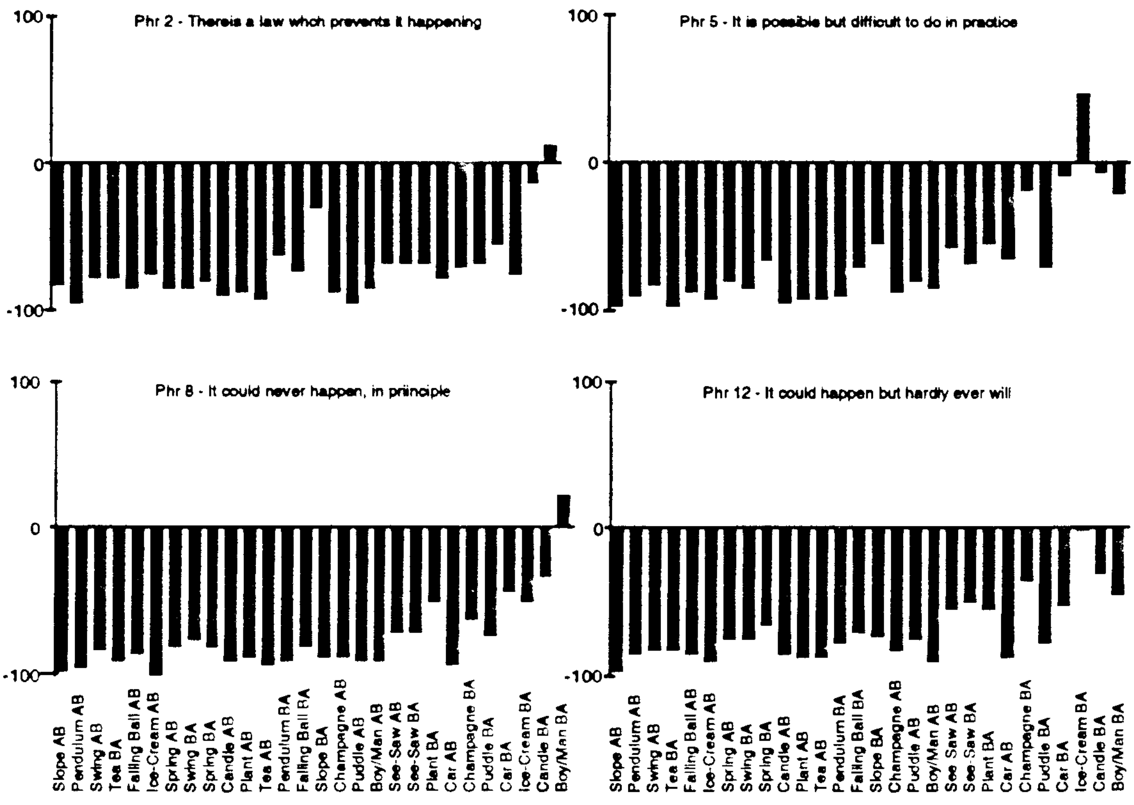
8.3.2.1 Events along dimension I: Most events are seen as able to happen

The frequencies of replies to each event on those phrases with high loadings on this dimension is shown in Figure 8.2. The events are in ascending order of their factor scores on this dimension: the origin represents the 'happens' extremity, and the far right side the 'does not happen' extremity.

For all groups, there is a concentration of AB events on the 'happens' side which inverts to BA events towards the 'not happen' side; this differentiation is a little sharper for the Chilean 13/14 and 16/17, and Brazilian 16/17. For nearly all events, most subjects deny Phrase 2 - 'law prevents it', Phrase 5 - 'possible, but difficult', Phrase 8 - 'never happens, in principle', and Phrase 12 - 'could happens, but hardly ever will', showing that the overwhelming majority of events, no matter whether AB or BA events, are seen as able to happen. Towards the very end of the 'not happen' extremity there is a tendency for fewer subjects to deny these phrases, although they still do, except for the rightmost event Boy/Man BA which seems to be considered as not likely to happen.



English 13/14 Group



English 16/17 Group

Figure 8.2 - *Frequencies of Replies for phrases with high loading on Dimension I*
(continued over)

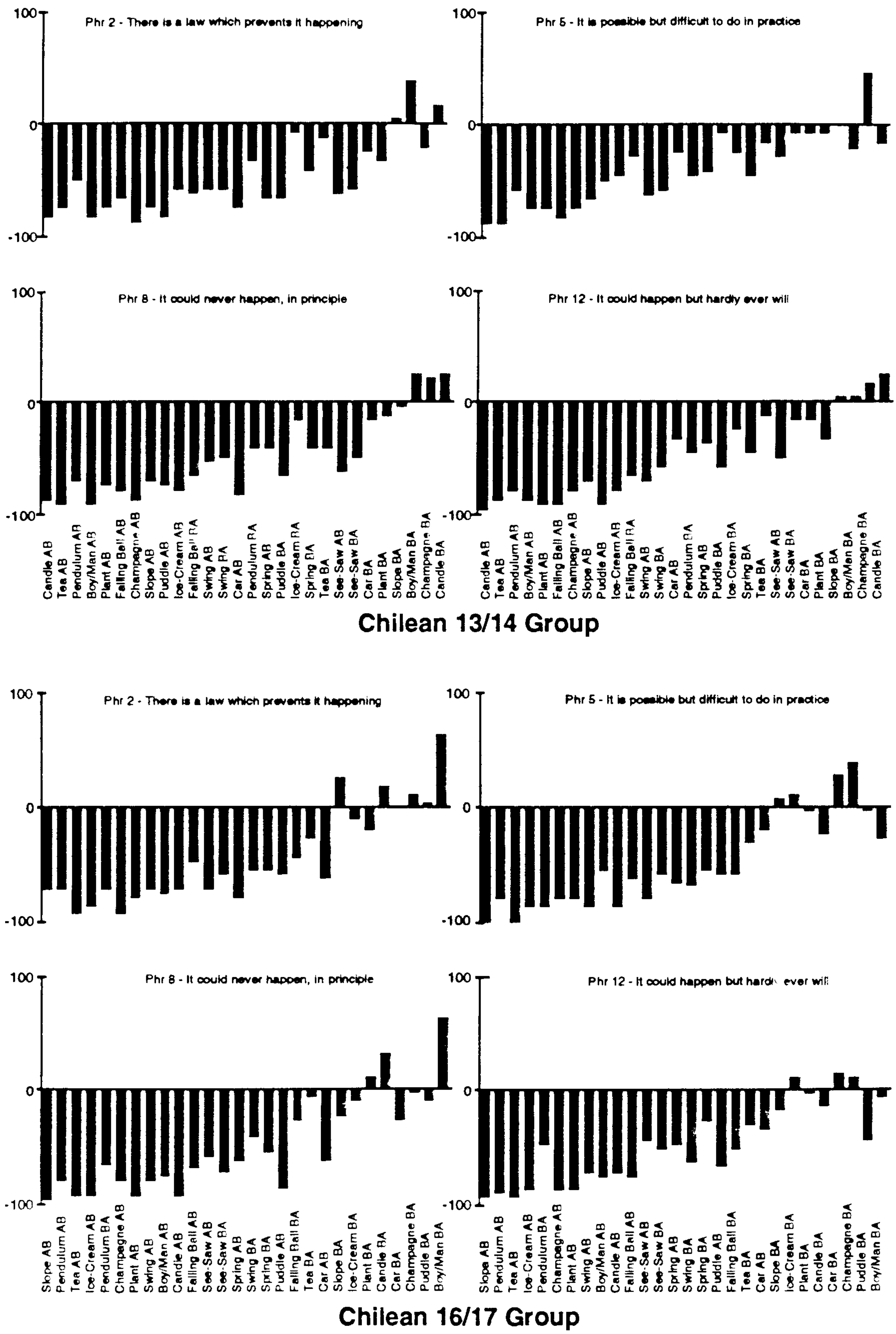


Figure 8.2 - *Frequencies of Replies for phrases with high loading on Dimension I*
(continued over)

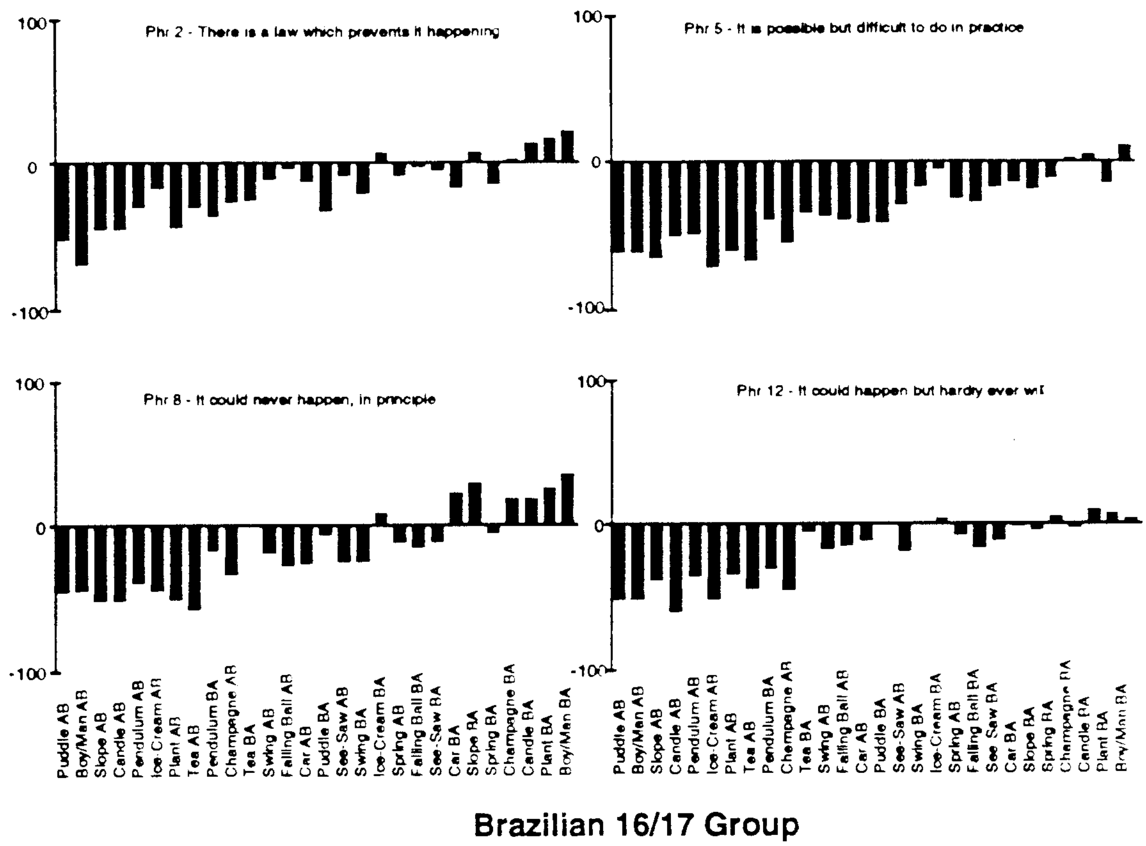


Figure 8.2 - *Frequencies of Replies for phrases with high loading on Dimension I*

There is an interesting contrast in relation to the profile of replies between the Brazilian 16/17 group and the others. While for the other groups the profiles show significant high frequencies of 'yes', with the English 13/14 and 16/17 having mostly high frequencies for all events and the Chilean 13/14 and 16/17 having high frequencies for the events located at the left hand side and relatively low frequencies of replies to events placed at the right hand side, for the Brazilian group the profiles show a smooth distribution of low frequencies along the two extremities.

Therefore, as the overwhelming majority of events are seen as able to happen, it appears that a less rigid interpretation should be given to this dimension. Instead of characterising it with a sharp opposition between 'happen' and 'does not happen', it could be named as 'HAPPENS' vs. 'LESS LIKELY TO HAPPEN'.

8.3.2.2 Events along dimension II: Most events are seen as needing an action to happen

The frequencies of replies to phrases with high loadings on dimension II are shown in Figure 8.2: the origin represents the 'needs an action' extremity while the far right side the 'happens by itself' extremity, and the events are in ascending order.

For all groups, there is a concentration of BA events on the 'needs an action' side which inverts to AB events towards the 'happens by itself' side; this division is clearer for the Chilean 13/14 and 16/17 groups, less sharp for the English 13/14 and 16/17 groups and still more moderate for the Brazilian 16/17 group.

For most events located towards the 'needs an action' side (left hand side), most subjects agree with Phrase 10 - 'needs an action'. This tendency is weakened towards the 'happens by itself' side (right hand side) with a inversion for the few rightmost events. Again the Brazilian 16/17 group shows a particular profile of replies in relation to the others: basically all events are seen as needing an action, through a continuum profile which changes smoothly from the 'needs an action' side where most subjects agree with Phrase 10 to the 'happens by itself' side where fewer subjects agree with it. The exception is the event Boy/Man AB with just a few subjects denying this phrase.

A similar inverted pattern of replies is observed for Phrase 1 -'naturally', Phrase 9 - 'spontaneous, all by itself', and Phrase 6 - 'cannot be stopped from happening'. It just ratifies the description above, where events located at the left hand side are seen as needing an action, therefore not happening either naturally or spontaneously, moreover, they can be stopped from happening providing the action which makes them happen is withdrawn. Once more the profile of replies given by the Brazilian group is distinct from the others with lower profile of replies.

Regarding Phrase 3 - 'accidentally' and Phrase 11 - 'randomly', for the majority of events, most subjects deny them, excepting for the events Car AB and Ice-Cream AB for which some subjects agree. This shows that the overwhelming majority of the events are considered as not happening accidentally nor randomly. Again the profile of replies for the Brazilian group presents lower frequencies.

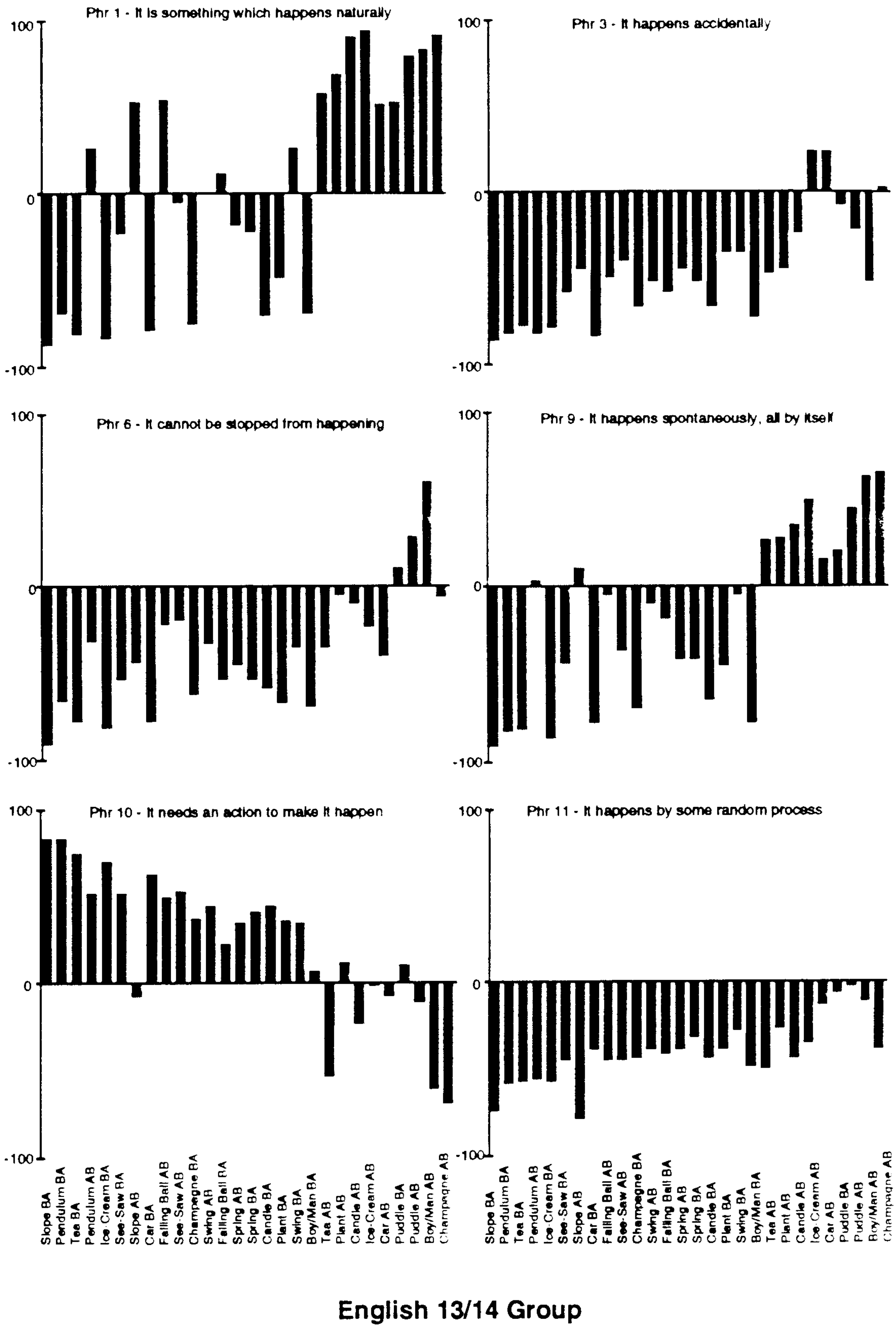
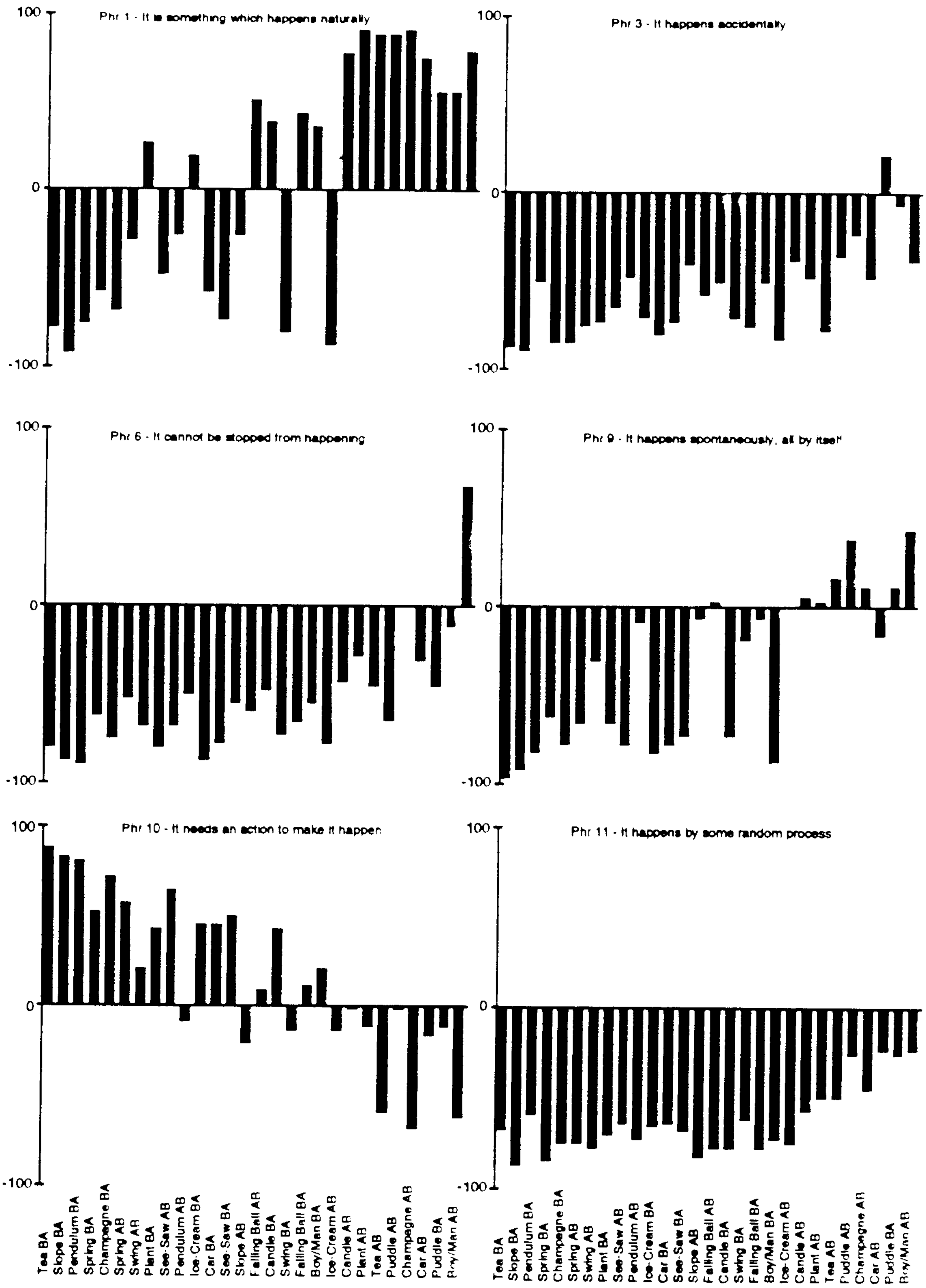
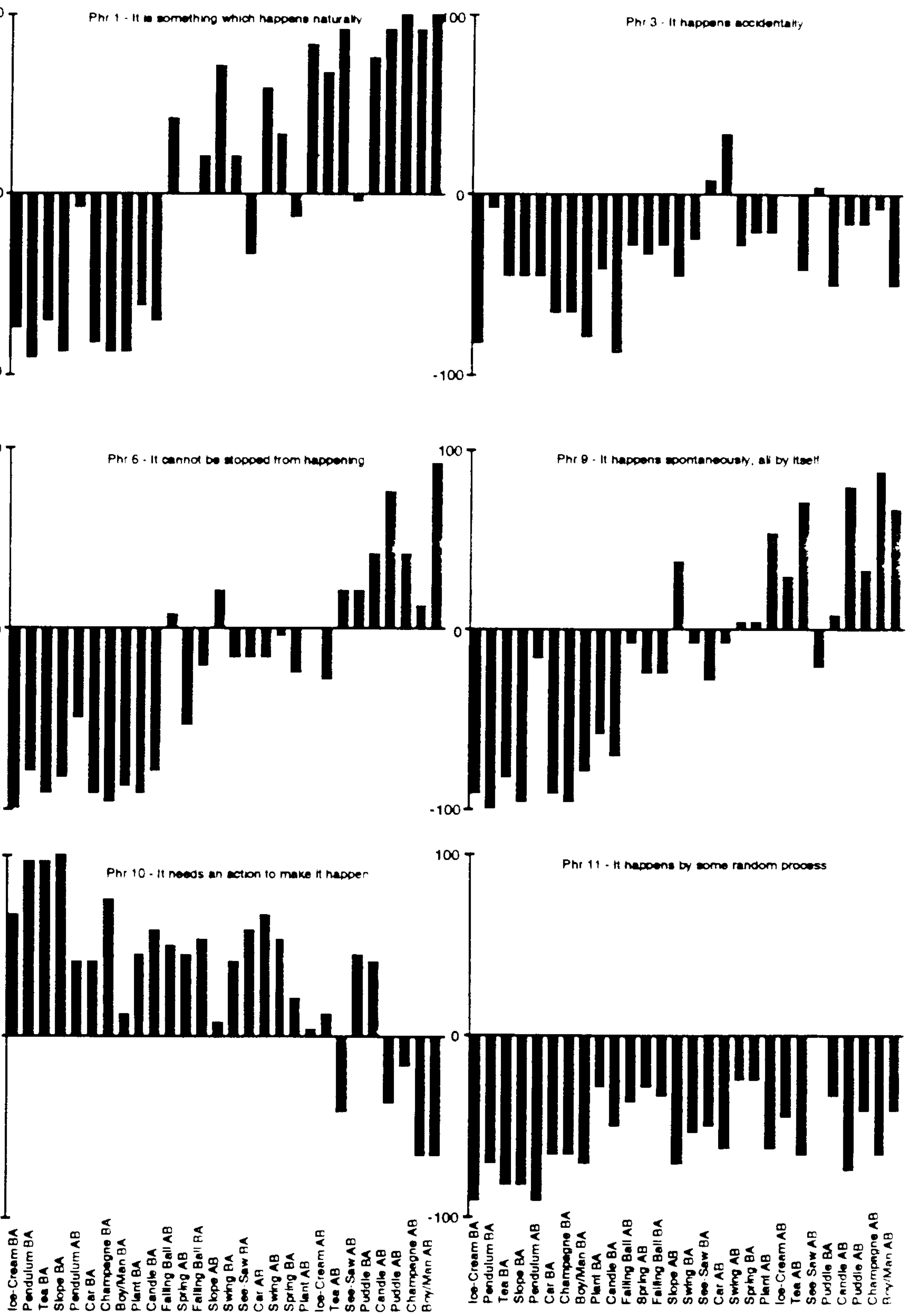


Figure 8.3 - *Frequencies of Replies for phrases with high loading on Dimension II*
(continued over)



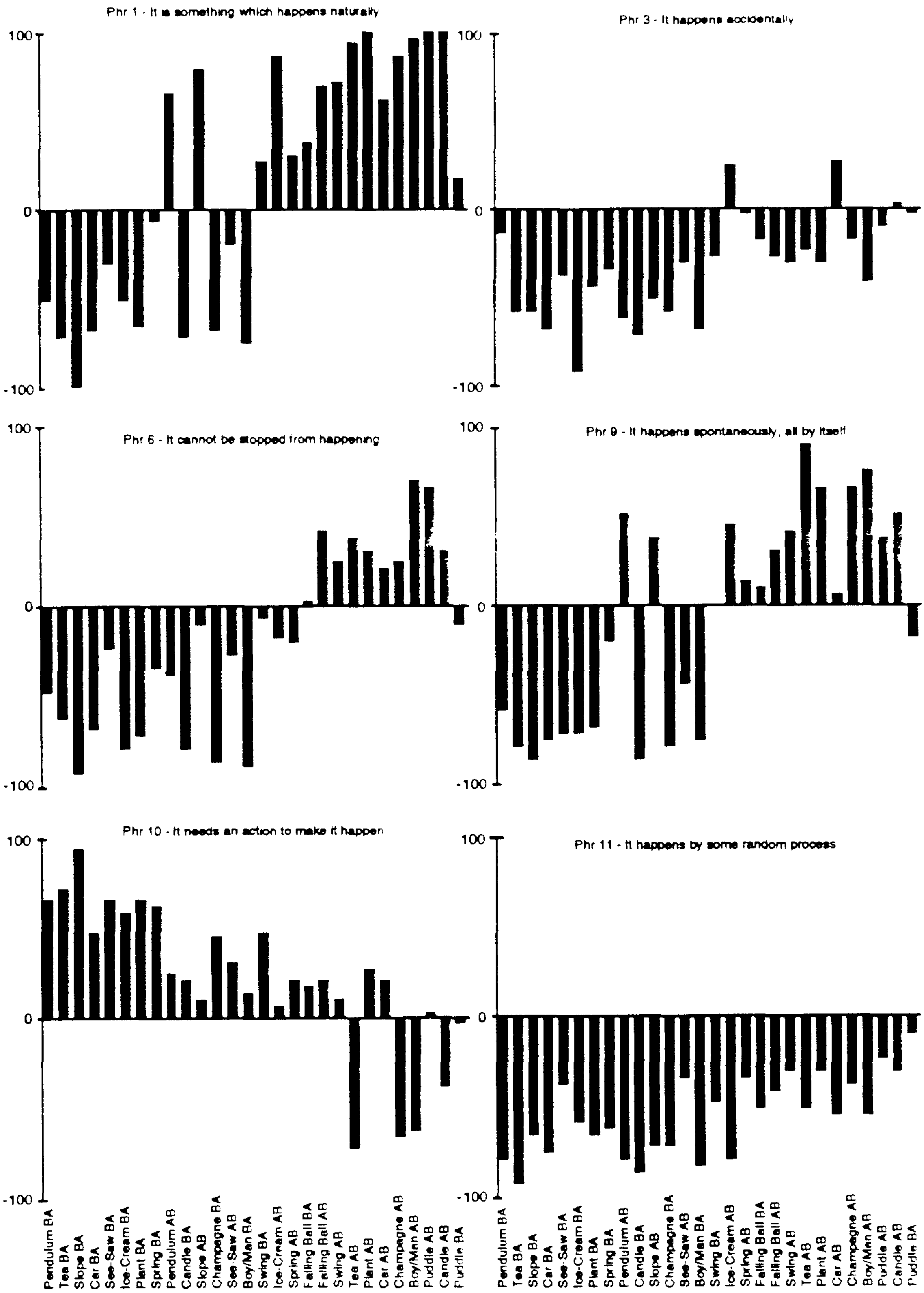
English 16/17 Group

Figure 8.3 - *Frequencies of Replies for phrases with high loading on Dimension II*
(continued over)



Chilean 13/14 Group

Figure 8.3 - *Frequencies of Replies for phrases with high loading on Dimension II*
(continued over)



Chilean 16/17 Group

Figure 8.3 - *Frequencies of Replies for phrases with high loading on Dimension II*
(continued over)

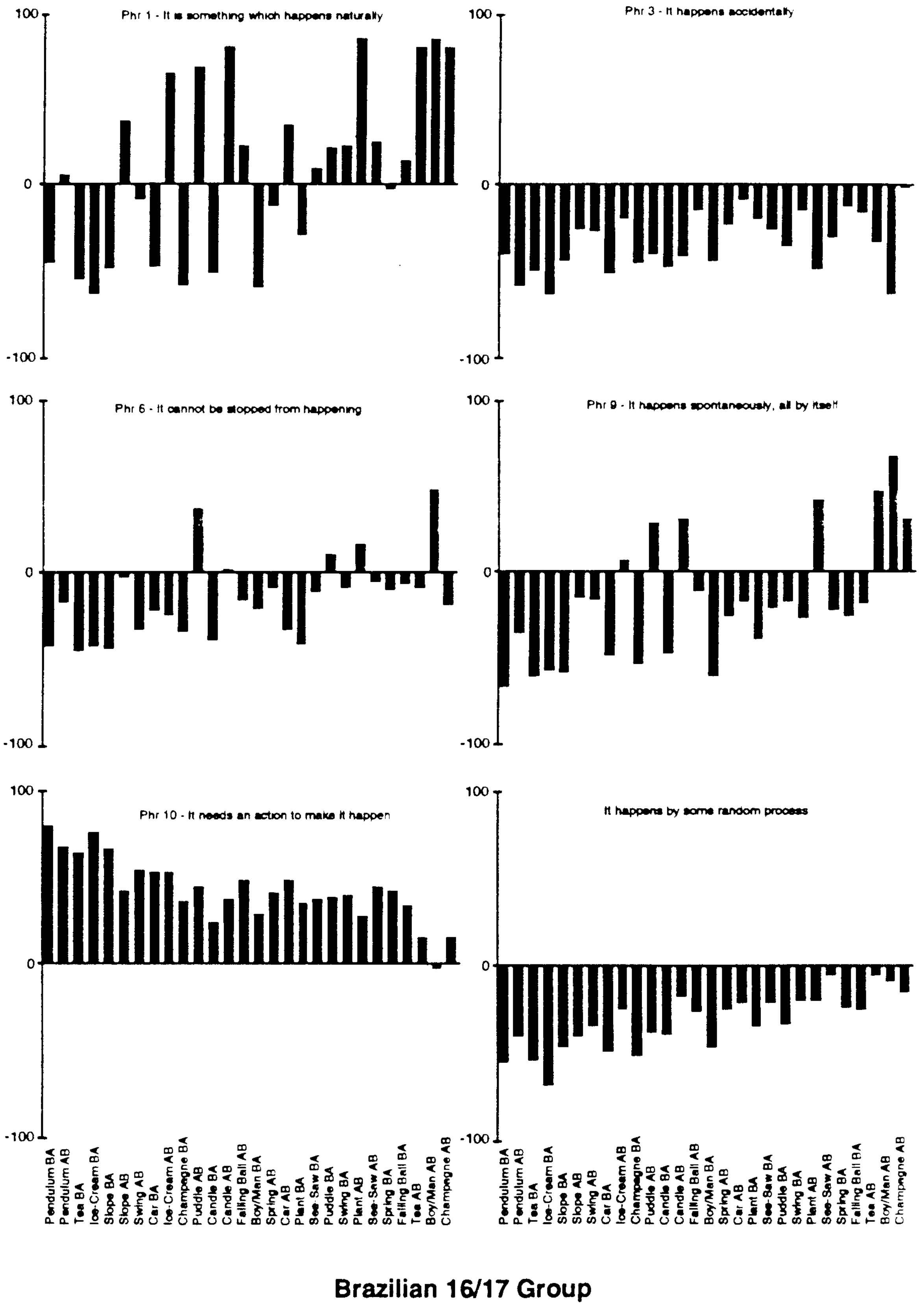


Figure 8.3 - *Frequencies of Replies for phrases with high loadingon Dimension II*

8.3.2.3 Events along the dimension III: Few events are seen as driven by a goal

In the graphs presented in Figure 8.4 the origin represents the 'no goal extremity and the right hand side the 'goal' extremity. In this case there is no clear definition of AB or BA events, unless by some small clusters along this dimension.

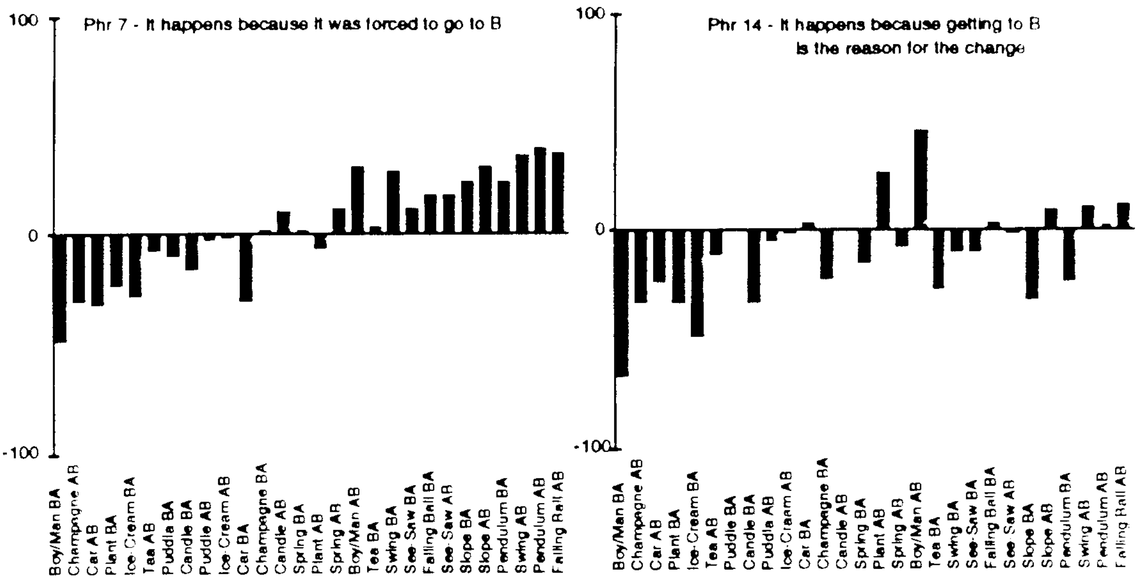
The profile of replies to Phrase 7 - 'forced to go' and Phrase 14 - 'getting there is the reason' are the most significant for this dimension and for all groups, although none of them having high frequencies of replies. For Phrase 7, there is a tendency that starts with some subjects denying it for the leftmost events which is weakened towards the right hand side; in the middle of the chart there is an inversion with some subjects agreeing with it. For the Brazilian 16/17 group, there is a different trend: it starts with the rightmost events (at the goal side) having many subjects agreeing with this phrase; this trend is weakened towards the 'no goal' side with just the very leftmost events having only a few disagreements about it. A similar pattern of replies is given by the Brazilian to Phrase 14.

For the English 13/14, Chilean 13/14, and Chilean 16/17, Phrase 14 has a similar profile of replies to Phrase 7, although the inversion towards the right hand side is less apparent. For the English 16/17, the profile is different: this phrase is evenly denied, with not very high frequencies of replies for all events but Plant AB.

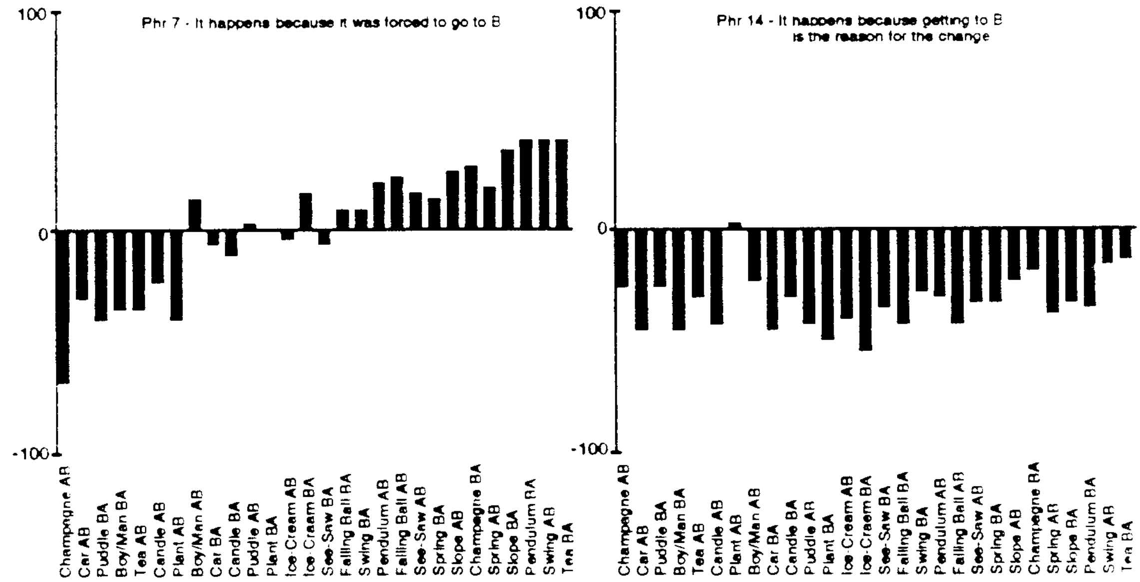
8.3.3 How each group see the events in the Common Factor Space

Although it was possible to find a common underlying way of explaining the events for all groups, the existence of factors common to the five different groups does not mean that each group judges each event in the same way. In fact, it turns out that they do not.

A way of analysing this is to plot the 5 x 28 'events' (treating each event as different for each group) in the factor space, using their factor scores given in Appendix H. Therefore Figures 8.5-8.9 show the events plotted in the common factor space, showing the twenty-eight events independently for each group. Each of Figures 8.5-8.9 selects the twenty-eight events as seen by one group. Superposed, these Figures would show all 'events' as seen by all groups. However, it is important to bear in mind that the positions of the events for each group is relative to the others, since they come from the same factor analysis. For simplicity, the factor space is presented by two two-dimensional projections. Events happening forward (AB events) are represented in the factor space as a (•), and events happening backward (BA events) as a (**x**).

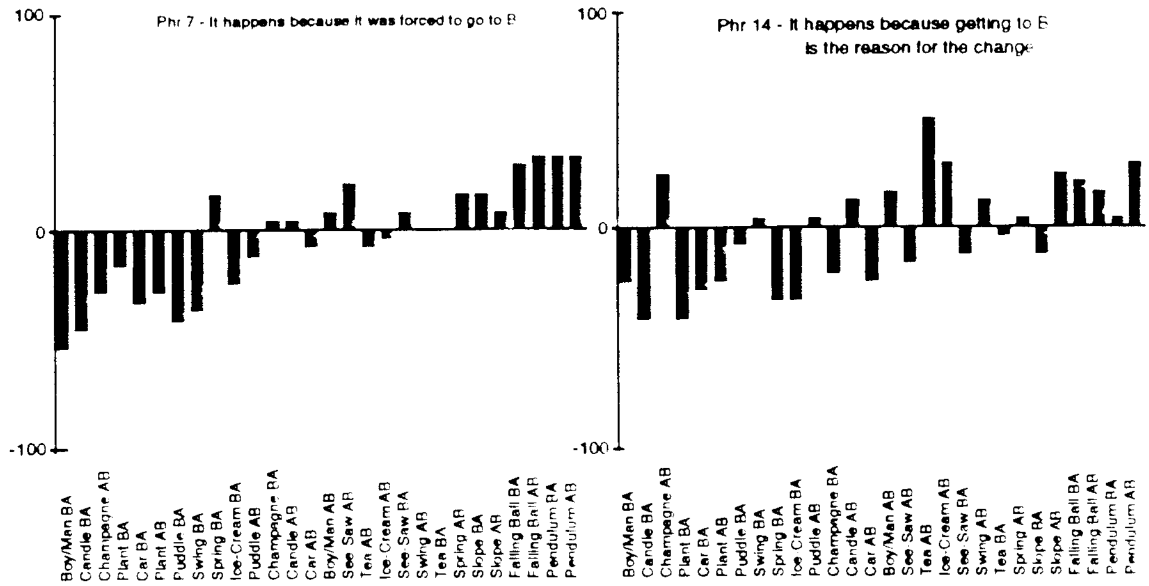


English 13/14 Group

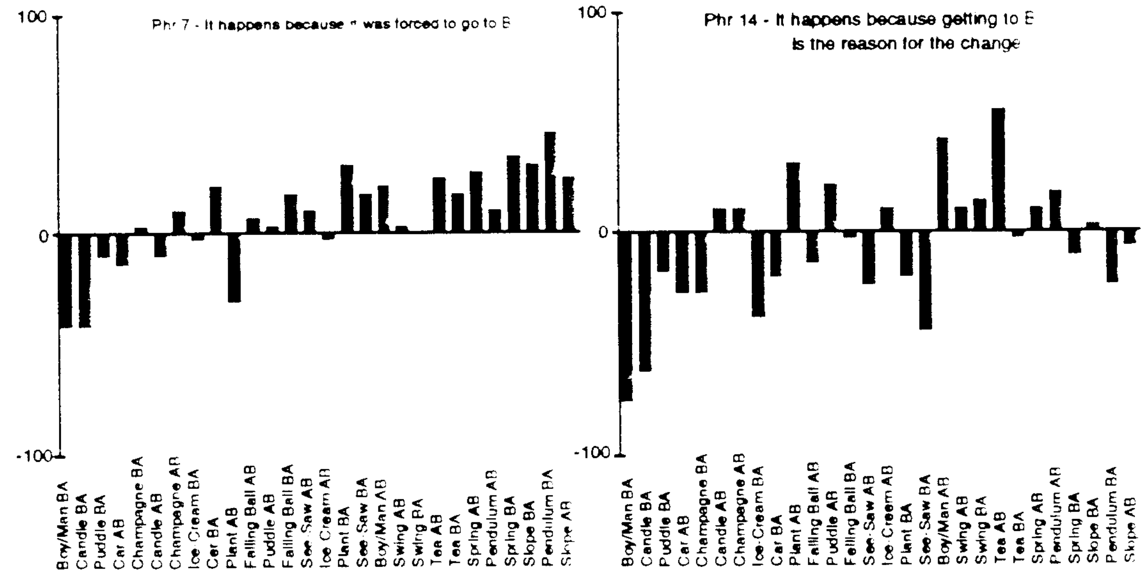


English 16/17 Group

Figure 8.4 - *Frequencies of Replies for phrases with high loadingon Dimension III*
(continued over)

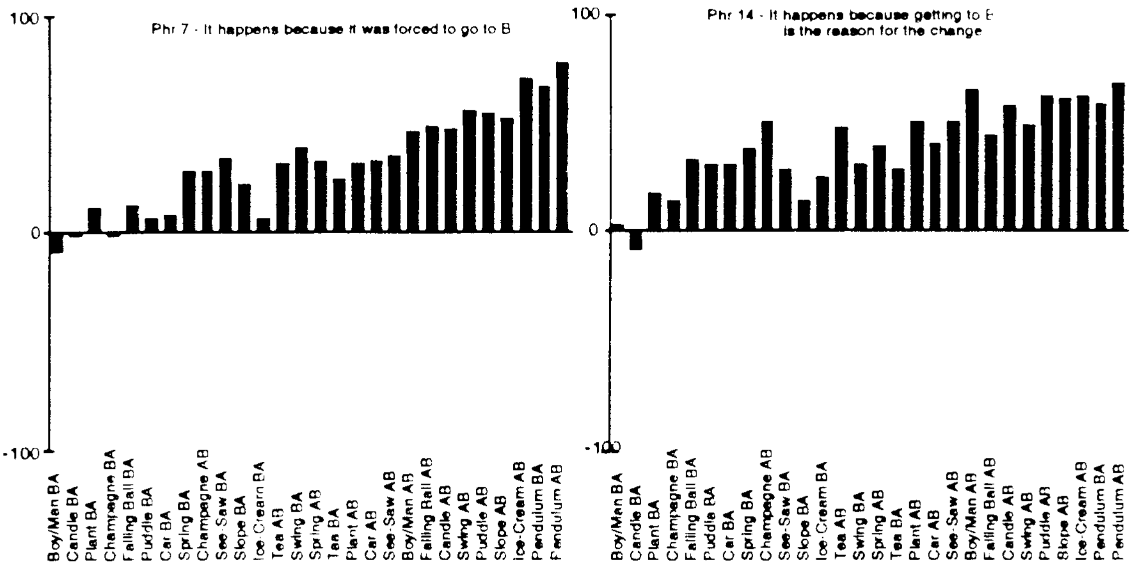


Chilean 13/14 Group



Chilean 16/17 Group

Figure 8.4 - *Frequencies of Replies for phrases with high loading on Dimension III*
(continued over)



Brazilian 16/17 Group

Figure 8.4 - *Frequencies of Replies for phrases with high* **loading** *on Dimension III*

8.3.3.1 English 13/14 year old Group

For the 13/14 year old English Group, all events happening forwards are located at 'happens' side, with most of them placed towards the 'happens by itself' side, although the events Pendulum, Slope, Falling Ball, See-Saw, Spring and Swing are seen as more needing an action (see Figure 8.5).

They are mostly seen as not happening due to a goal, although the events Pendulum, Falling Ball, Swing, Slope and See-Saw are located more towards the goal side. As far as the events happening backwards are concerned, they are equally located in between the 'happens' and 'not happens' end, but located more towards the 'needs an action' extremity, with only the event Puddle located at the 'happens by itself' end. They also have the tendency to lie along a diagonal in the plot of dimension 1 and 3 in the lower part of Figure 8.5. It can be understood as if the events which do not happen, have no goal at all, while the ones which happen, might happen due to a goal.

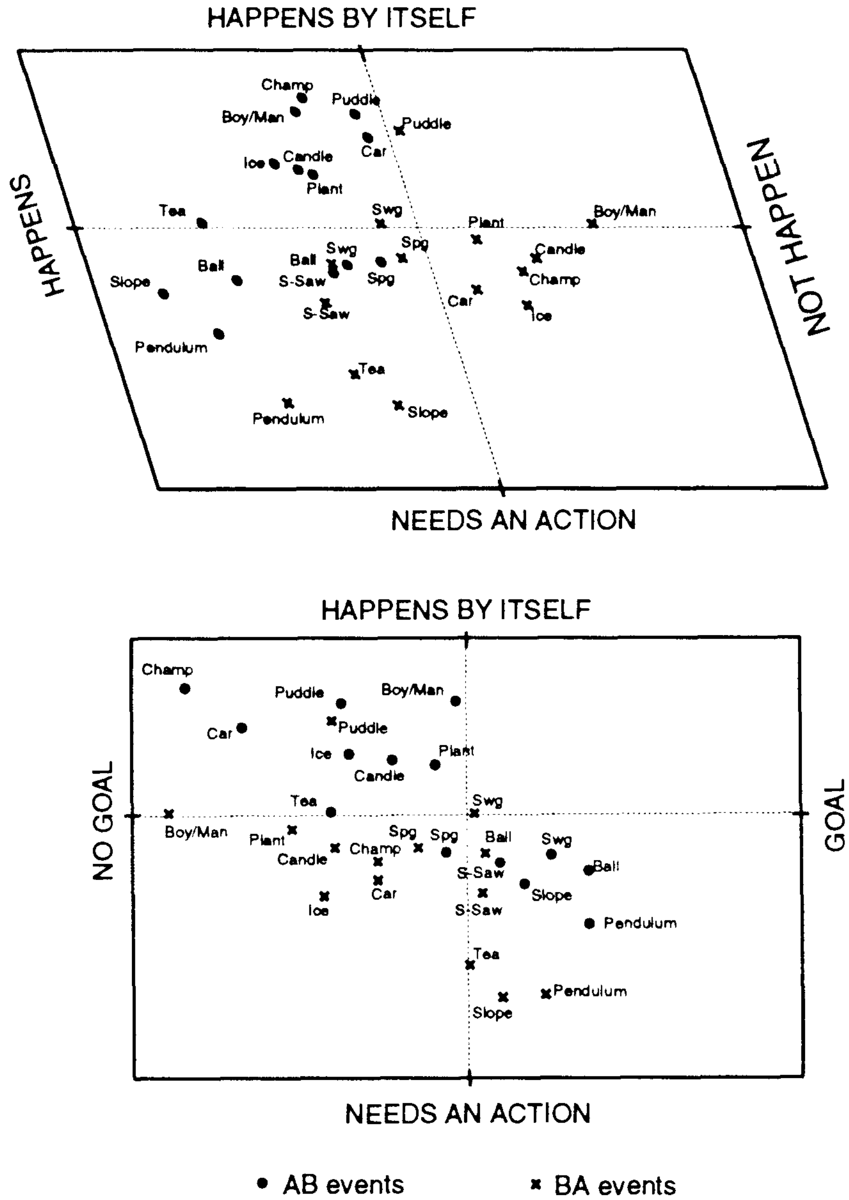


Figure 8.5 - *The events in the common factor space for the English 13/14 group*

8.3.3.2 English 16/17 year old Group

For the 16/17 year old English Group the events have to some extent a similar distribution, although less spread than for the 13/14 English group.

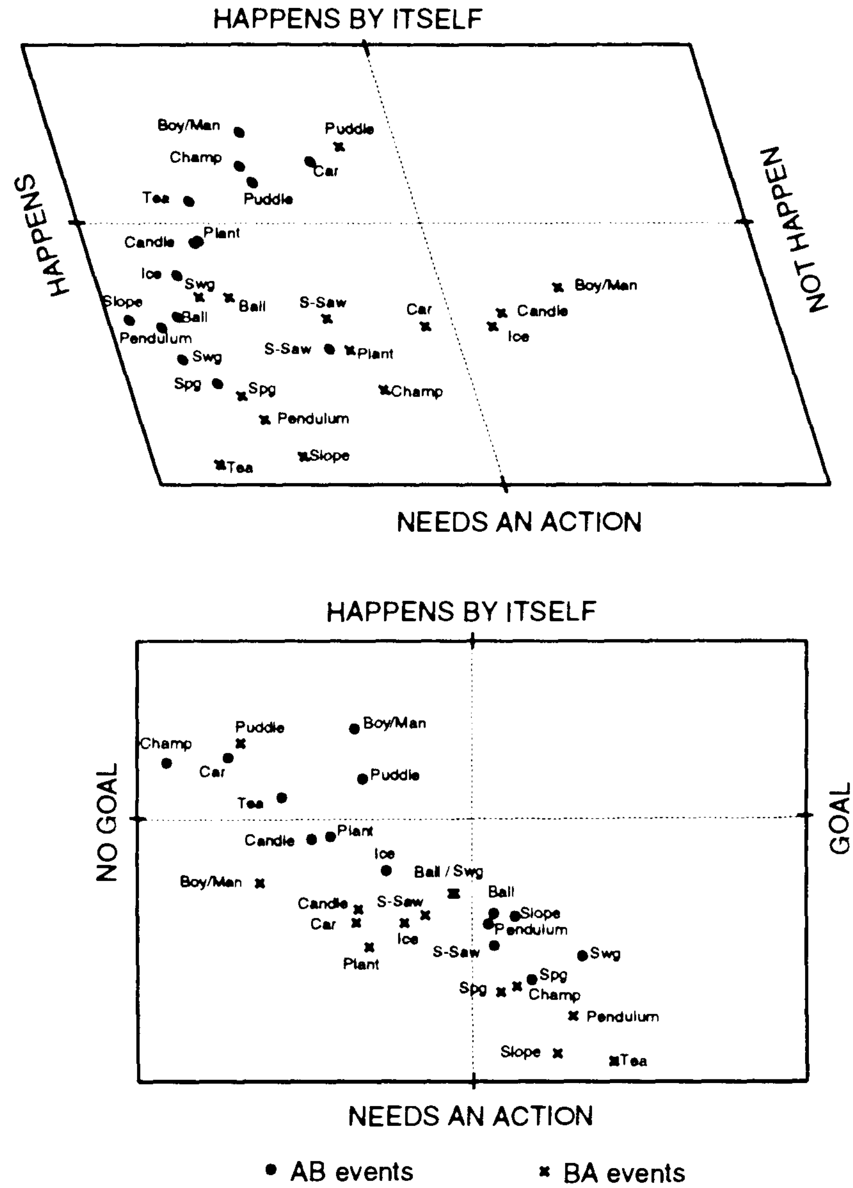


Figure 8.6- *The events in the common factor space for the* English 16/17 group

The AB events tend to be concentrated at the 'happens' extremity, but also towards the 'needs an action' side in opposition to the previous group, although the events Boy/Man, Champagne, Car, Puddle and Tea are seen more as happening by themselves. The AB events also have the tendency to lie along a diagonal in the plot of dimension 2 and 3 in the middle part of Figure 8.6, and the location of the events Spring, Swing, Pendulum, Slope, and Falling Ball in the quadrant 'needs an action' and 'goal' may be interpreted as being seen as happening through an action taken with the goal of making them happening.

The BA events are mostly located towards the 'happens' and 'needs an action' side, with only the event Puddle placed at the 'happens by itself' end, while the events Boy/Man, Candle, Ice-Cream, and Car are seen as less likely to happen than the others. Regarding the third dimension, the events are placed towards the 'no goal' side although the events Tea, Slope, Pendulum, Champagne, and Spring are seen as more goal-oriented.

8.3.3.3 Chilean 13/14 year old Group

For the 13/14 year old Chilean Group, the AB events are mostly concentrated on the quadrant defined by the 'happens' and 'happens by itself' extremities, although the event Pendulum is seen as more needing an action.

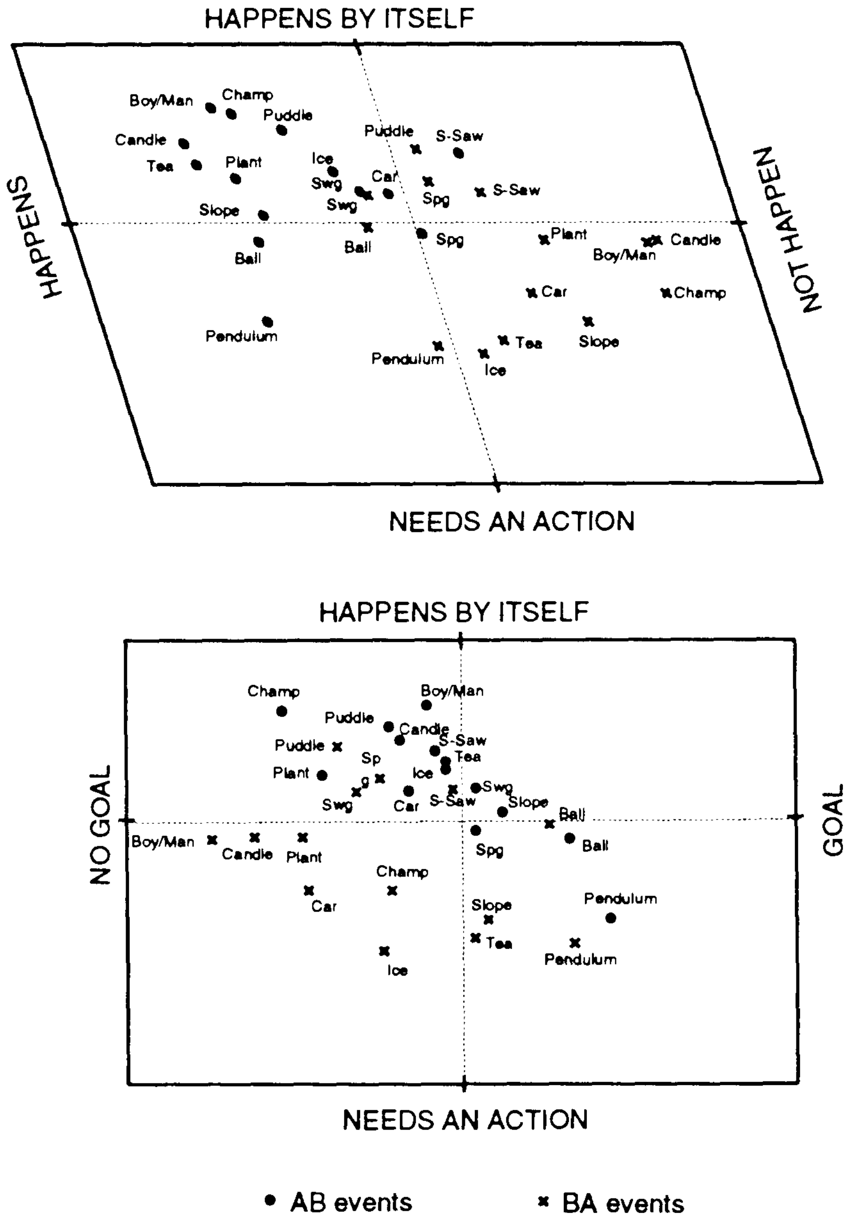


Figure 8.7 - *The events in the common factor space for the Chilean 13/14 group*

There is little discrimination in relation to the third dimension, except by few a events such as Champagne, Plant located towards the 'no goal' side, and Pendulum and Falling Ball towards the 'goal' end (Figure 8.7). The BA events are mostly concentrated on the quadrant defined by 'not happens' and 'needs an action', with a slight trend towards the 'no goal' side, excepting for the event Pendulum seen as more with a goal. This can be interpreted as if these events are usually seen as not happening, unless an action is taken, and yet, in the case of Pendulum this action is goal-oriented.

8.3.3.4 Chilean 16/17 year old Group

Events for the 16/17 year old Chilean group lie somewhat similarly to the 13/14 year old Chilean group in the common space, but the AB events have less discrimination on the 'goal' dimension (Figure 8.8).

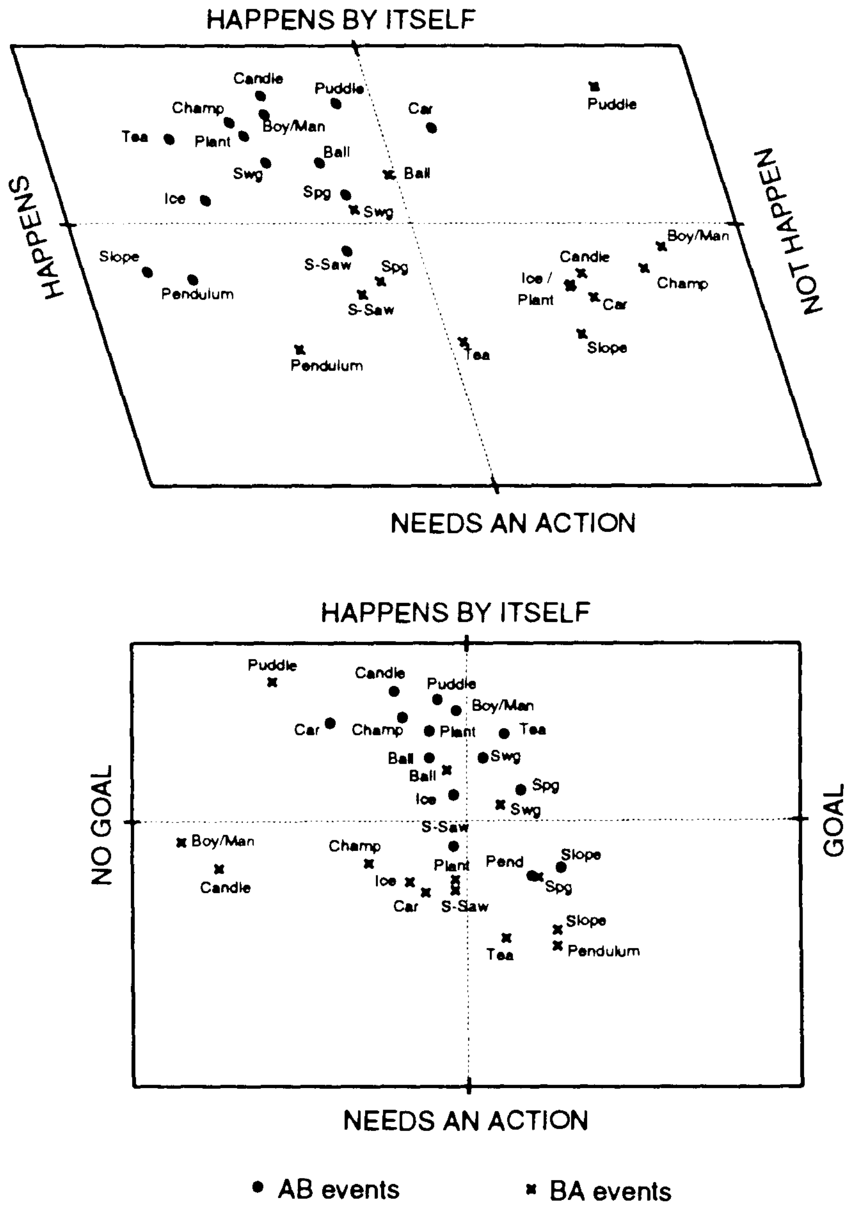


Figure 8.8 - *The events in the common factor space for the* Chilean 16/17 group

Particularly, the event Puddle happening backwards is placed at the very high end of 'happens by itself' and 'not happens' which may be seen as an anomaly. However, it may be that this event is seen as unlikely to happen, but if it happens, it will happen by itself.

8.3.3.5 Brazilian 16/17 year old Group

The 16/17 year old Brazilian Group has the distribution of events most unlike those of the others (Figure 8.9). Most AB events are located towards the 'happens by itself' side, and are concentrated in the middle of the dimension 'happens- not happens', excepting for just a few events - Spring, See-Saw, Car, Falling Ball, and Swing - seen as less likely to happen. They are also concentrated towards the GOAL side. The event Pendulum is a case considered as needing an action, which is goal-oriented.

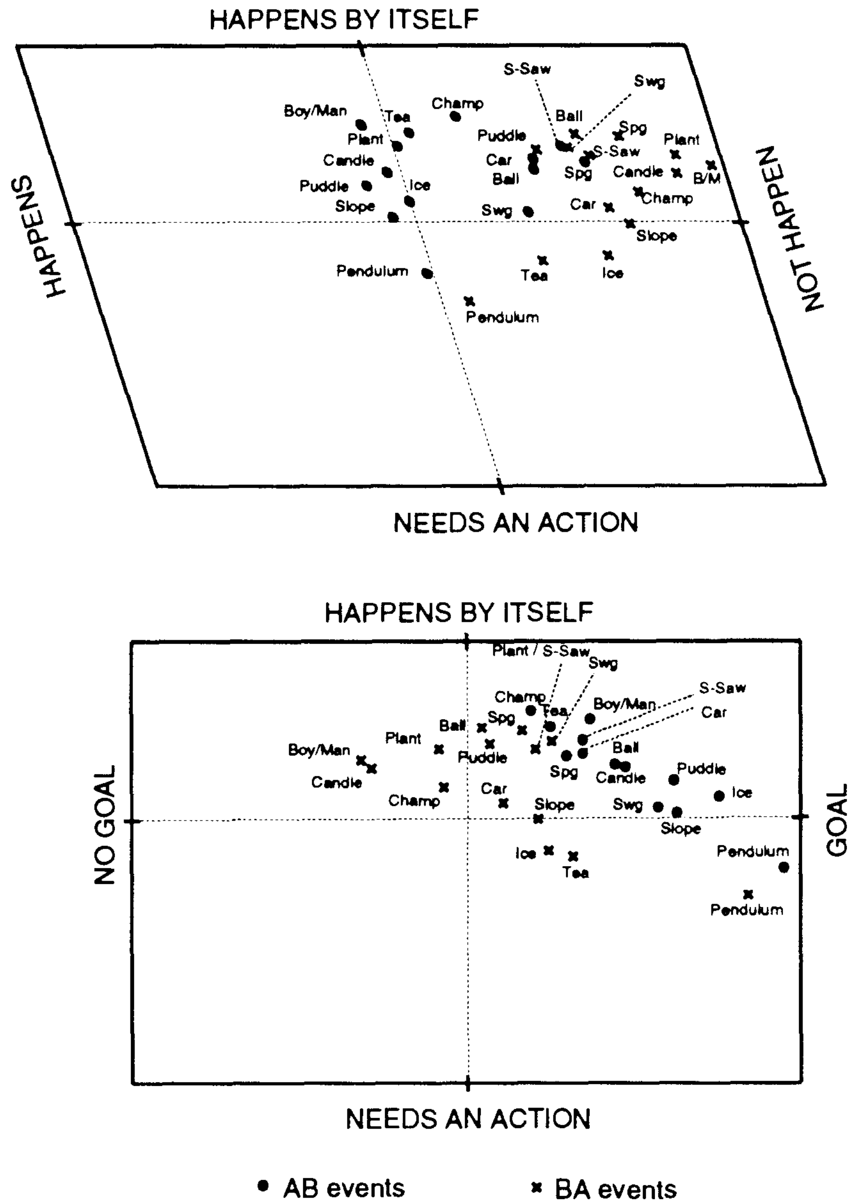


Figure 8.9 - *The events in the common factor space for the Brazilian 16/17 group*

Most BA events are located on the quadrant defined by 'not happen' and 'happens by itself' extremities, with significant concentration around the NOT HAPPEN side. They are mostly located halfway through the 'goal' and 'no goal' extremities, excepting the event Pendulum which is seen as highly goal-oriented.

Although the Brazilians has the tendency to place most events towards the quadrant defined by 'not happen' and 'happens by itself' extremities, it is important to remember that the placing of the events by each group in the common factor space is relative to the others since this result comes from the factor analysis of groups combined. The absolute information of each group is only given by the frequencies of 'yes' responses.

8.4 Summary of Factor Space

Looking now at the common factor space shown in Figures 8.1 and its interpretation, the location of the events by each group shown in Figures 8.2-8.6 and the overall description of the dimensions presented in section 8.3.2, we can summarise as follows.

8.4.1 Summary of the Interpretation of the Factor Solution for the Groups Combined

The factor analysis by groups independently, which allows the underlying structure for each group to emerge, showed that there were similarities at the level of the interpretation of factors among all groups, as summarised in Table 8.1. Therefore, a factor analysis for all groups combined was carried out to see whether a common factor structure could be found. It turned out that there was and that the common underlying way of explaining the event for all groups can be described in terms of a non-orthogonal three dimensional space.

In this space, the first and strongest dimension is related to the possibility or impossibility of an event happening, labelled with the opposition between HAPPENS vs. NOT HAPPEN.

The second dimension, positively correlated to the first, relates to the necessity or not of an action to be taken to make an event happen, thus, the two opposite sides were labelled as NEEDS AN ACTION vs. HAPPENS BY ITSELF.

The last and less strong dimension is connected with the idea that an event happens due to a goal or law, or is made to happen to fulfil a purpose, so named as GOAL vs. NO GOAL. Therefore an interpretation of these dimensions is:

HAPPENS vs. NOT HAPPEN
HAPPENS BY ITSELF vs. NEEDS AN ACTION TO HAPPEN
HAPPENS DUE TO A GOAL vs. HAPPENS WITH NO GOAL.

The analysis of the frequencies of replies to phrases with high loadings on each dimension suggested that the first dimension could also be labelled as 'happens vs. less likely to happen'.

Despite the common factor structure, groups judge events differently regarding these common underlying dimensions. These peculiarities are summarised in the following section.

8.4.2 Summary of the Results concerning each Group

An overall description of the location of the events in the factor space by the groups is that:

• 1 The English 13/14 and 16/17 groups are more positive towards the possibility of both forward and reverse events happening: they are all mainly considered as likely to happen, with just a few events happening backwards seen as less likely to happen, such as Boy/Man, Candle, Ice-Cream;

• 2 The Chilean 13/14 and 16/17 groups make a little more differentiation between the forward and backward events: the AB events are more concentrated towards the 'happens' extremity while the BA events towards the 'not happen' side, with the events such as Boy/Man, Candle, Champagne being considered as less likely to happen;

• 3 The Brazilian 16/17 group concentrates most events in the quadrant 'happens by itself' and 'not happen', but with most AB events concentrated more towards the 'happens' side, most BA events concentrated at the 'not happen' extremity, while the events Car, Falling Ball, See-Saw, Spring, and Swing happening forward as well as backwards are placed close together in the middle of this quadrant. They also consider events as more goal oriented In contrast with the English groups, the Brazilian group seems less positive or more sceptical about the possibility of any event happening.

8.4.3 Summary of the Results concerning the Description of Events

In relation to the way the events are described we see the following tendencies:

- 1 Most events are seen by all groups as able to happen, with some BA events being considered as less likely to happen;

- 2 Many events are seen by all groups as needing an action to happen, particularly but not exclusively the BA events;

- 3 Most events are seen by all groups as not happening accidentally or randomly;

- 4 A few events are seen as driven by a goal.

These two kinds of results can explain the different distribution of events in the factor space given by each group. The factor space reflects the trends in the frequencies of replies plots, but not the absolute values. As this analysis is based upon the factor analysis of groups combined, the factor space reflects the trends relative to one another.

Thus, the constant and high negative profile of replies to phrases with high loading on the first dimension, for most events given by the English 13/14 and 16/17 groups pulls them more towards the quadrant defined by the 'happens' and 'needs an action' extremity.

For the Chilean 13/14 and 16/17 groups, the less negative profile of replies to phrases which define the first dimension for the events located at the 'happens' side and the low negative profile of replies for the events at the 'not happen' extremity bring the events to be more distributed in the middle of the factor space.

Finally, the moderate low profile of replies to phrases with high loading on the first dimension, for most events (and even lower for events around the extremity 'not happen') given by the Brazilian 16/17 group, pulls their distribution towards the quadrant "happens by itself' and 'not happens'.

9

Main Study - The Events: How They are Described

A common factor space for the five different groups was described in Chapter 8. This does not mean that each group judged each event in the same way. And as described there, the distribution of events varied to some extent between each group.

In order to describe the way students explain events happening forward and backwards, given the common factor space, it is now necessary to describe differences in the way that each group located each event in the factor space.

While looking at the location of each event in the common space, the answers to the open-ended questions related to actions and causes and the frequencies of replies to each phrase of the question in the form of a grid are also considered in order to bring together these two kinds of data to compare what they say.

Cluster analysis is not included in this procedure. In the pilot study it was used to seek clusters among the events in the factor space using their factor scores for just one group of students. However, in the main study the data are from 5 different groups which were put together but treating the responses of each group to each event in the two questionnaires as different, this summing up 5 (groups) x 28 (events) 'events'. This means that each event is presented 5 times and the cluster analysis would be mixing differences between events with differences between groups.

9.1 The Procedure of Analysis

The description of each event involves three sources of information as above, namely the location of events in the factor space, the frequencies of replies of 'yes' responses to phrases, and the open-ended answers to questions about the events. The aim is to relate these for each events.

9.1.1 Analysis of the Action/Cause Questions

Following the procedure used in the pilot study, the analysis of the extended questions related to actions and causes was initially based on the systemic network described in Chapter 6 (Figure 6.1). However in looking through the responses to all events of each group it was possible to improve it and a improved network was produced as shown in Figure 9.1.

As the previous network, the new one represents a way of explaining an event in terms of the notions of action and cause, according to students' view. However, the new network is more comprehensive in that the notions of action and cause are considered with more details. It can be described starting from the leftmost term, which gives the main outlines, down through increasing levels of delicacy to the right hand terminals, which are closer to what is in the data (Bliss, Monk & Ogborn, 1983).

The network represents students as making a choice whether the process (change) is able to happen or not, which is portrayed through the first BAR: possible (**P**) or not possible (**X**).

Taking the first option, if the process is seen as possible to happen, it has two attributes considered in the first BRA. The first, represented by the HOW top second BAR, is concerned with *action* and explains how the event happens, whether through an intervention (which is a subject's intervention, represented by the capital letter **A**) or a non-intervention (natural, represented by **N**). The second attribute, represented by the WHY bottom second BAR, is related to *causes* and explains why the event happens, whether this explanation is just in terms of a description of either the action taken or what would happen, or a causal explanation.

The second option in the first BAR is when the process is seen as not possible. In this case, either it is explicitly declared that the process is impossible (**I**), or although impossible, students give either some imaginative solution (**Im**) or answers where the object is substituted by a new one (**R**), which are like (**A**) answers.

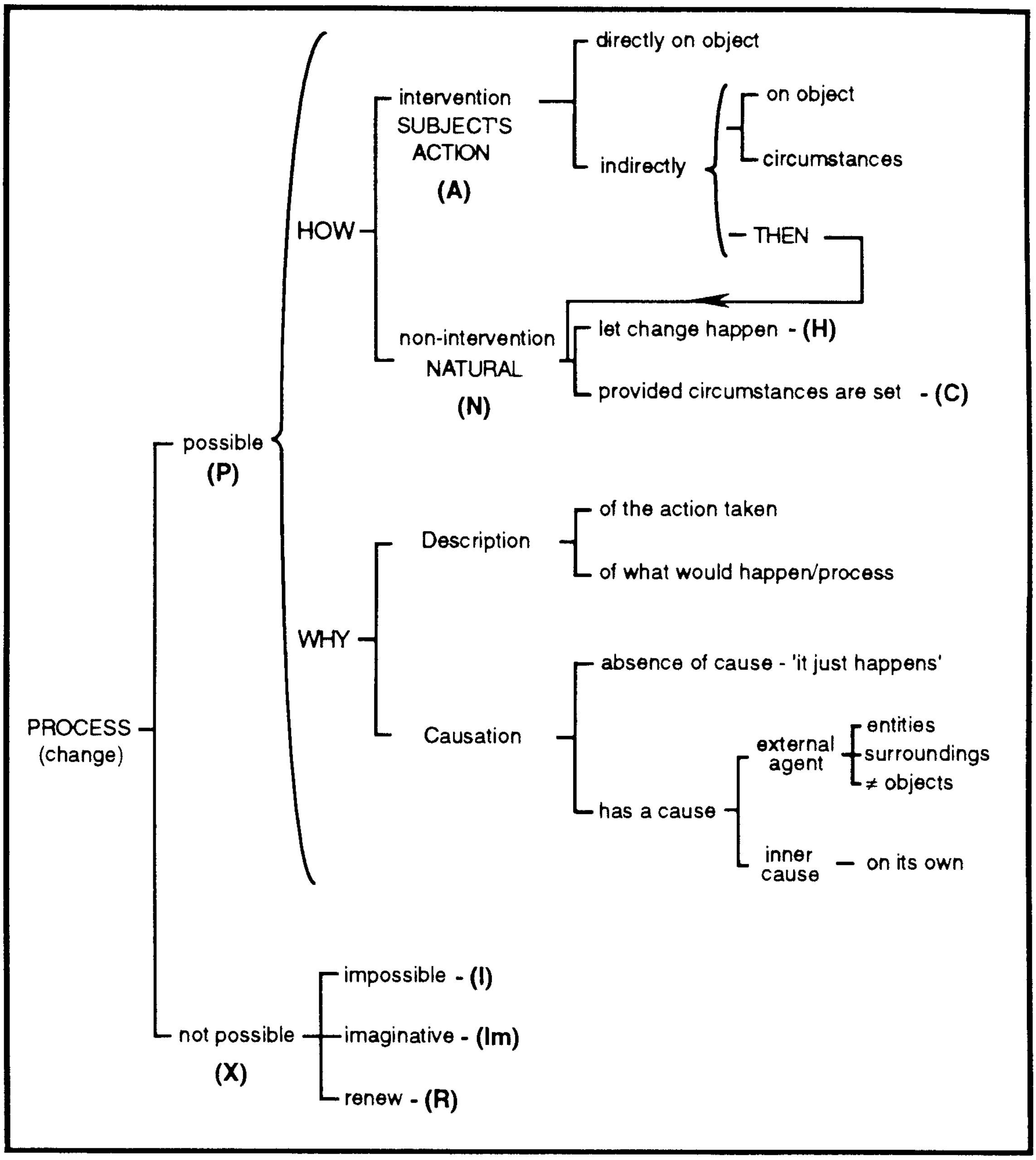


Figure 9.1 - *The network for analysing the action/cause responses*

9.1.2 The Plot of Events

Each of the fourteen events is plotted in the factor space for all groups in turn, taking both forward - AB - and backward - BA - events together so as to contrast them and to be able to analyse their reversibility as understood by subjects.

For this analysis, the factor space is represented by the projection of two planes, which are two-dimensional projections of the non-orthogonal three dimensional space: the angled plane is a plot with the first dimension on the horizontal axis and the second dimension on the vertical axis, while the orthogonal plane is the plot of the second dimension on the vertical axis and the third dimension on the horizontal axis. The first plot is represented by an angled plane because factor I is correlated to factor II. In these plots the events happening forwards are represented by the dot symbol (•), while the cross symbol (x) represents the event happening backwards. To aid visual recognition, points for English students are labelled with *italic underlined* type - English 13/14 - *E13/14* and English 16/17 - *E16/17* -, those for Brazilians with underlined type - Brazilian 16/17 - B16/17, and for Chileans with normal type - Chilean 13/14 - C13/14 and Chilean 16/17 - C16/17.

9.1.3 Frequencies of Replies to the Phrases of Question 2

The frequency of replies to each phrase on each event of each group is plotted to help the description of the interpretation of each event. The frequencies of replies for each phenomenon happening forwards (AB) and backwards (BA) and for all groups are presented together in the same chart. The frequencies of replies are represented on the vertical axis and show the agreement - positive numbers - or disagreement - negative numbers - with each phrase, which are represented in the horizontal axis with their description on the bottom of each chart. Zero means an equal number of 'yes' and 'no' responses. If a fraction *f* of students respond 'yes', the value plotted is 100 (f - [1 - f]).

9.2 Description of Events

For each event, a description is given based upon the way it is seen happening forwards, backwards, and how reversibility is understood for that event. The events numbered from 1 to 7 belong to Questionnaire 1 and those numbered from 8 to 14 belong to Questionnaire 2.

9.2.1 PENDULUM - 'a pendulum stops swinging'

9.2.1.1 Forwards

On average, two thirds of the English 13/14, English 16/17, and Chilean 16/17 students saw this event as happening with no subject's intervention (**NH**). The typical answer was 'leave the pendulum to stop', with causes being related to external agents - entities - such as 'gravity', 'friction', or different objects such as 'air molecules'. The other third answered that a direct action on the object would have to be taken (**A**), 'use your hand to stop it', with cause being either a description of the action taken, 'the force of your hand', or a description of what would happen, 'the motion is stopped'. For the two other groups of students, Chilean 13/14 and Brazilian 16/17, most of the answers were in terms of a subjects' direct action on the object (A), as for the other groups; the remainder were in terms of a non intervention.

In the factor space (Figure 9.2) for all groups, this event is located in the quadrant 'happens' and 'needs an action', and in the quadrant 'goal' and 'needs an action'. Thus, they all consider that it happens, mainly due to an action and to a certain extent due to a goal. Although the positions in the plot are broadly similar, the Chilean 13/14 and the Brazilian 16/17 groups place both forward and reverse events as less likely to happen than do the others, and more with a goal. It is these groups who give answers above in terms of a subject's intervention.

Although basically considered as happening with no subject's intervention, this does not mean that there is no action involved in this process. It is seen as happening naturally due to an external agent associated with entities such as 'gravity', 'molecules'. Figure 9.3 shows the frequencies of replies to phrases and reveals that Phrase 1 - 'It is something which happens naturally', has a frequency of replies as important as the frequencies of replies to Phrase 7 - 'It happens because it was forced to go to B', and Phrase 10 - 'It needs an action to make it happen', which means that it is seen as happening naturally due to an external action, not taken by the subject.

The strong goal-like feature for the Brazilian 16/17 group is explained by the pattern of frequencies of replies to Phrase 7 - 'It happens because it was forced to go to B', Phrase 13 - 'There is a law which makes it happen', and Phrase 14 - 'It happens because getting to B is the reason for the change'.

9.2.1.2 Backwards

All answers of all groups were in terms of a subject's action on the object (A), such as 'push the pendulum', with causes being either a description of the action itself - 'the applied force' - or a description of what would happen - 'giving energy to it'.

The plot of this event (Figure 9.2) shows that it has a similar location as for the AB situation, therefore being considered as possible to happen, due to an action, and with certain degree of goal. As already pointed out, the Chilean 13/14 and Brazilian 16/17 students consider it less likely to happen than do the English 13/14, English 16/17 and Chilean 16/17.

The frequencies of replies to each phrase for each group for this event (Figure 9.3) shows a persistent pattern of frequencies of replies to Phrase 7 - 'It happens because it was forced to go to A', and Phrase 10 - 'It needs an action to make it happen', for all groups. This pattern of answers added to the high positive frequencies of replies to Phrase 13 - 'There is a law which makes it happen', and Phrase 14 - 'It happens because getting to A is the reason for the change', given by the Brazilian 16/17 group to explain its detached goal-like position.

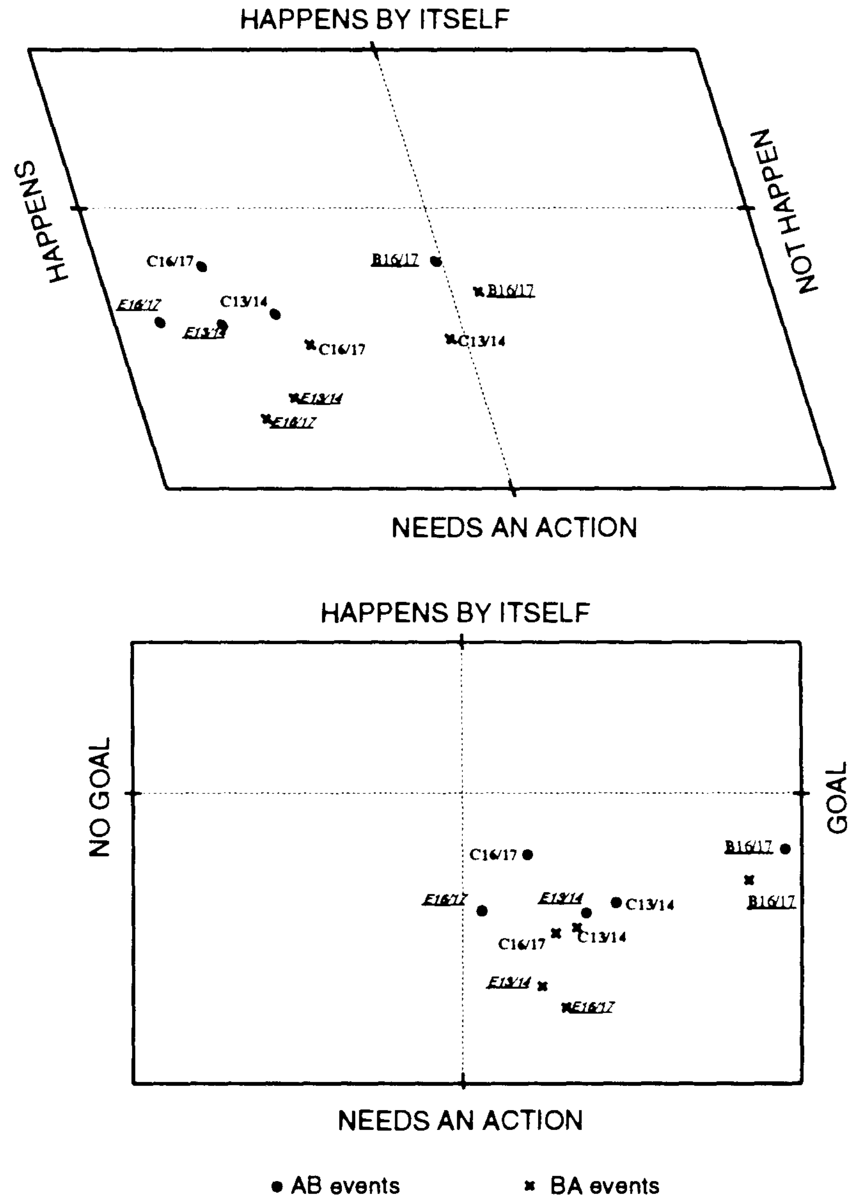


Figure 9.2 - *Plot of the events Pendulum AB (•) and Pendulum BA (x) in the common factor space*

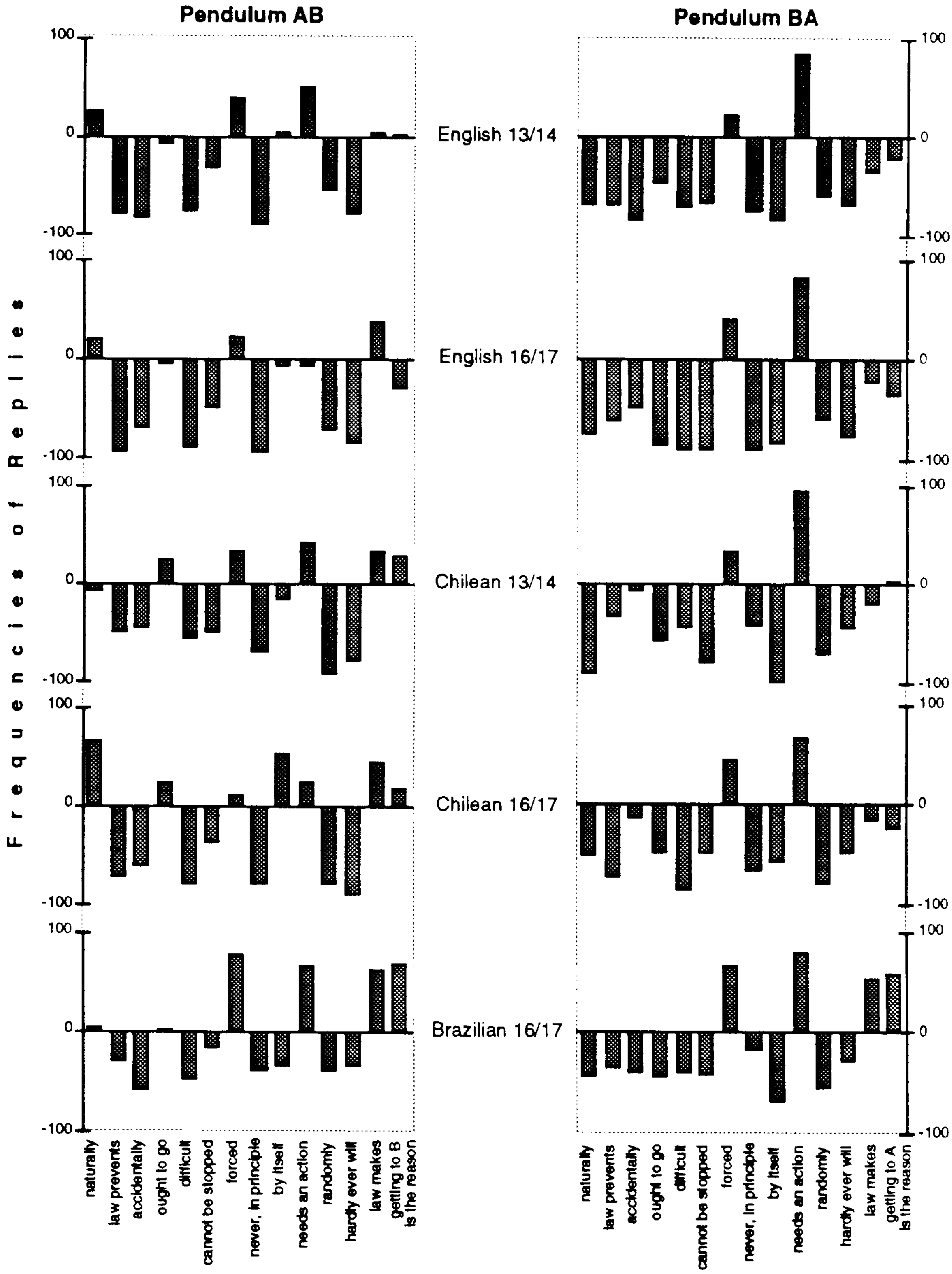


Figure 9.3 - *Frequencies of replies to each phrase for each group for the events Pendulum AB and Pendulum BA*

9.2.1.3 Reversibility

This is basically seen as a natural process happening due to an external agent associated with entities such as 'gravity'; sometimes the action is seen as taken by the subject. It is reversed through a subject's action. The importance of the role played by action in this process can be observed by the location of the AB as well as the BA events in the quadrant 'happens' and 'needs an action'.

9.2.2 ICE-CREAM - 'an ice-cream melts'

9.2.2.1 Forwards

All answers of all groups were about a natural process focusing on circumstances (NC). Most of the answers considered the circumstances as already existing, such as 'leave it in a warm place', and the remainder were answers setting the circumstances, such as 'apply heat', 'heat it'. Causes in this case were mostly related to entities such as 'heat', 'thermal energy', 'temperature'; there were some related to the surroundings - 'it is a hot day', 'it is not cold enough' - and some which were a description of what would happen -'the ice-cream melts'.

The plot of this event in the factor space (Figure 9.4) shows that it is mainly located between the extremities 'happens' and 'happens by itself' for all groups, and mainly towards the 'no goal' dimension, excepting for the Brazilian 16/17 students who see it as highly goal-oriented. Thus it is generally considered as happening naturally with no subject's intervention at all.

Similarly to the event Pendulum, the frequencies of replies to phrases for this case (Figure 9.5) reveals that although this event is considered as happening naturally, action seems to play an implicit important role. This is shown by the high positive frequency of replies to Phrase 1 - 'naturally' for all groups, the important frequency of replies to Phrase 9 - 'spontaneously, all by itself' for most of them, with nearly no positive replies to Phrase 7 - 'forced to go to B', and Phrase 10 - 'needs an action'. In this case, action seems to be associated with an external agent related to entities such as 'heat', 'temperature'.

The exception is for the Brazilian 16/17 group where these two last phrases have a high frequency of replies, but together with the high positive frequency of replies to Phrase 13 - 'There is a law which makes it happen', and Phrase 14 - 'It happens because getting to B is the reason for the change', explain their goal-like feature.

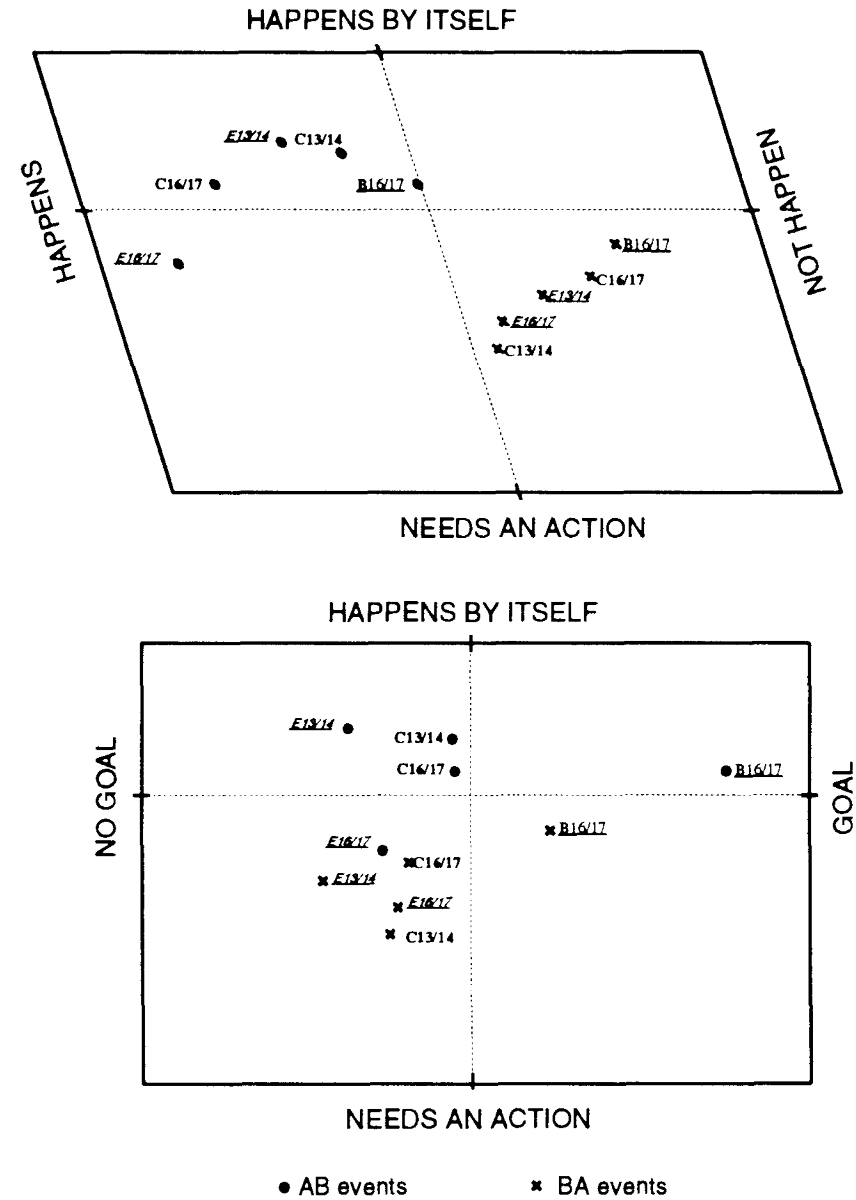


Figure 9.4 - *Plot of the events Ice-Cream AB (•) and Ice-Cream BA (x) in the common factor space*

9.2.2.2 Backwards

Nearly all answers for all groups were concerned with a series of actions on the object (**A**) to restore the initial state, such as 'collect it, freeze it, scoop it and put it back on the cone', with causes being mainly a description of what would happen, e.g. 'the ice-cream freezing', with some being a description of the action, e.g. 'human action'. There were just a few related to the impossibility of it happening, either stating that it would not be possible, or giving a renew-like answer (**R**), such as 'buying some ice-cream'.

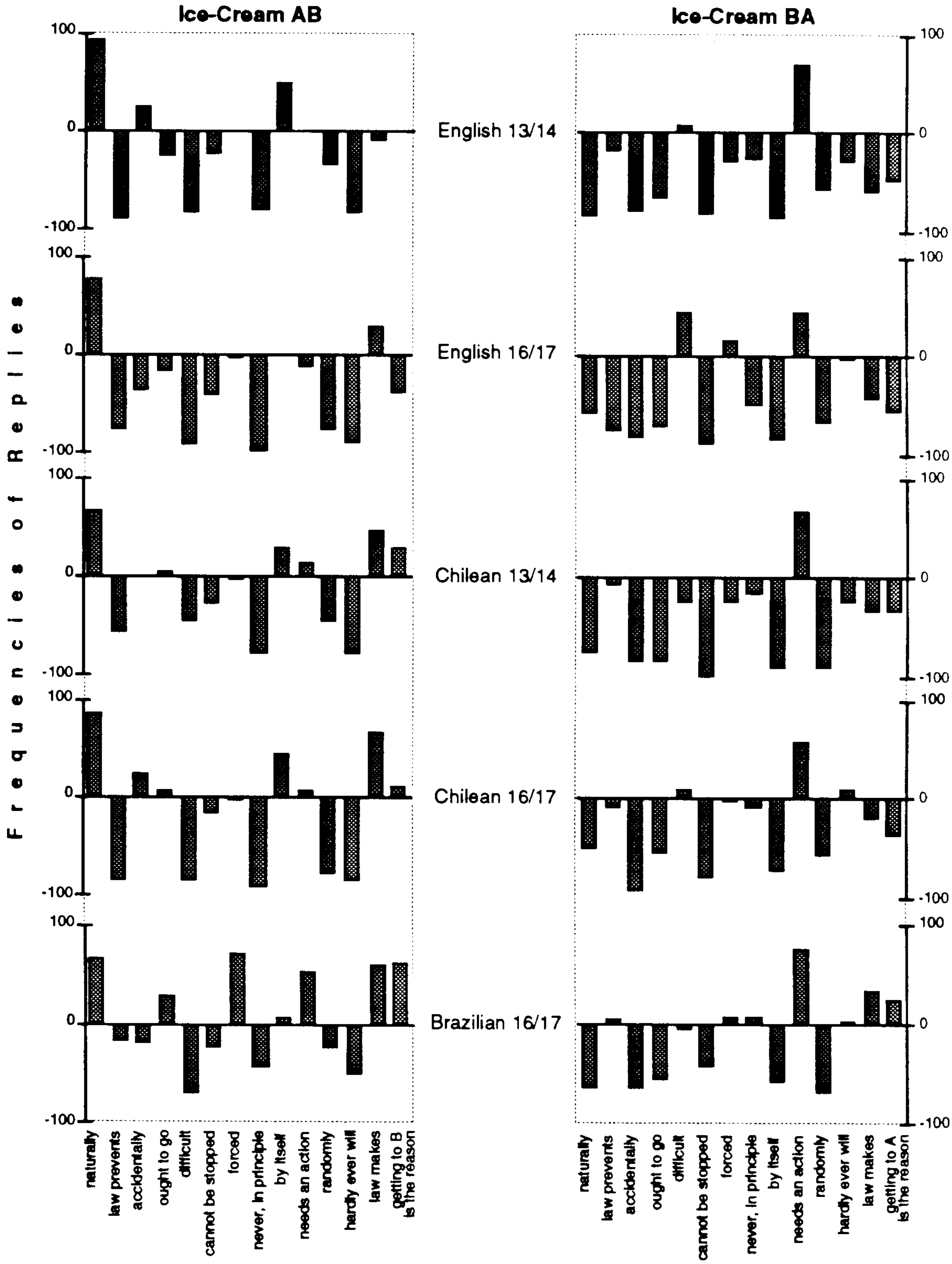


Figure 9.5 - *Frequencies of replies to each phrase for each group for the events Ice-Cream AB and Ice-Cream BA*

In the factor space (Figure 9.4) it is located between the extremities 'not happens' and 'needs an action', with not much discrimination in the goal dimension, although the Brazilian 16/17 group sees it as less likely to happen and more goal-oriented than do the others. It seems to be considered possible to happen provided that an action is taken.

Figure 9.5 shows that the location towards the 'not happen' extremity can be explained by the relative low profile of negative frequencies of replies to Phrase 2 - 'There is a law which prevents it happening', Phrase 8 - 'It could never happen in principle', Phrase 12 - 'It could happen but hardly ever will', and the approximately nil sometimes positive frequency of replies to Phrase 5 - 'It is possible, but difficult to do in practice'. This pattern of responses, which to an certain extent expresses an agreement with these phrases can be understood as expressing the unlikeness of this event to happen, unless an action is taken.

9.2.2.3 Reversibility

This is a natural process, reversible with difficulty, through an action taken by the subject. The naturalness of this process can be discerned from the location of the AB events in the quadrant 'happens-happens by itself' in opposition to the difficulty of reversing it, discerned from location of the BA events in the opposite quadrant 'not happens-needs an action'.

9.2.3 PUDDLE - 'water in a puddle evaporates'

9.2.3.1 Forwards

All answers of the Chilean 13/14, Chilean 16/17, and Brazilian 16/17 students were about a natural process, involving no subject's intervention (NH), such as 'leave it', 'wait', 'the water evaporates', with causes being associated with different reasons. On average, two thirds of the causes were related to entities such as 'heat', 'temperature', 'energy', 'kinetic energy'; the remainder were equally related to either a different object, 'the sun', or the surroundings, 'hot weather', with just a few referring to no cause at all, 'it happens naturally'. The English 13/14 and English 16/17 groups gave similar answers, excepting just a few focusing on circumstances to be set, such as 'heat it', with causes being a description of what would happen.

In the factor space (Figure 9.6), this event is located in the quadrant 'happens' and 'happens by itself' for all groups, and in the quadrant 'no goal' and 'happens by itself', excepting for the Brazilian 16/17 students who see it as goal-oriented. It means that this event is considered as happening naturally with no subject's intervention.

Figure 9.7 shows a high positive frequency of replies to Phrase 1 - 'naturally', and a significant positive frequency of replies to Phrase 9 - 'spontaneously, all by itself', and Phrase 6 - 'It cannot be stopped from happening', for all groups. Thus it is seen as something that unavoidably happens but which is unpredictable, i.e., it is not possible to say when it happens. Yet, it happens naturally with no subject' intervention.

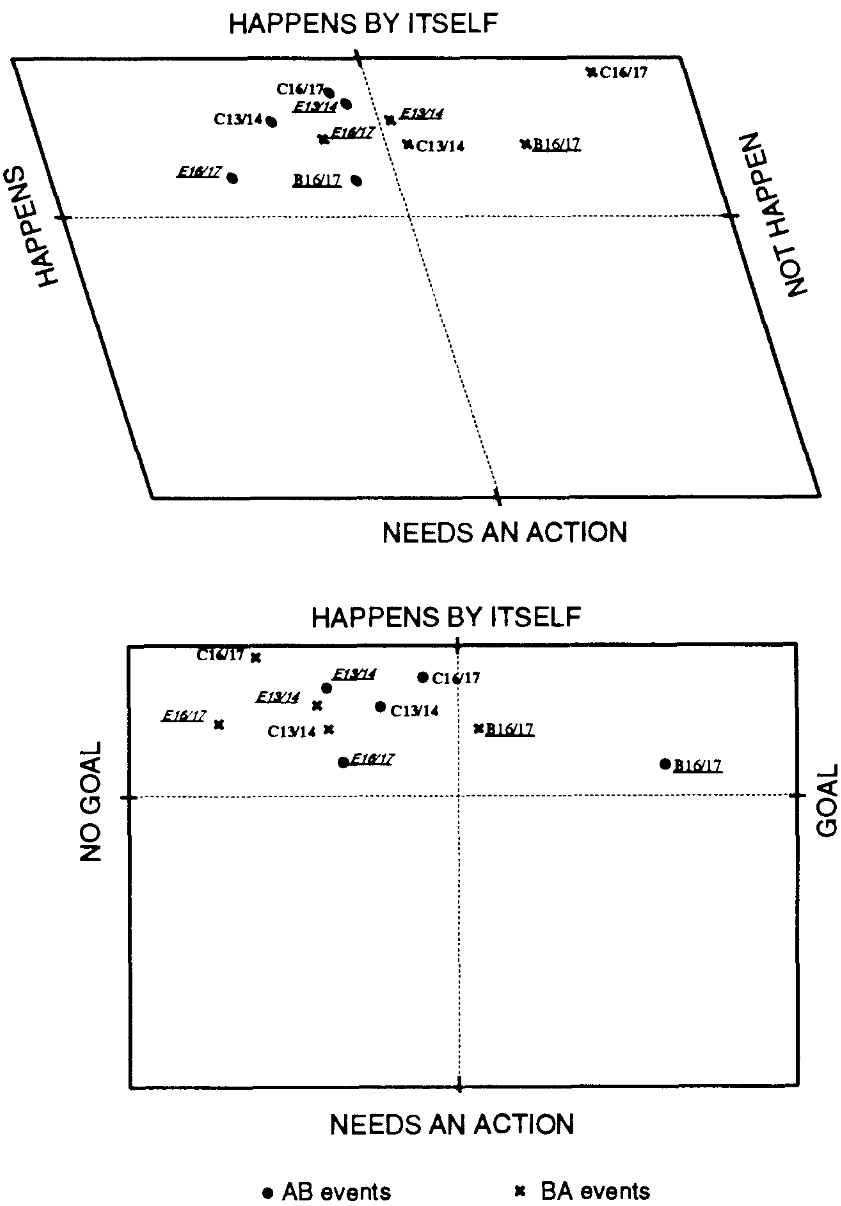


Figure 9.6 - *Plot of the events Puddle AB (•) and Puddle BA (x) in the common factor space*

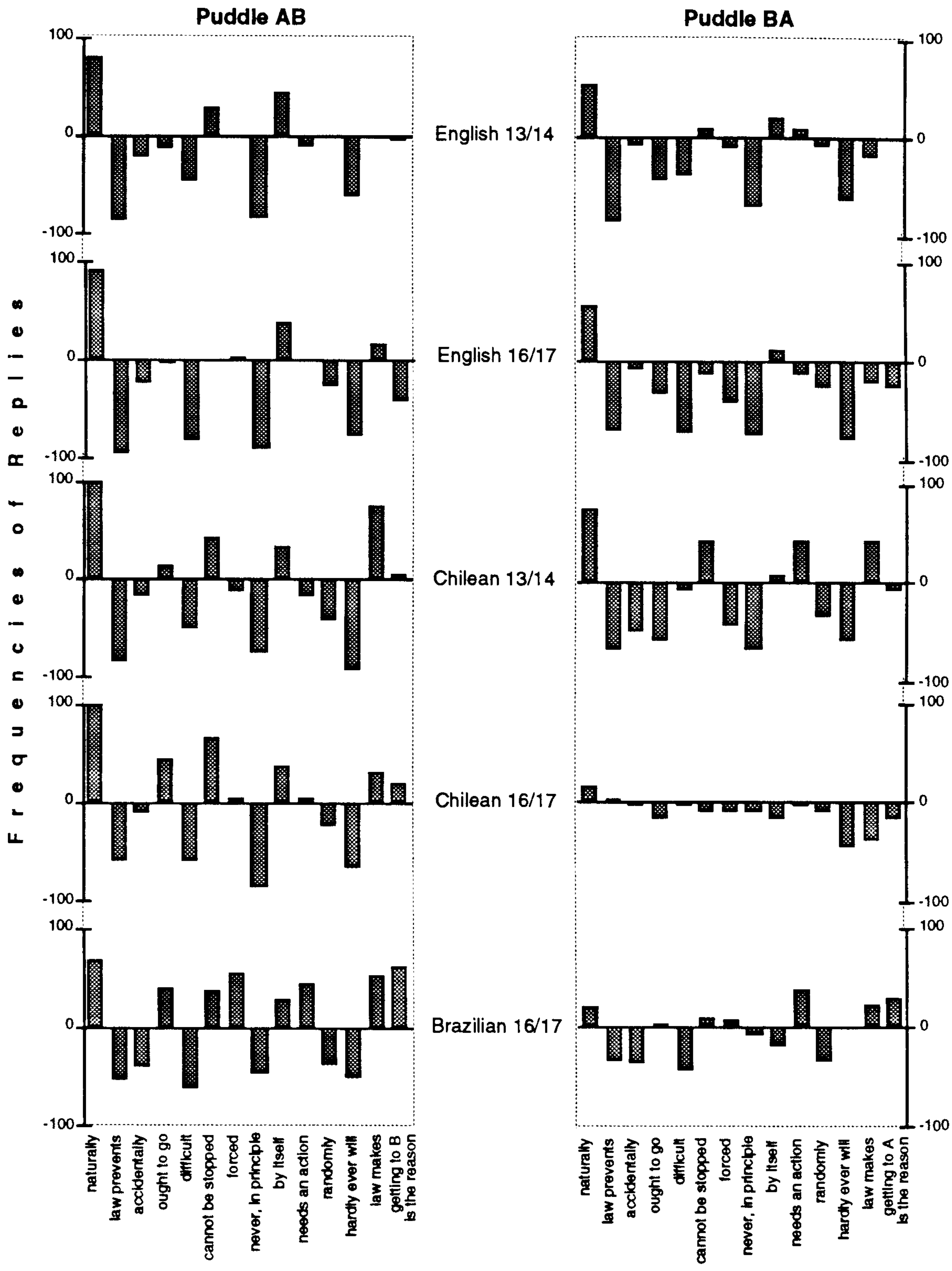


Figure 9.7 - *Frequencies of replies to each phrase for each group for the events Puddle AB and Puddle BA*

The profile of replies to Phrase 7 - 'forced to go to B', and Phrase 10 - 'needs an action', being nearly zero for all groups excepting for the Brazilian group, essentially means that half of the population agree with them and half disagree. Therefore, although mainly considered as happening by itself, it seems that there is a built-in action-like feature associated with the causes related to entities and objects. This situation is similar to the events Pendulum and Ice-Cream, but in this case there were just a few cases where it was openly externalised when some students from the Chilean 16/17 and Brazilian 16/17 groups gave explanations such as 'due to the action of the heat of the sun, the water evaporates', or 'due to the action of the sun'.

In the case of the Brazilians, the high positive frequency of replies to these phrases together with Phrase 13 - 'There is a law which makes it happen', and Phrase 14 - 'It happens because getting to B is the reason for the change', account for the placing of the event near the goal extremity.

9.2.3.2 Backwards

Nearly all answers for all groups were in terms of natural process (NH), such as 'it rains', 'wait for the rain', with causes being mainly related to the object itself, 'the rain'. There were some answers associating causes with a description of processes such as 'water cycle', 'condensation', 'change of temperature', some with the surroundings, 'weather', and just a few stating that 'it just happens'. The remainder were about a subject's intervention such as 'fill it up again' with causes being a description of the action, 'the filling'. There were a few students in the Chilean 16/17 and Brazilian 16/17 groups stating that it would be impossible.

In the factor space (Figure 9.6), this event is concentrated around the extremity 'happens by itself', but with the Chilean 16/17 and the Brazilian 16/17 placing it as less likely to happen. It is also located towards the 'no goal' side, excepting for the Brazilian 16/17 who consider it as more goal-oriented.

Figure 9.7 shows that Phrase 1 - 'naturally', has a substantial positive frequency of replies for all groups, and the frequency of replies to Phrase 10 - 'needs an action', is high and positive for the Chilean 13/14 and Brazilian 16/17, whilst being nearly zero for the English 13/14, English 16/17, and Chilean 16/17. Similarly to Puddle AB, it seems that the students associate an action-like feature with this natural process, which is stated explicitly in a few cases when they declare 'it must have an action in order for the water become liquid' or 'the action by which the vapour becomes liquid'.

The location of this event as less likely to happen by the Chilean 16/17 and Brazilian 16/17 is explained by the low profile of replies to phrases defining this dimension, i.e. Phrase 2 - 'law which prevents it', Phrase 5 - 'possible, but difficult', Phrase 8 - 'never happen in principle', and Phrase 12 - 'hardly ever will. Besides, it is these groups who give some answers declaring the impossibility of this event happening. Perhaps, it is more associated with the difficulty of having the pond re-filled, rather than with a definite impossibility of reversing this process.

9.2.3.3 Reversibility

This is a reversible process involving natural changes in both directions. The AB as well as the BA events are located at the 'happens by itself' extremity, although a little spread along the dimension 'happens-not happen'

9.2.4 CAR - 'a car rusts away'

9.2.4.1 Forwards

All answers were related to a natural process happening in certain circumstances (NC), either considering them as already existing, e.g. 'leave the car by the sea', 'leave the car in the rain', or setting them, e.g. 'park the car at the sea', 'expose the car to water and weather'. Half of the answers saw this natural process caused by different objects such as 'oxidising agents', 'oxygen of the air', 'salted water', 'rain', 'humidity', and for the other half causes were related to a description of what would happen such as 'metal being oxidised', 'metal reacts with water and oxygen'.

In the factor space (Figure 9.8) this event is located towards the 'happens by itself' extremity by all groups, and halfway through the extremities 'happens' and 'not happen', with the English 16/17 group seeing it as more likely to happen and the Brazilian 16/17 group as less likely to happen than the others. It is also located in the quadrant 'happens by itself' and 'no goal', excepting for the Brazilian 16/17 group who sees it as more goal-oriented, although the Chilean 13/14 and Chilean 16/17 groups also place it more towards the goal side. Therefore, depending on the existence of certain circumstances, this event is seen as happening naturally, with no subject's intervention.

Figure 9.9 shows a high positive frequency of replies to Phrase 1 - 'naturally', and a consequential positive frequency of replies to Phrase 3 - 'It happens accidentally' for all groups excepting for the Brazilian 16/17 group. Basically this event is seen as happening not only naturally, but also to a certain extent by chance.

The frequency of replies to Phrase 10 - 'needs an action', is high and positive for the Chilean 13/14, Brazilian 16/17, low but still positive to the Chilean 16/17 and low and negative to the English 13/14 and English 16/17. Likewise the previous events, although considering it as happening naturally, it seems that there is a action-like feature aligned with the causes, which just in a few cases is stated, such as 'action of water', 'action of weather', 'action of time', 'water and other agents' most often in the Chilean and Brazilian groups.

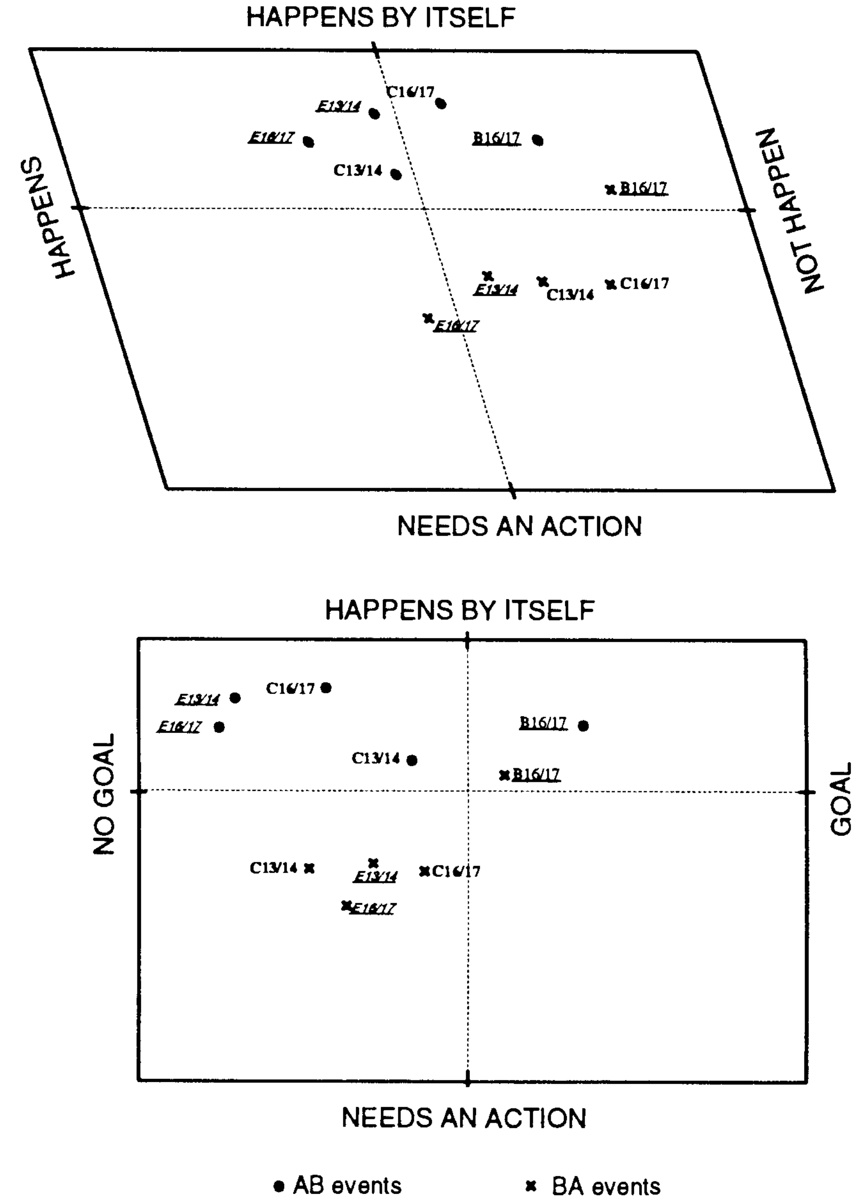


Figure 9.8 - *Plot of the events Car AB (•) and Car BA (x) in the common factor space*

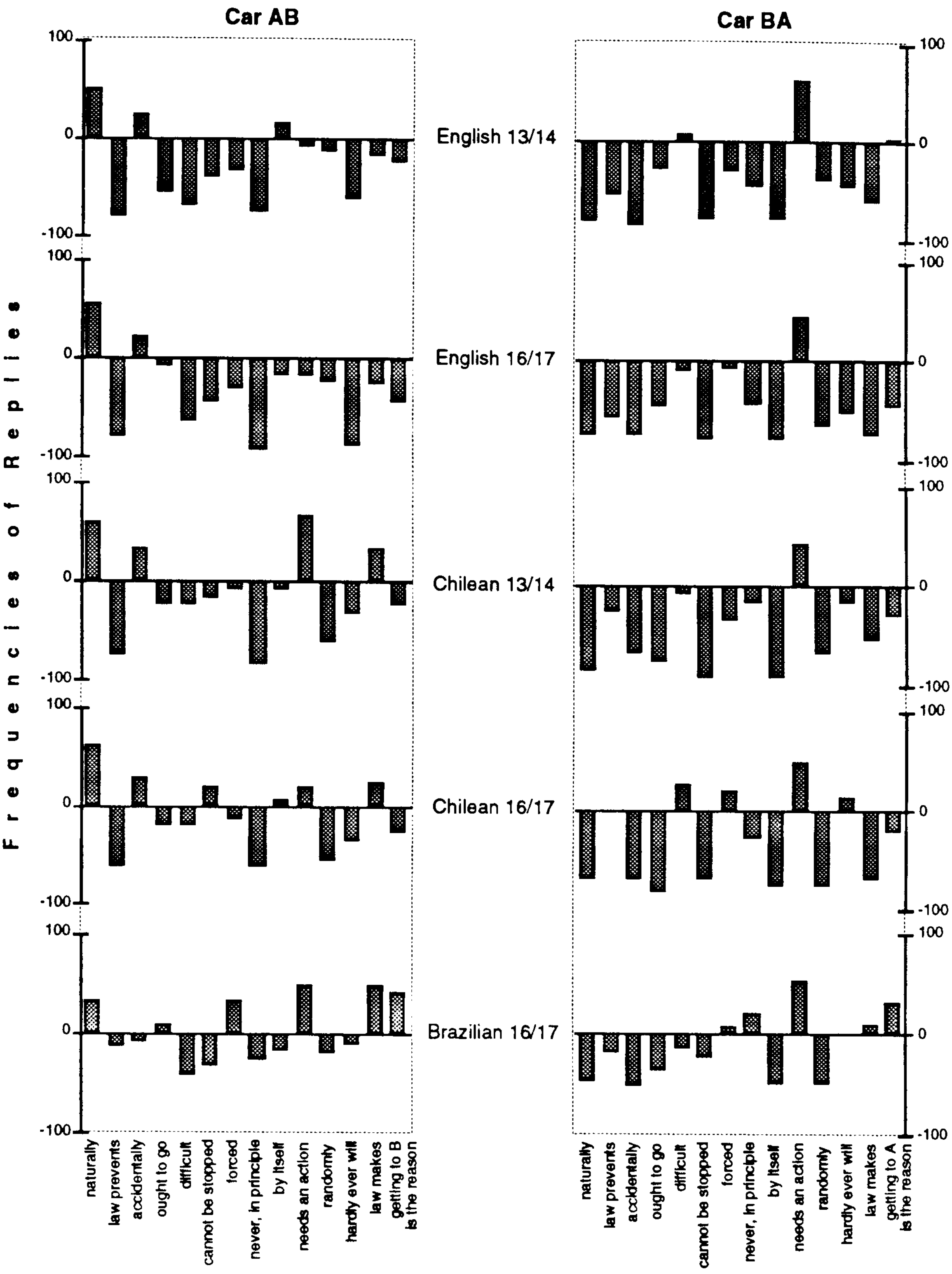


Figure 9.9 - *Frequencies of replies to each phrase for each group for the events Car AB and Car BA*

The positive frequency of replies to Phrase 10 - 'needs an action', that together with the high frequency of replies to Phrase 7 - 'forced to go to B' for the Brazilian 16/17 group and the nearly nil frequency for the Chilean 13/14 and Chilean 16/17, can explain the goal-like feature being distinct for these groups in comparison to the English groups.

9.2.4.2 Backwards

The majority of answers given by the Chilean 13/14, Chilean 16/17, and Brazilian 16/17 groups, were in terms of a sequence of direct actions on the object (**A**), such as 'sand it, clean it and repaint it', with the cause being a description of the action itself. There were a few stating that it would be impossible. Regarding the English 13/14 and English 16/17, just above half of the answers were in terms of a subject's intervention (**A**), either with a sequence of direct action on the object, such as 'sand rust off + repaint it', or an indirect action on the object, such as 'take it to repair', with causes being related to a description of the action itself, e.g. 'the car being repaired'. The other part saw the reverse as not possible, mainly expressed through **R** replies e. g. 'buy a new car', 'replace the rusted parts', which are very like (**A**) replies, and just a few stating that it would be impossible.

The plot of this event in the factor space (Figure 9.8) shows that it is mainly located towards the 'not happen', 'needs an action', and 'no goal' extremities, excepting the Brazilian 16/17 group which places it as less needing an action and more with a goal. They also consider this event as less likely to happen in contrast to the English 16/17 group who locates it as more likely to happen than do the others. Thus, this event is basically considered as not likely to happen, unless an action is taken.

Although most of the answers were related to an action, which eventually would lead the event to happen, the location of this event in the factor space towards the 'not happen' extremity can be explained by the not very high negative and sometimes low positive frequency of replies to phrases which define this dimension, i.e. Phrase 2 - 'law prevents it ', Phrase 5 - 'possible, but difficult ', Phrase 8 - 'never happen in principle', and Phrase 12 - 'hardly ever will (Figure 9.9). Therefore, although considered as possible to happen through an action, it seems that there is a basic tendency to consider it not likely to happen.

Perhaps, this is connected with the fact that this event seems to be considered more as a reconstruction than a reversion, because it is considered that it is not possible to retrieve the rusted parts, shown when they make statements such as 'part of the metal has wasted way', or give R replies such as 'impossible, unless parts are changed'.

9.2.4.3 Reversibility

This is a natural process seen as happening under certain circumstances, but considered as basically as non-reversible. Even when an action is taken to reverse the process, it is more like a 'start again' than a 'go back'.

9.2.5 BOY/MAN - 'a man grows old'

9.2.5.1 Forwards

All answers of all groups described it as a natural process (**NH**), such as 'just happens', 'time', 'living', with causes being a description of what would happen, e.g. 'natural process of ageing', 'growing up', 'process of life'.

In the factor space (Figure 9.10), this event is located in the quadrant 'happens' and 'happens by itself', and concentrated around the 'happens by itself' extremity. The points are also located halfway between the 'goal' and 'no goal' extremity, with the Brazilian 16/17 placing it more towards the 'goal' direction and the English 16/17 more towards the 'no goal' side. In essence it means that this event is seen as happening naturally, with no subject's intervention.

Figure 9.11 shows that the high positive frequencies of replies given by all groups to Phrase 1 - 'naturally', Phrase 4 - 'it ought to go to B', Phrase 6 - 'It cannot be stopped from happening', and Phrase 9 - 'spontaneously, all by itself', explain the location of this event around the 'happens by itself' extremity. Another two aspects can be analysed: firstly, the notably goal-like feature of this event for the Brazilian 16/17 group is shown by the positive frequency of replies to Phrases 7 - 'forced to go to B', Phrase 13 - 'law makes it ', and Phrase 14 - 'getting to B is reason for the change', and the approximately nil frequency of replies to Phrase 10 - 'needs an action', while the low profile of answers to the same phrases, given by the English 16/17, explains the detached location of this event towards the 'no goal' extremity for them.

9.2.5.2 Backwards

All answers of all groups considered the reversal as not possible (**X**), with over half of the answers declaring that it would be impossible, the reminder giving **R** replies, such as 'plastic surgery', and with just a few giving imaginative actions such as 'travel back in time', 'run around the world at the speed of light', 'take rejuvenating pills'.

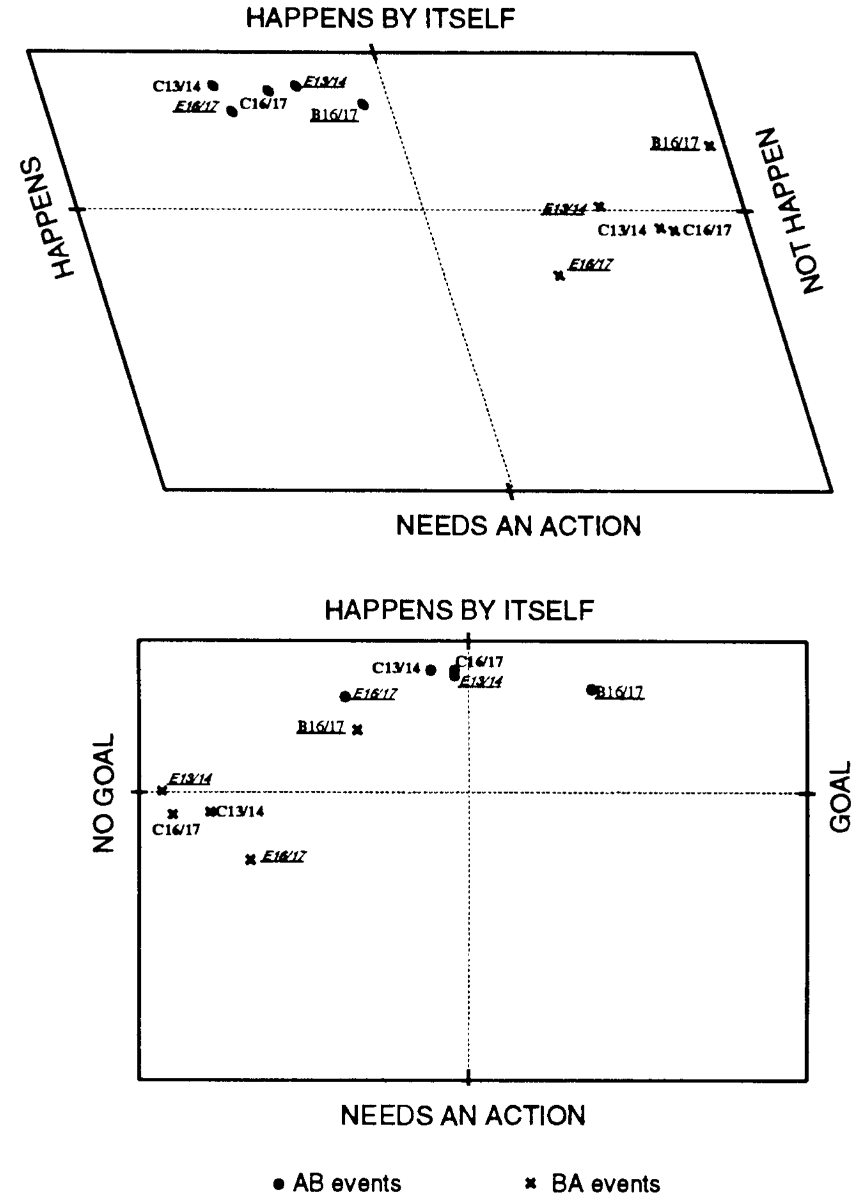


Figure 9.10 - *Plot of the events Boy/Man AB (•) and Boy/Man BA (x) in the common factor space*

This event in the factor space (Figure 9.10) is concentrated around the 'not happen' and 'no goal' extremities and midway on the dimension 'happens by itself' and 'needs an action', although the Brazilian 16/17 group places it a little removed towards the goal side. Essentially this event is considered as very unlikely to happen.

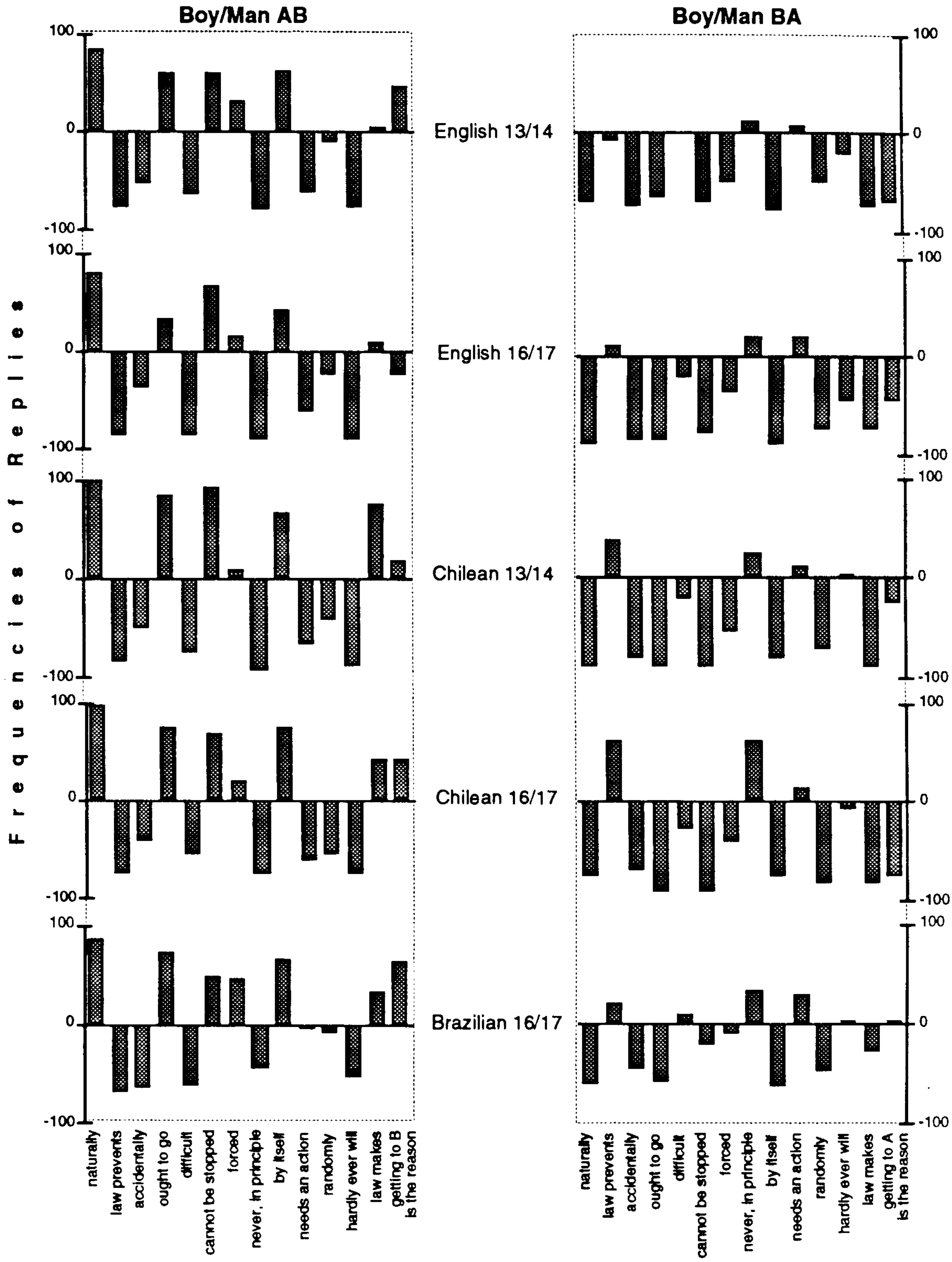


Figure 9.11 - *Frequencies of replies to each phrase for each group for the events Boy/Man AB and Boy/Man BA*

Although considered as not possible to happen, as indicated by the mainly positive frequency of replies to Phrase 2 - 'There is a law which prevents it happening', and Phrase 8 - 'It could never happen in principle', shown in Figure 9.11, the frequency of replies to Phrase 10 - 'needs an action' is not negative, which in a way has the opposite meaning. Therefore, it seems that even when an event is openly considered as impossible, there may always be an action that can be thought of as being taken to reverse it, such as the **R** replies. In some cases, even if the result of this action does not produce the proposed reversion, it seems that the reversion is considered as successful, as shown by answers such as 'you cannot change age, but you can make him look younger', 'we can never take years off, but we can try by exercising'.

9.2.5.3 Reversibility

This phenomenon is considered as a natural irreversible process with the AB events located at the 'happens by itself' extremity, while the BA events are placed at the 'not happen' extremity. Time reversal is mentioned.

9.2.6 FALLING BALL - 'the ball falls and bounces back up'

9.2.6.1 Forwards

All answers of all groups were about a natural process. On average half of the answers were in terms of a non-intervention (**NH**), e.g. 'leave the ball fall', 'let it fall', and the other half in terms of an initial action on the object taken to trigger the natural process (**AN**) e.g. 'drop the ball from your hand', drop it from a height'. In both cases, causes were related to either entities such as 'gravity', 'force', 'elasticity', or a description of what would happen, e.g. 'it bounces'.

In the factor space (Figure 9.12), this event lies approximately along a diagonal in the plot of the two first factors and is scattered towards the goal extremity in the second plot. However, the English 16/17, English 13/14 and Chilean 13/14 groups see this event happening more due to an action than do the others. The Chilean 16/17 and the Brazilian 16/17 groups see it as happening more by itself, but with the latter considering it as less likely to happen, but more goal-oriented.

The frequencies of replies to phrases shown in Figure 9.13 reveals some subtlety in the way it is located by each group. The pattern of answers of the English 13/14 and Chilean 13/14 groups is very similar, thus lying close together in the factor space. The English

16/17 group also has an approximately similar profile of responses, therefore placing it near those above but slightly removed towards the 'happens' side, due to the high frequency of replies to Phrase 13 - 'law makes it', and towards the 'no goal' side due to the proportionately less positive profile of replies to the phrases of this dimension, i.e. Phrase 7 - 'forced to go to B', Phrase 10 - 'needs an action', and Phrase 14 - 'getting to B is the reason for the change'.

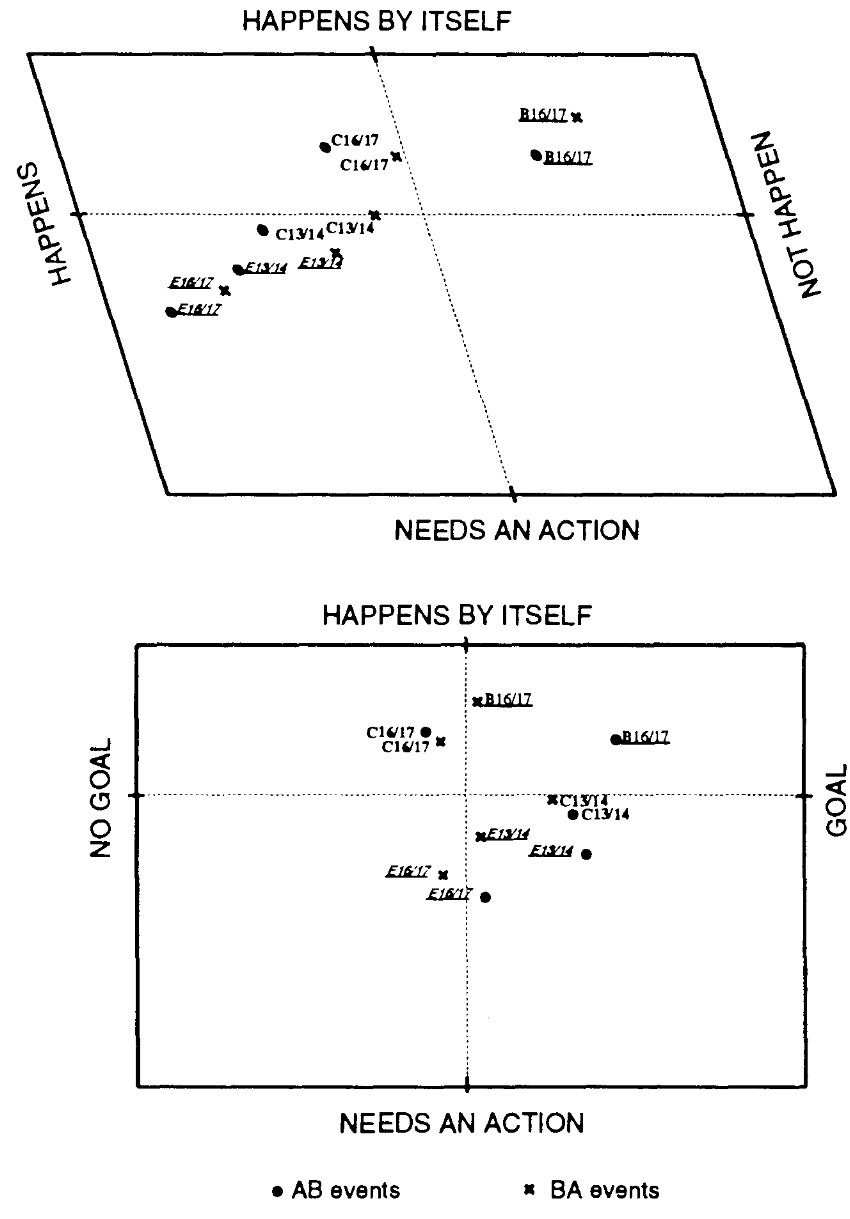


Figure 9.12 - *Plot of the events Falling Ball AB (•) and Falling Ball BA (x) in the common factor space*

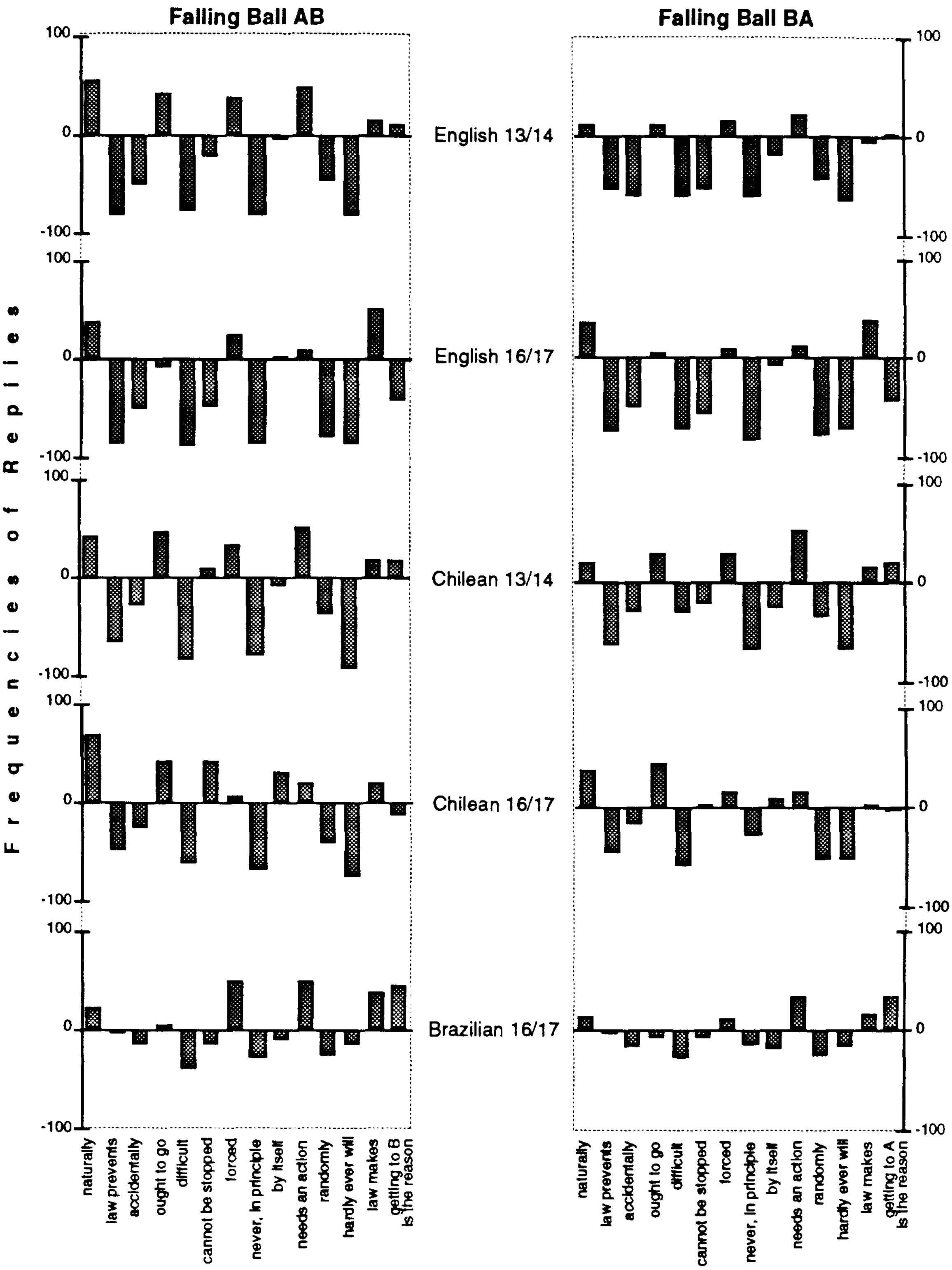


Figure 9.13 - *Frequencies of replies to each phrase for each group for the events Falling Ball AB and Falling Ball BA*

The Chilean 16/17 group also sees it happening, although as less likely to happen in relation to the previous groups, due to the relatively less negative frequencies of replies to the phrases which define this dimension, i.e. Phrases 2 - 'law which prevents it', Phrase 5 - 'possible, but difficult', Phrase 8 - 'never in principle', and Phrase 12 - 'hardly ever will'. And yet, they place it as happening by itself, due to the high frequency of replies to Phrase 1 - 'naturally', and low frequency of replies to Phrase 7 - 'forced to go to B' and Phrase 10 - 'action'.

The most unlikely location is given by the Brazilian 16/17 group, who see it as rather unlikely to happen due to the negative profile of replies to the phrases of this dimension just mentioned above. The 'happens by itself' feature can be understood in the sense that, something that is unlikely to happen, can just happen by itself, when it happens. The high positive frequency of replies to Phrases 7 - 'forced' and Phrase 10 - 'action', is more goal related together with the high frequency of replies to Phrase 13 - 'law makes it' and Phrase 14 - 'getting to B is the reason for the change -, what pulls it towards the 'goal' side.

9.2.6.2 Backwards

The general description of the falling ball happening backwards is very similar to its description when happening forwards, although the event is a little shifted towards the 'no goal' side. Answers to the open-ended question were all about a natural process, either in terms of a non-intervention (NH), such as 'allow it continue its trajectory', or in terms of an initial action on the object to trigger the natural process (AN), such as 'throw the ball upwards'. In both cases, causes were related either to entities such as 'gravity', 'force', or to a description of what would happen 'it goes back again'. The distribution of answers among the groups were similar to those for the event happening forwards with the students giving the same kind of answers in both directions.

The location of this event in the factor space (Figure 9.12) is very similar to the location of the same phenomenon happening forwards. Likewise, the profile of replies to phrases in this case (Figure 9.13), is to a certain extent similar to the AB event. Therefore, the way this event is seen when happening backwards is very similar to how it is seen when it is happening forwards.

9.2.6.3 Reversibility

This is a reversible process involving natural change in both directions. Although the location of this event in the factor space varies a little, each group places the AB and BA events close together, therefore seeing them happening in a similar way.

9.2.7 SEE-SAW - 'the see-saw is tilted a little'

9.2.7.1 Forwards

All answers of all groups were related to an action on the object (**A**), and they can be classified in three different kinds:

- 1. answers related to *movement* such as 'the man on the right moves forward'. In this group, on average half of the answers were unequivocal about which man should move to cause the unbalance, while the other half seemed to have shown hesitancy about it when they answered 'one person walks forwards', or 'moving' or ' both men take a step in the same direction';

- 2. answers related to *weight* such as 'a person eats a lot and gets heavier' or 'a person is given a weight to hold';

- 3. answers related to *force* such as 'a force is applied downwards'.

Causes were related to either a description of what would happen, e.g. 'moving', 'the increase of weight causes disequilibrium', or related to entities such as 'gravity, 'weight', 'food'.

In terms of the three types of answers above, for the English 13/14, English 16/17, and Chilean 16/17 groups, on average, two fifths of the answers were in terms of type 1, the other two fifths were related to type 2, and the remainder in terms of type 3. For the Chilean 13/14 group, two thirds were in terms of type 2, and the remainder distributed between types 1 and 2. Finally, for the Brazilian 16/17 group, half were related to type 2, one fourth to type 1, and the other fourth to type 3.

The location of this event in the factor space (Figure 9.14) is basically divided in two groups, with some differences within them. The English 13/14, English 16/17, and Chilean 16/17 groups place it in the quadrant 'happens' and 'needs an action', while the Chilean 13/14 and Brazilian 16/17 groups in the quadrant 'happens by itself' and 'not happen'. There is not much distinction as far as the third dimension is concerned, excepting for the Brazilian 16/17 who locate it a little more towards the goal extremity. Therefore, the English 13/14, English 16/17, and Chilean 16/17 groups see it as happening due to an action, whilst the Chilean 13/14 and Brazilian 16/17 groups see it as less likely to happen, although if it happens, it will happen by itself.

The frequencies of replies to phrases shown in Figure 9.15, reveals that the English 13/14, English 16/17, and Chilean 16/17 groups have an approximate similar profile of answers, all with a significant positive frequencies of replies to Phrase 7 - 'forced to go to B' and Phrase 10 - 'needs an action'; therefore placed close together in the space. However the English 16/17 is more towards the 'action' extremity due to the relatively more negative frequency of replies to the phrases associated with 'happens by itself' side, i.e. Phrase 1 - 'naturally', Phrase 9 - 'spontaneously, all by itself', Phrase 11 - 'It happens by some random process'.

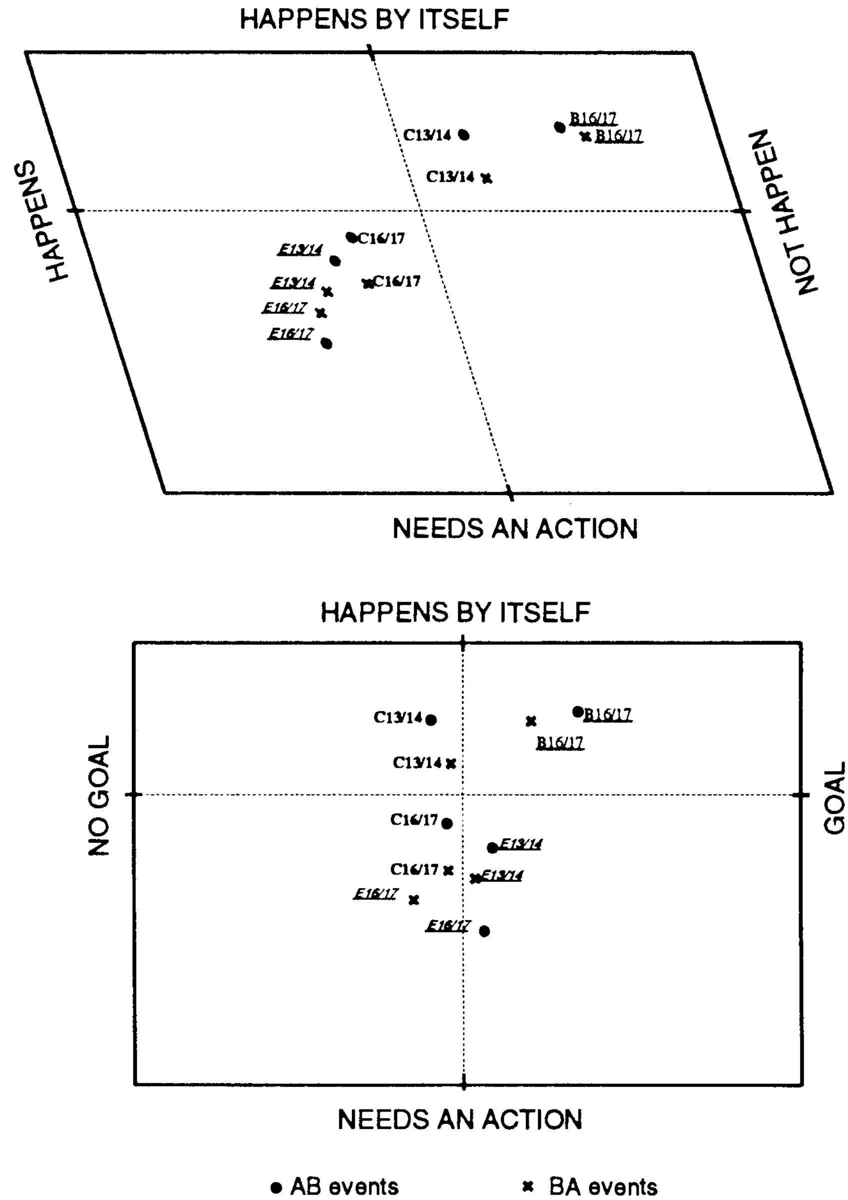


Figure 9.14 - *Plot of the events See-Saw AB (•) and See-Saw BA (x) in the common factor space*

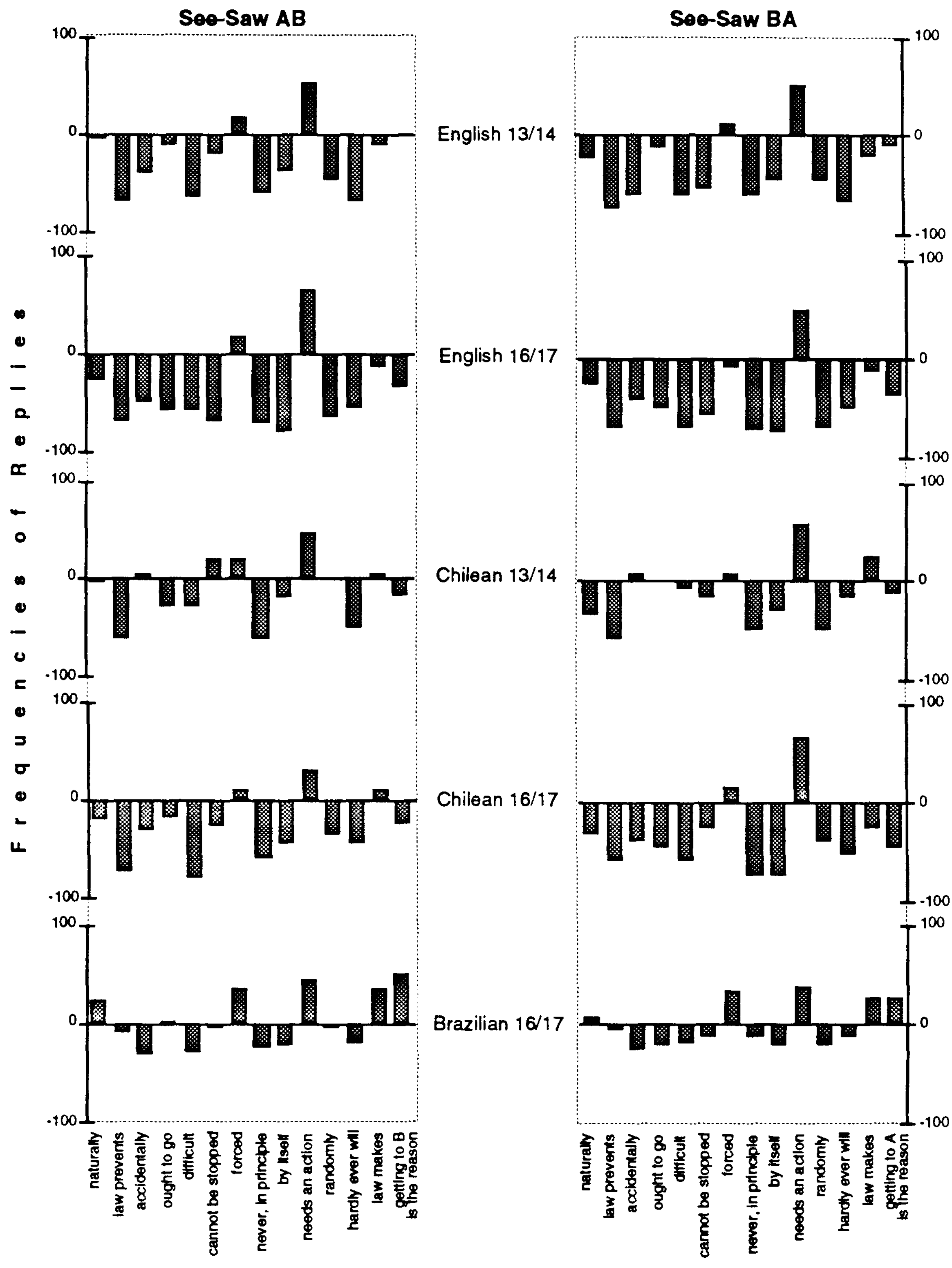


Figure 9.15 - *Frequencies of replies to each phrase for each group for the events See-Saw AB and See-Saw BA*

In regard to the Chilean 13/14 and Brazilian 16/17 groups, although having a significant positive pattern of replies to Phrase 7 - 'It happens because it was forced to go to B' and Phrase 10 - 'action', their less negative profile of replies to the just mentioned phrases related to the 'happen by itself' side, pulls them towards this direction. And yet, for the Brazilians the positive frequency of replies to the action phrases (Phrases 7 and 10) is more related to the goal dimension together with the high frequency of replies to Phrase 13 - 'law makes' and Phrase 14 - 'getting to B is the reason for the change', as if they considered this event as less likely to happen, but when happening, it happens by itself and due to a purpose.

9.2.7.2 Backwards

All answers of all groups were related to an action on the object (A), within the same types of responses described for the event going forwards, and in about the same proportions for each group. In fact, the answers were all in terms of the inversion of the answers given for the forwards direction. These inversions were in terms of either the *reverse of the action* taken to go forwards, such as 'the man on the right side moves backwards', ' the person goes on diet', 'leave it, it balances out', or an *action which would compensate* the action taken to go forwards, e.g. 'the person on the left side moves forwards', 'the other person eats the same food', 'the same force is applied on the other side'.

The location of this event in the factor space shown in Figure 9.14 is very similar to the location of the same phenomenon happening forwards; and the same similarity appears in the frequencies of replies to phrases shown in Figure 9.15. Therefore, this phenomenon happening forwards and backwards has the same structure of description.

9.2.7.3 Reversibility

This is a process started by an external action and reversed by actions which are either the inversion or the compensation of the action taken to go forwards. Similarly to the event Falling Ball, each group locates the AB and the BA process close together in the factor space, and the pattern of replies to phrases is similar in both cases, seeing them happening in a very similar way.

9.2.8 SLOPE - 'a ball rolls down'

9.2.8.1 Forwards

The vast majority of answers were in terms of a non intervention (**NH**), such as, 'let it roll down', 'let go of the ball', with the process caused by entities e.g. 'gravity', 'force'. In just a very few cases for all groups, the answers were in terms of a direct action on the object, such as 'push the ball'.

In the factor space (Figure 9.16) the English 13/14, English 16/17, and Chilean 16/17 groups, concentrate this event in the 'happens' extremity, and a bit towards the 'action' side, while the Chilean 13/14 and Brazilian 16/17 groups place it as less likely to happen than do the others, and in between the extremities 'by itself' and 'action'. All groups locate it towards the goal side, although the Brazilian 16/17 group sees it as more goal-oriented than do the others. Thus, this event is seen as happening due to an action and somewhat goal-oriented.

The frequencies of replies in Figure 9.17 show that although considering this event as happening naturally, with positive frequency of replies to Phrase 1 - 'naturally' for all groups and positive frequency to Phrase 9 - 'spontaneously, all by itself' for all but the English 16/17 group, they also consider it as being forced to happen with the relative positive frequency of replies to Phrase 7 - 'forced to go to B' and nearly equal positive and negative replies to Phrase 10 - 'needs an action' for all groups. Therefore, again in this case, it seems that the fact that this event is seen as happening with no subject's intervention or naturally, does not necessarily means that there is no action involved in it. In fact, there is and, when associating causes with entities such as 'gravity', it seems they consider such a cause as a 'natural agent', such as when they answer 'do nothing, let it happen naturally' and say that the cause for the change is 'gravity'.

9.2.8.2 Backwards

All answers of all groups were in terms of a direct action on the object (**A**), such as 'push it back up', 'roll it up', with cause being either a description of the action itself, e.g. 'a force', or a description of what would happen, e.g. 'the ball being pushed'.

In the factor space for all groups (Figure 9.16) the English 13/14 and English 16/17 groups locate this event in the quadrant 'happens' and 'action' close to the 'action' extremity, while the Chilean 13/14 and Chilean 16/17 place it in the centre of the quadrant 'needs an action' and 'not happen'. The Brazilian 16/17 locate it as less likely to happen than do the others. All groups place this event approximately as happening due to some goal. Thus, the English groups see this event as happening due to an action, as do the Chilean groups but less so, while the Brazilian group makes no clear assertion related to action but see it as less likely to happen than do the Chilean. They all see it as a little goal-oriented.

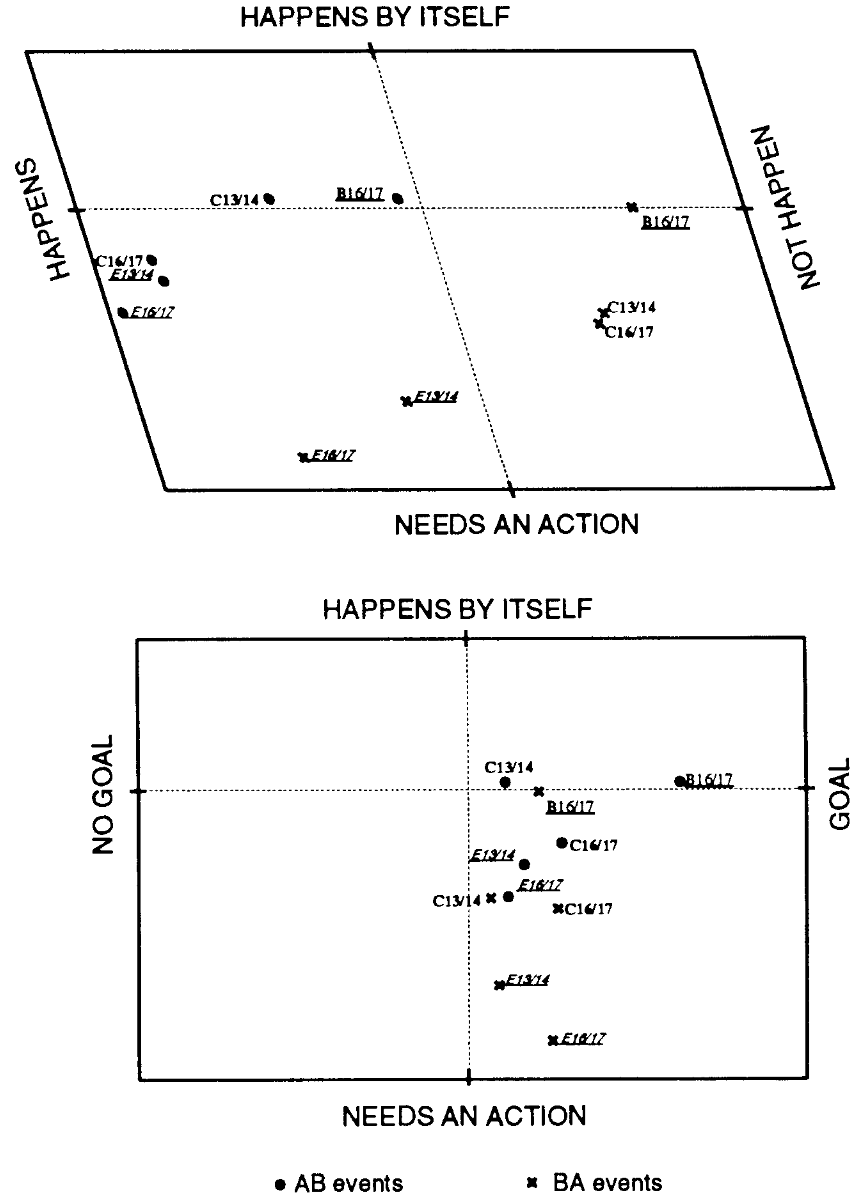


Figure 9.16 - *Plot of the events Slope AB (•) and Slope BA (x) in the common factor space*

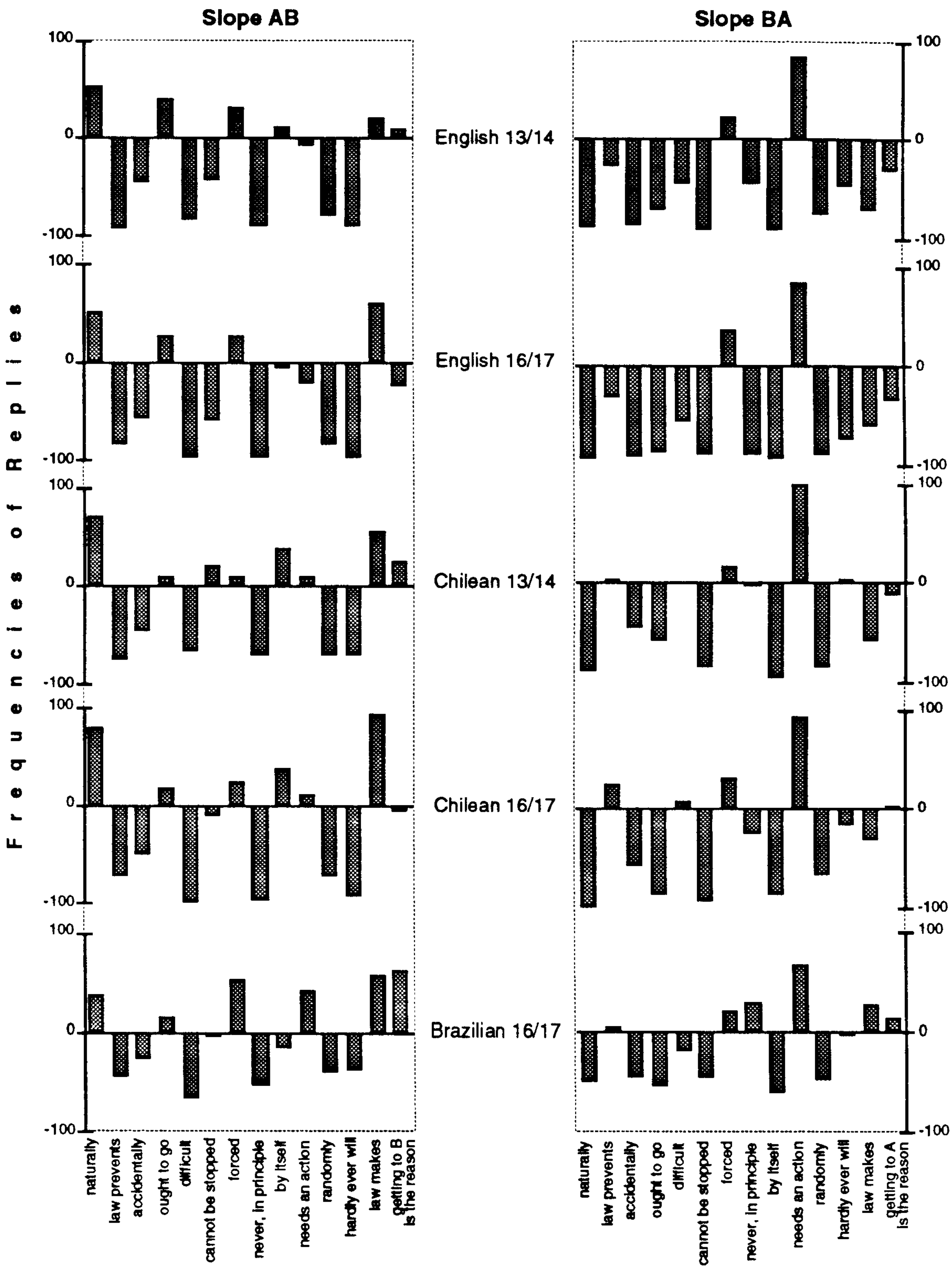


Figure 9.17 - *Frequencies of replies to each phrase for each group for the events Slope AB and Slope BA*

Figure 9.17 shows that the patterns of responses to phrases are similar for the English groups and Chilean groups, so that their events lie close together in the factor space. The similar low frequency of replies to Phrases 2 - 'law prevents it', Phrase 5 - 'possible, but difficult', Phrase 8 - 'never happen in principle', and Phrase 12 - ' hardly ever will' given by the Chilean groups explains their location of this event towards the 'not happen' side, and the positive frequency of replies to Phrase 8 given by the Brazilian group explain their location a bit further in this direction.

9.2.8.3 Reversibility

This is mainly a natural process reversed by an external action.

9.2.9 TEA - 'a cup of tea becomes cold'

9.2.9.1 Forwards

The overwhelming majority of answers of all groups were about a natural process with no subject's intervention (NH), e.g. 'leave it'. Most of the causes were a description of what would happen such as 'loss of energy', loss of heat', 'change of temperature', 'it cools down'. Some stated that it would happen naturally. There were a few answers about a subject's action to set the proper circumstances for it to happen, 'put it in a freezer', with causes being a description of what would happen.

In the factor space (Figure 9.18), this event is located in the quadrant 'happens' and 'happens by itself' towards the 'happens' extremity, excepting for the Brazilian 16/17 group which sees it as less likely to happen than do the others. The Chilean 13/14, Chilean 16/17 and Brazilian 16/17 groups concentrate it towards the 'happens by itself' side and more towards the goal side than do the English 13/14 and English 16/17 groups.

The frequencies of replies to phrases (Figure 9.19) shows that they all consider it as happening naturally and spontaneously (Phrases 1 and 9), and unavoidable (Phrases 4 and 6). Moreover, the significant frequency of replies to Phrase 7 - 'It happens because it was forced to go to B', Phrase 13 - 'law makes it' and Phrase 14 - 'getting to B is the reason for the change' given by the Brazilian 16/17 and Chilean 16/17, and Chilean 13/14 groups, explain their location towards the goal end.

9.2.9.2 Backwards

All answers of all groups were in terms of a subject's action. Most of them were related to a direct action on the object (A), e.g. 'heat it up', and the remainder about an action to set circumstances (AC), e.g. 'put it in a microwave'. Causes were equally related to entities such as 'heat energy', 'heat', 'change of temperature', or with a description of what would happen, e.g. 'heating it'.

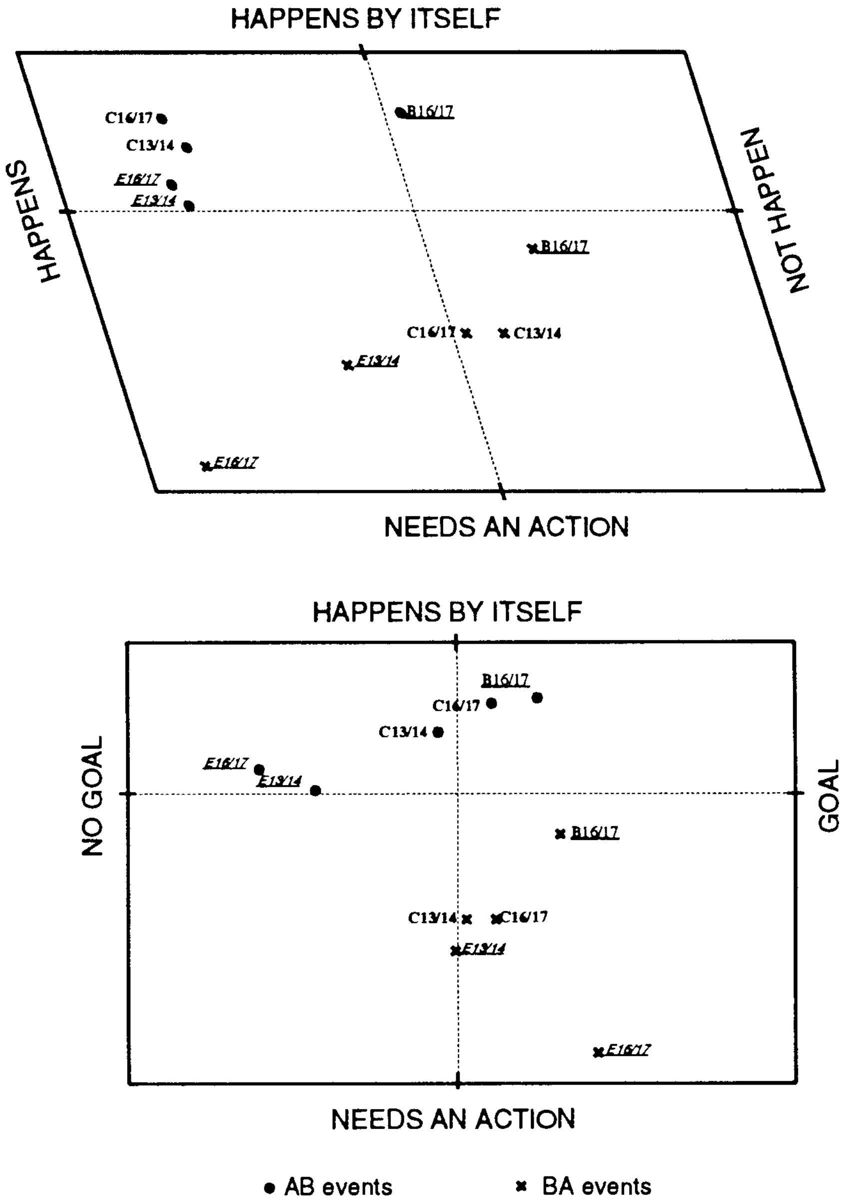


Figure 9.18 - *Plot of the events Tea AB (•) and Tea BA (x) in the common factor space*

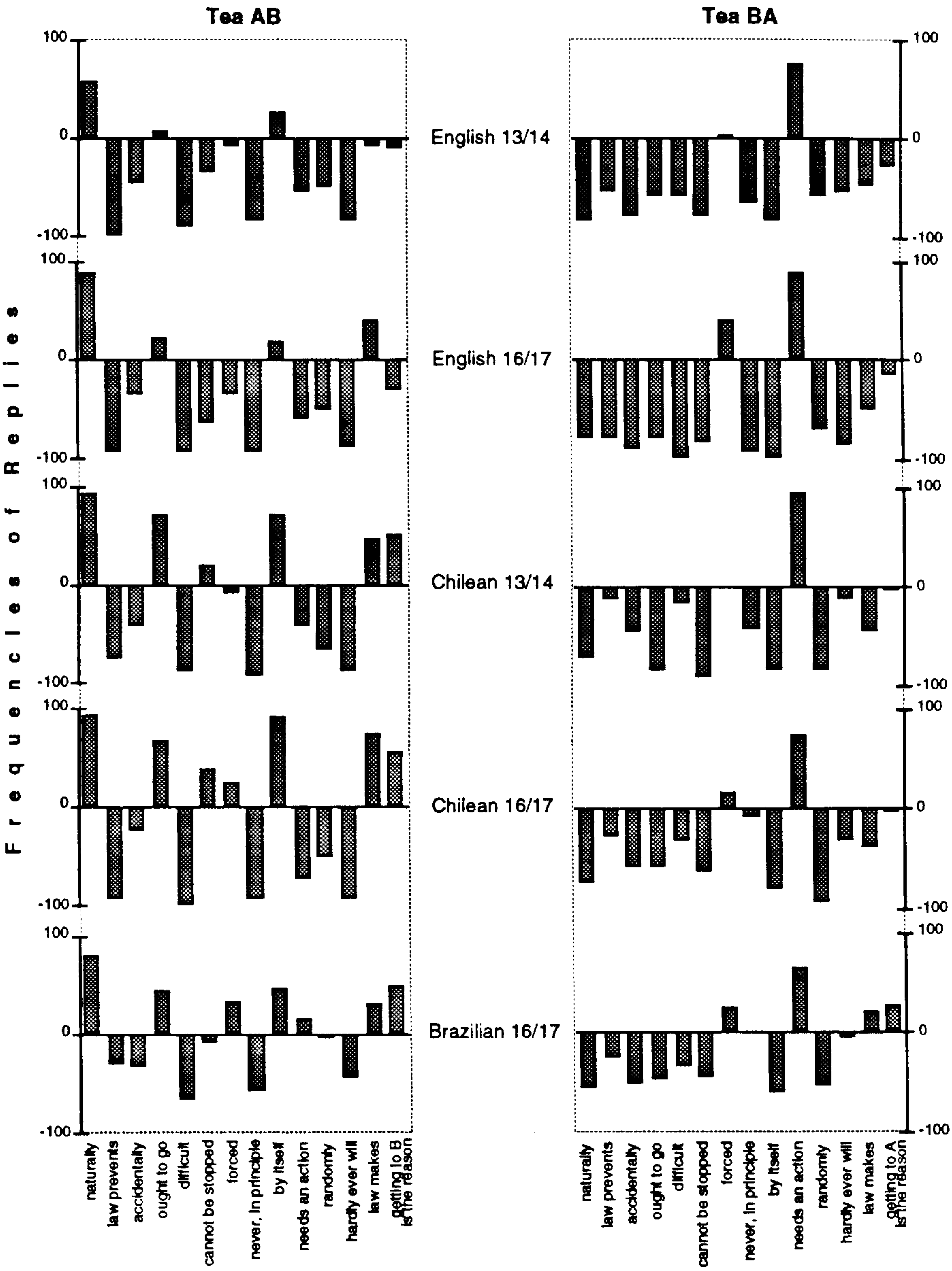


Figure 9.19 - *Frequencies of replies to each phrase for each group for the events Tea AB and Tea BA*

In the factor space (Figure 9.18), the English 16/17, and English 13/14 group place it in he quadrant 'happens' and 'needs an action', with the latter locating it more towards the 'not happen' side. The Chilean 13/14, Chilean 16/17, and Brazilian 16/17 place it in the quadrant 'not happen' and 'needs an action', with the latter placing it as less likely to happen and less needing an action than do the others. They all locate it as a bit goal-oriented, with the English 16/17 placing it slightly more detached towards this side. Therefore, this event is seen as possible to happen due to an action, which is taken on purpose.

The profile of replies to phrases shown in Figure 9.19 together with the location of this event in the factor space reveal a different attitude for describing this event depending on the group. The English 16/17 group places it at the extremities 'happens' and 'needs an action', and their pattern of replies to the phrases expressing unlikeliness for something to happen, i.e. Phrase 2 - 'law prevents it', Phrase 5 - 'possible, but difficult', Phrase 8 - ' never happens, in principle', and Phrase 12 - 'hardly ever will', being highly negative suggests that they take for granted that there is an action that can be taken to make this event to happen, and they are positive about this. The other groups, and in particular the Brazilian 16/17 group, when placing it towards the 'not happen' side, seem to assume a more sceptical position stating that it is possible to take an action to make it happen, but nevertheless, that there is a law which naturally prevents it happening (Phrase 2), 'it is possible, but difficult to do' (Phrase 5), 'in principle, it would never happen' (Phrase 8), or 'it could happen, but it is extremely difficult' (Phrase 12), all of them with a less negative frequency of replies compared to the English 16/17.

9.2.9.3 Reversibility

The process is reversible, and involves natural changes in both directions. However in the forward direction, it mainly 'just happens' - AB events located towards the 'happens by itself' end -, while in the reverse direction action plays a important active role - BA events being placed towards the 'needs an action' side.

9.2.10 CHAMPAGNE - 'the champagne goes flat'

9.2.10.1 Forwards

All answers of all groups were about a natural process just happening (NH). The typical answer was 'leave it', with causes being a description of what would happen, e.g. 'gas escaping', 'loss of CO_2', 'diffusion of bubbles'.

The plot of this event in the factor space (Figure 9.20) shows that all groups concentrate it at the high end of 'happens by itself', with the Brazilian 16/17 seeing it as less likely to happen. The English 13/14, English 16/17 groups concentrate it at the very end of the 'no goal' extremity, and the Chilean 13/14, Chilean 16/17, and Brazilian 16/17 groups place it gradually and respectively as more goal-oriented.

Also in this case, the frequencies of replies to phrases (Figure 9.21) reveals that the goal-like feature for the Brazilian 16/17 is explained by the significant profile of replies to the 'action' phrases (Phrases 7 and 10) and Phrase 13 - 'There is a law which makes it happen', and Phrase 14 - 'It happens because getting to B is the reason for the change'.

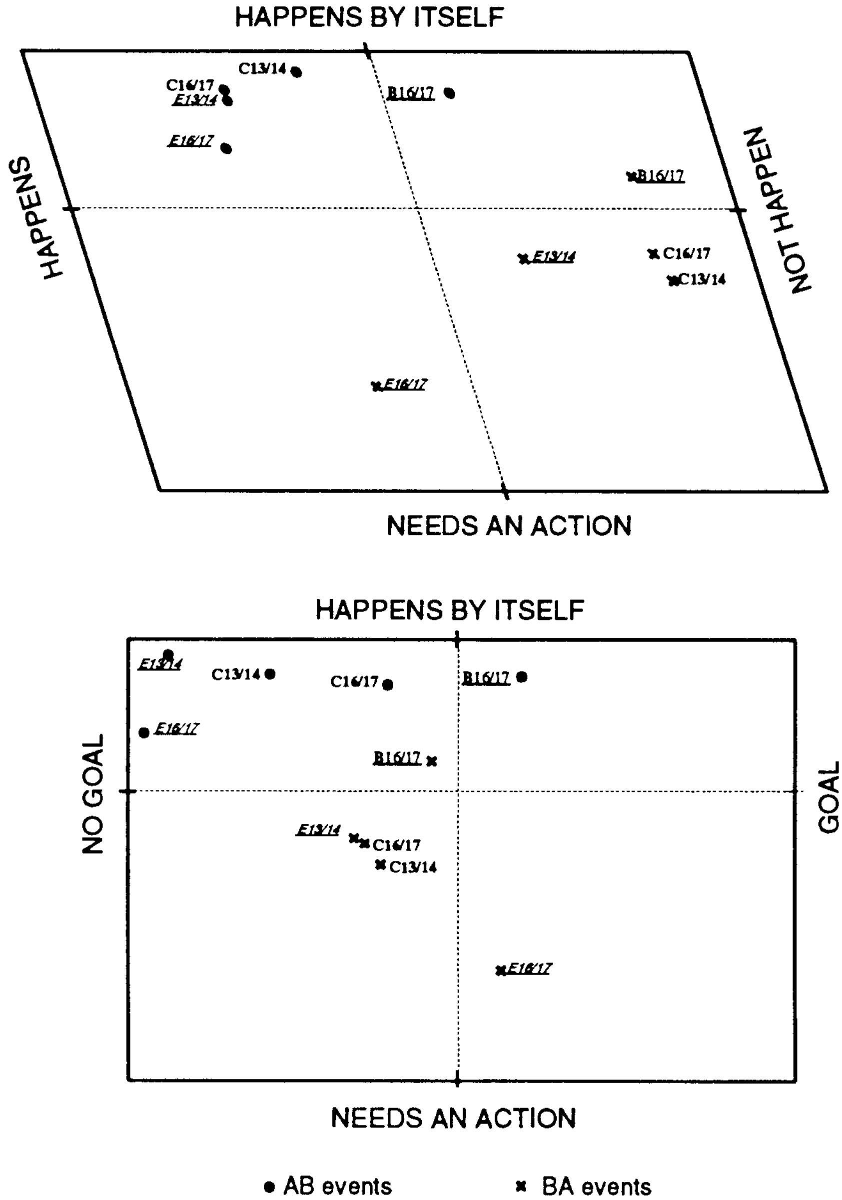


Figure 9.20 - *Plot of the events Champagne AB (•) and Champagne BA (x) in the common factor space*

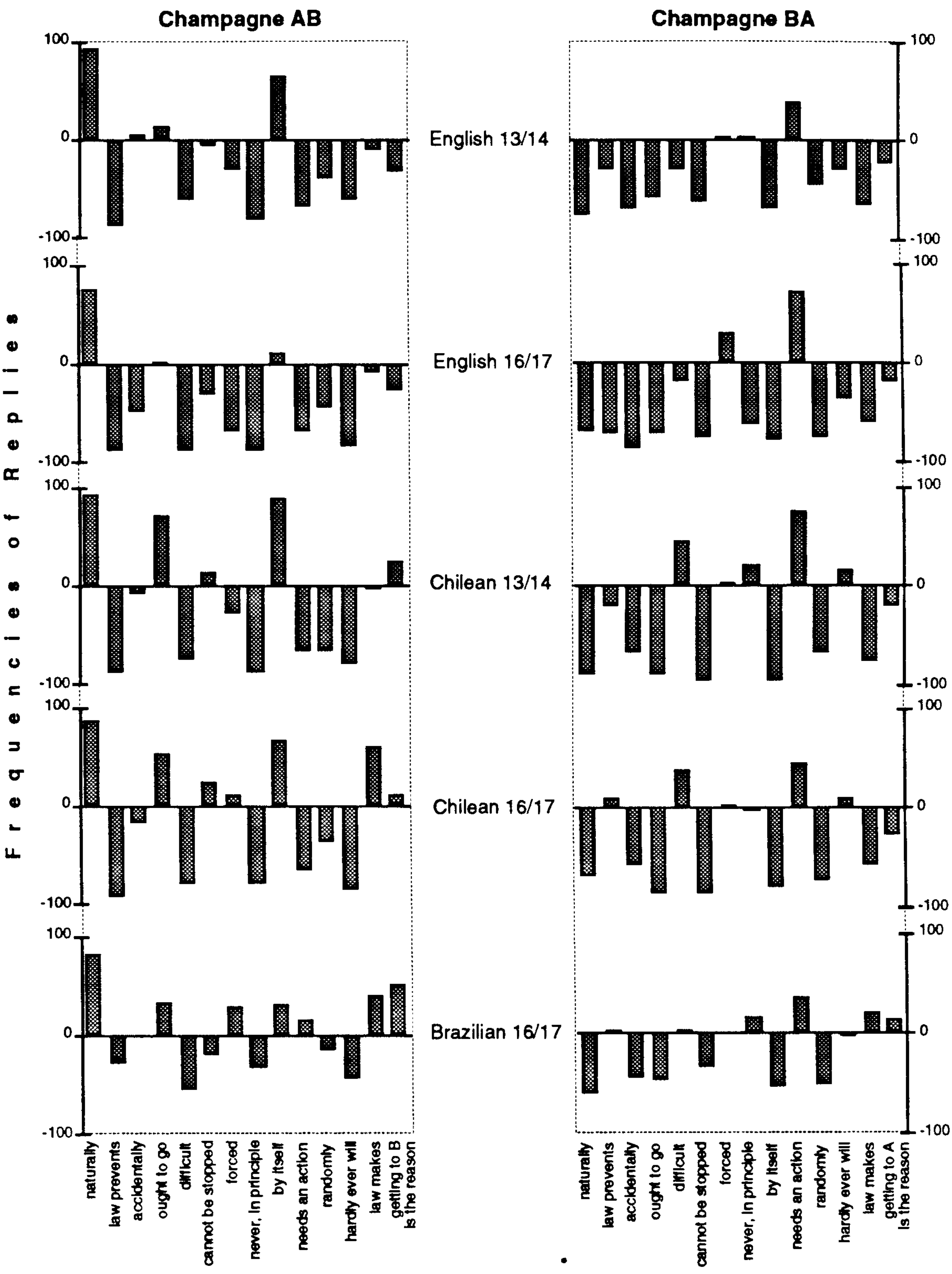


Figure 9.21 - *Frequencies of replies to each phrase for each group for the events Champagne AB and Champagne BA*

9.2.10.2 Backwards

Most answers were in terms of a subject's action on the object (**A**) to restore the initial state, such as 'add CO_2', 're-carbonate it', with causes being a description of what would happen, e.g. 'adding CO_2'. The remainder saw it as not possible, with some giving **R** replies, e.g. 'pour a new glass of champagne', which is much like an **A** reply, and just a few stating that it would be impossible.

In the factor space (Figure 9.20) this event is located towards the 'not happen' side and in the middle of the 'by itself' and 'action' dimensions, excepting the English 16/17 group which sees it as happening more due to an action. This group also sees it as more goal-oriented than do the others.

As happened for the tea cooling, the English 16/17 group seems to assume a more positive attitude towards this event, as if they were expressing 'it is possible to make it happen, when an action is taken'. This is seen in the location in the factor space and is shown by the frequencies of replies to phrases in Figure 9.21, where their profile of replies to phrases connected with the impossibility of something happening is definitely less negative compared with the others (Phrase 2 - 'law prevents it ', Phrase 5 - 'possible, but difficult', Phrase 8 - 'never happens, in principle', and Phrase 12 - 'hardly ever will').

9.2.10.3 Reversibility

This is a natural process reversed by an external action which restores the original state.

9.2.11 CANDLE - 'a candle burns away'

9.2.11.1 Forwards

All answers of all groups were about a natural process (**NH**) with no subject's intervention. e.g. 'leave it', 'allow it to burn'. About half of the causes were a description of what would happen, e.g. 'the wax melts' or a statement about the naturalness of the event, such as 'it is natural'. In the other half causes were related to entities such as 'heat', 'thermal energy', 'fire', 'flame'.

In the factor space (Figure 9.22), all groups place it towards the 'happens' and 'happens by itself' side, given that the Brazilian 16/17 group place it as less likely to happen and the English 16/17 group as less 'by itself' than do the others. In relation to the goal dimension, the English 13/14, English 16/17, Chilean 13/14, and Chilean 16/17 groups locate it towards the 'no goal' side. The Brazilian 16/17 group locates it as goal-oriented.

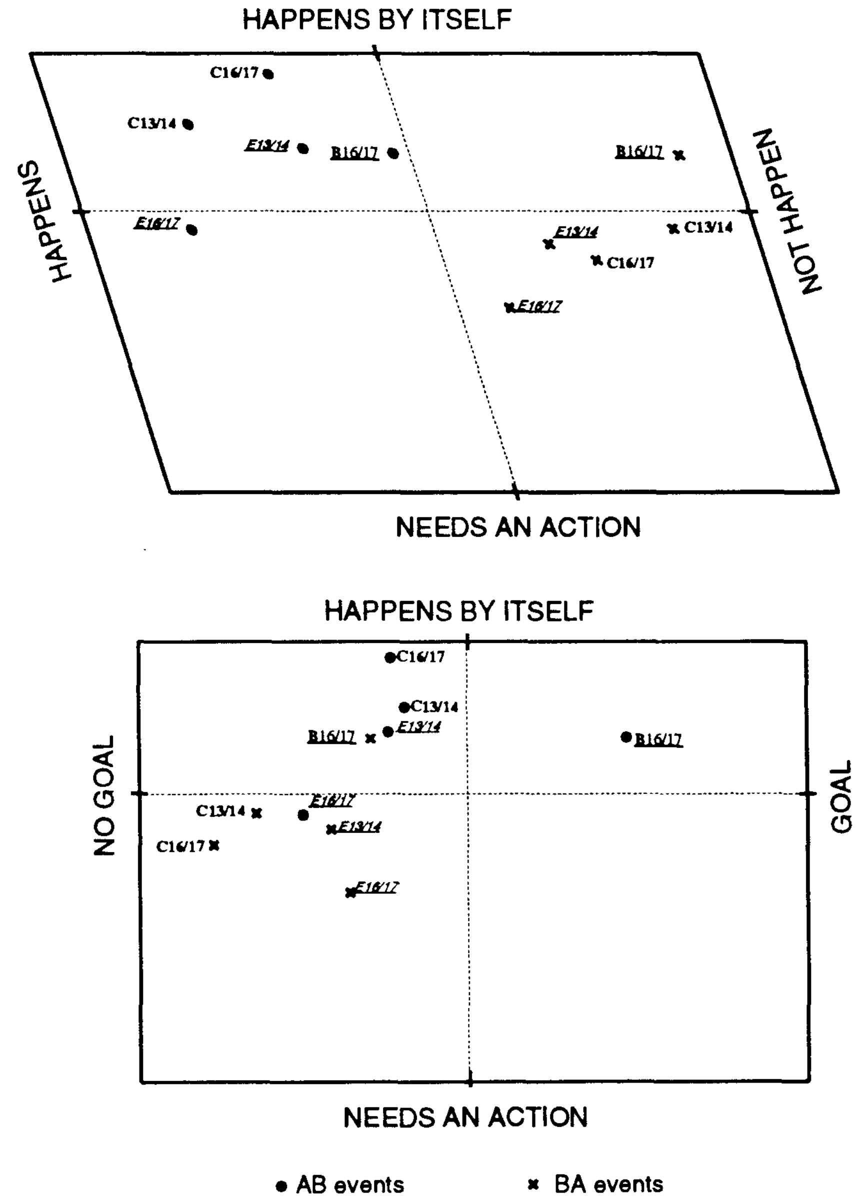


Figure 9.22 - *Plot of the events Candle AB (•) and Candle BA (x) in the common factor space*

Figure 9.23 shows that all groups consider this event as happening naturally (Phrase 1) or spontaneously (Phrase 9). The nearly equal positive and negative replies to Phrase 10 - 'It needs an action to make it happen' - given by the English 16/17 group accounts for their slightly displaced location from the other groups, towards the 'action' side. As pointed out in the description of the Pendulum, the fact that an event happens naturally with no subject's intervention, does not mean that there is no agency involved in the process.

Therefore, in this case it seems that, at least the English 16/17 group sees it as happening naturally due to an external agent associated with entities such as 'heat'.

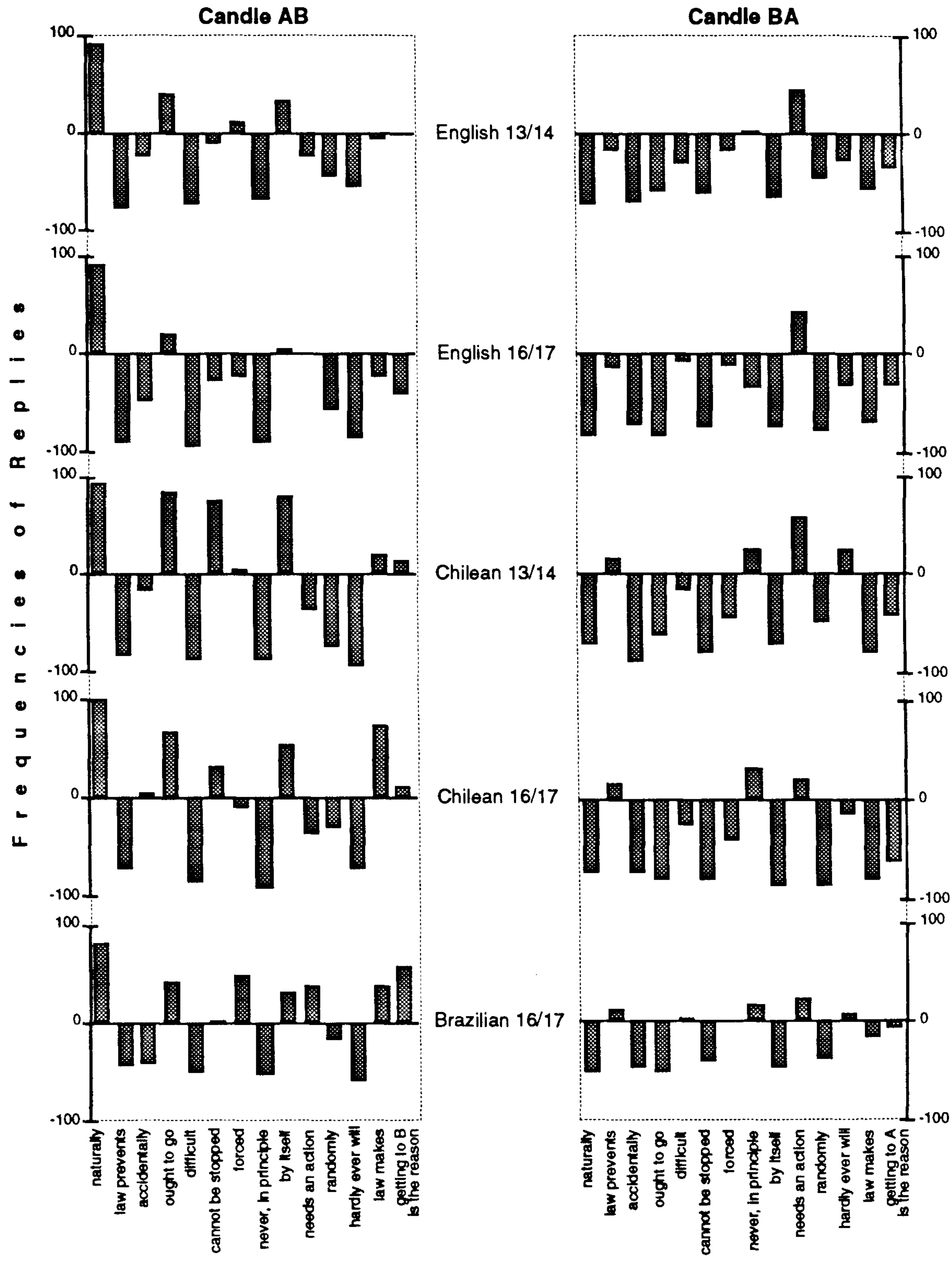


Figure 9.23 - *Frequencies of replies to each phrase for each group for the events Candle AB and Candle BA*

In the case of the Brazilian 16/17 group, the high frequency of replies to the 'action' phrase (Phrase 10) seems to relate to their goal-oriented feature together with the positive profile of Phrase 7 - 'forced to go to B', Phrase 13 - 'law makes it happen', and Phrase 14 - 'getting to B is the reason for the change'.

9.2.11.2 Backwards

On average, two thirds of the answers of all groups saw this event as not possible to happen (**X**). Within this group, less than half of the answers were a statement that it would be impossible, a similar fraction being in terms of **R** replies, e.g. 'buy a new candle', and the few remaining being imaginative answers such as 'go back in time'. The other third of the total were a combination of external action (**A**) such as 're-collect wax and re-shape it'.

In the factor space (Figure 9.22), all groups concentrate this event at the 'not happen' and 'no goal' sides, in between the 'action' and 'by itself' extremities. The English 16/17 group sees it as more likely to happen, and the Chilean 13/14 and Chilean 16/17 see it as less goal-oriented than do the others.

The frequency of replies to phrases (Figure 9.23) shows Phrase 10 - 'It needs an action to make it happen' with a persistent positive profile throughout all groups. Therefore, similarly to the event Boy/Man it seems that even when considered as not possible to happen, the students still think of a possible action to be taken to make it happen.

The location of this event as not possible to happen and happening by itself given by the Brazilian 16/17 group can be explained by their relatively less negative profile of replies to the phrases which define the second dimension, i.e. Phrase 1 - 'It is something which happens naturally', Phrase 4 - 'ought to go to B', Phrase 6 - 'cannot be stopped', and Phrase 9 - 'spontaneously, all by itself', and Phrase 11 - 'randomly' and the less positive profile to Phrase 10 - 'action'. This kind of profile might have a connection with the object/substance dilemma mentioned in section 3.4.1. When answering this question they might have been puzzled by the idea of reversing either the 'object candle', which would demand an subject's action or the 'melted substance', which could reverse naturally.

9.2.11.3 Reversibility

A natural process which is seen as mainly irreversible, but sometimes seen as reversible through actions, close to renewal in nature, which re-establishes the original shape/form (external appearance) using either the same material, e.g. 're-collect wax' or not, e.g. 'add some more wax'. But even in this case it seems that it is not considered as fully reversible because of answers such as 'you could melt some more wax and make the candle longer, *but that would be cheating*'. This fact seems to be expressed by the location of this event in the factor space, when the AB events are placed towards the 'happens by itself' side and the BA events concentrated around the 'not happens' end. Time reversal is mentioned.

9.2.12 PLANT - 'a plant grows'

9.2.12.1 Forwards

All answers of all groups were about a natural process, with most of them seeing it as just happening naturally (**NH**) and some as started by an action (**AN**) such as 'water the plant', 'feed the plant'. Causes were related to either different objects such as 'nutrients of the soil', or the surroundings - 'good conditions', or description of processes such as 'photosynthesis', 'cell reproduction', or a description that can be related to a kind of inner cause such as 'natural growth'. On average, two thirds of the English 13/14, Chilean 13/14, Chilean 16/17, and Brazilian 16/17 groups answered in terms of NH responses, while the other third were AN responses. For the English 16/17 group, answers were equally distributed between them.

In the factor space (Figure 9.24), this event is approximately located in the quadrant 'happens' and 'happens by itself', with the English 16/17 group seeing it as more likely to happen and the Brazilian 16/17 group as less likely to happen than do the others. With respect to the goal dimension, the English 16/17, Chilean 13/14, English 13/14, Chilean 16/17 groups locate it towards the'no goal'side. The Brazilian 16/17 group places it as more goal-oriented. Thus, this event is basically seen by all groups as happening by itself, and due to no goal, excepting the Brazilian 16/17 group which sees it as goal-oriented.

The frequencies of replies to phrases shown in Figure 9.25 reveals that the goal-oriented location by the Brazilian 16/17 group is because of the significant positive profile of answers to Phrase 7 - 'It happens because it was forced to go to B', Phrase 10 - 'needs an action', Phrase 13 - 'law which it happen', and Phrase 14 - 'getting to B is the reason for the change'. The reverse profile to these phrases given by the English 16/17 and Chilean 13/14, explains their location of this event as having no goal.

9.2.12.2 Backwards

There were three different kinds of answers in this case: firstly answers in terms of a subject's action on the object (**A**) such as 'prune the plant' with cause being related to a description of the process, e.g. 'the cutting'; secondly answers in terms of non-intervention (**NH**) such as 'stop feeding the plant', which looks like a kind of answer related to action on circumstances; and finally answers seeing it as not possible (**X**), either declaring that it would be impossible, or giving **R** replies, e.g. 'dig old plant and replace with a new one', or suggesting 'travel in time'.

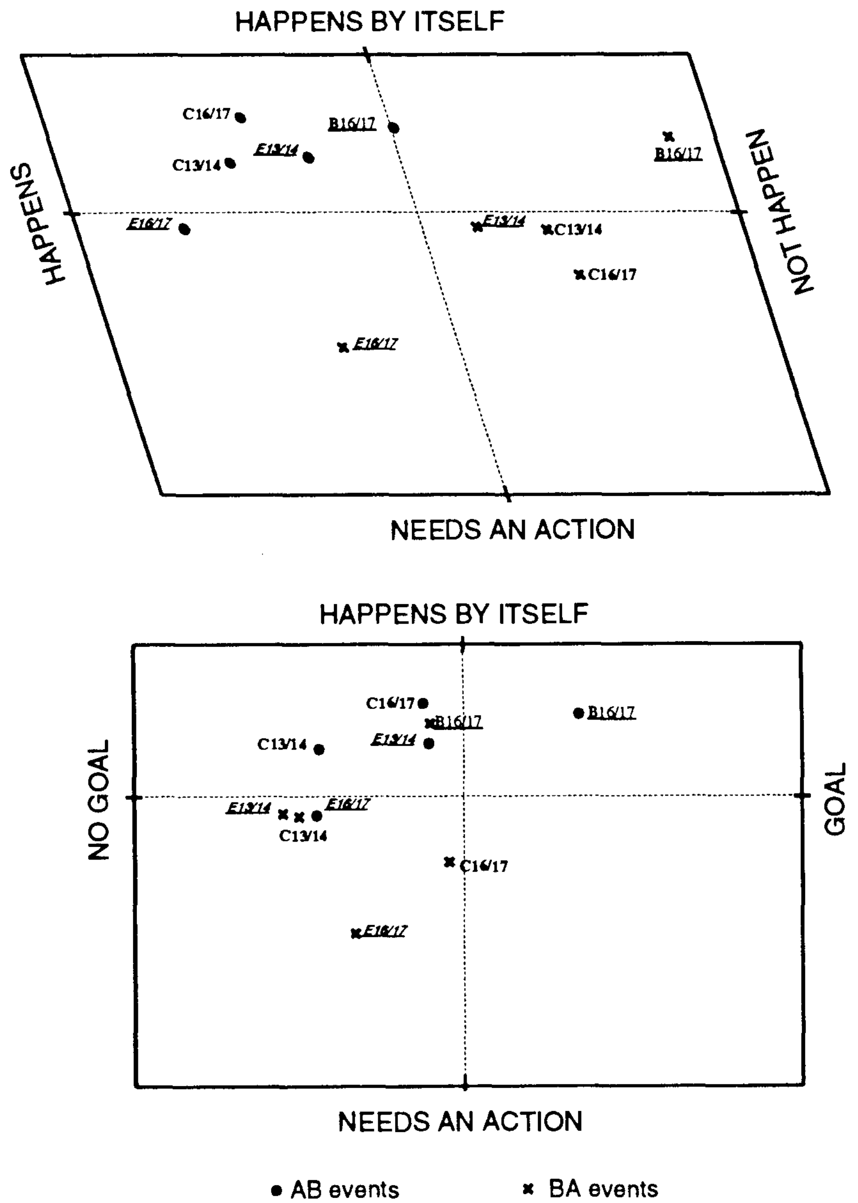


Figure 9.24 - *Plot of the events Plant AB (•) and Plant BA (x) in the common factor space*

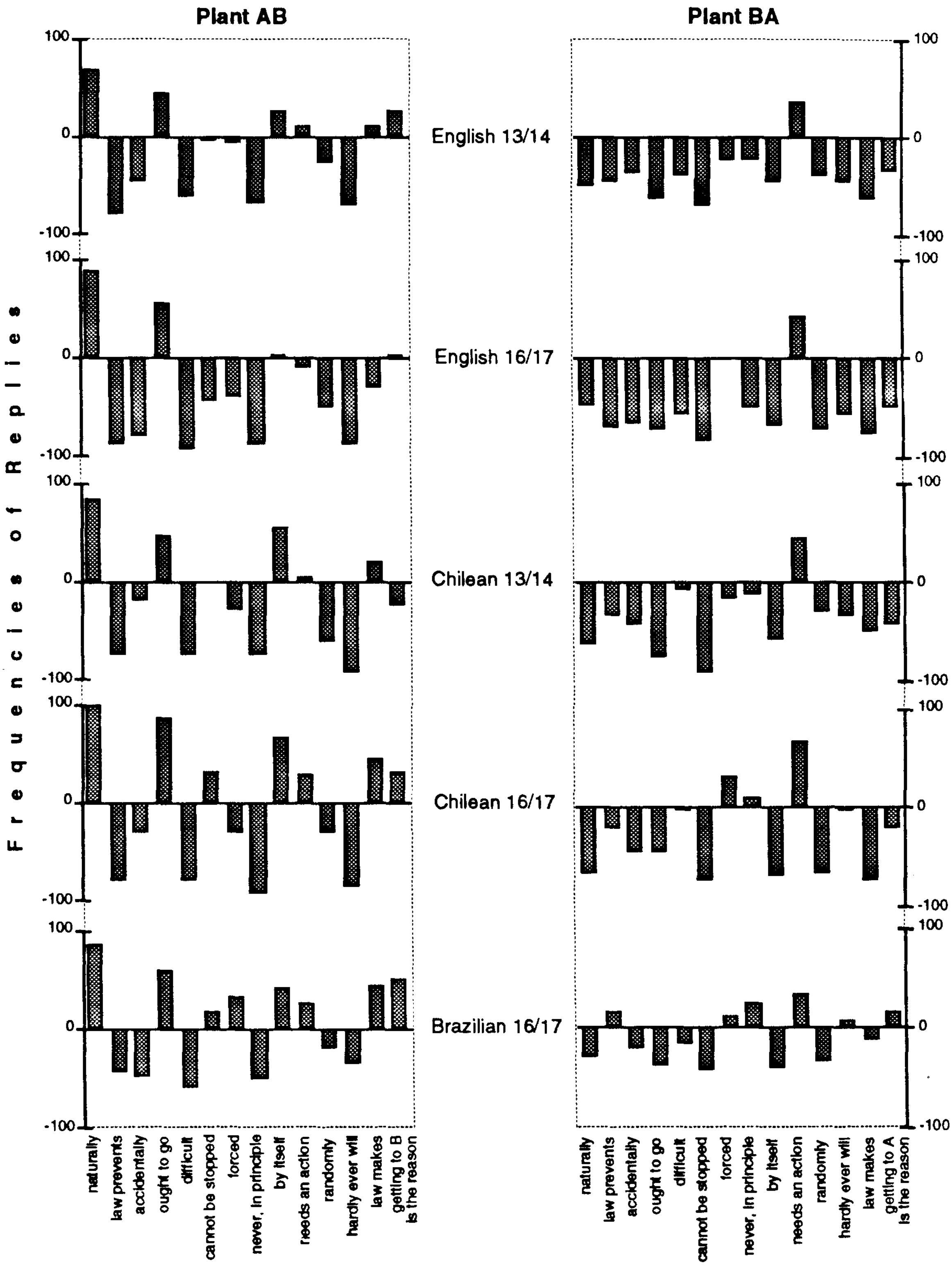


Figure 9.25 - *Frequencies of replies to each phrase for each group for the events Plant AB and Plant BA*

For the English 13/14, Chilean 13/14, and Chilean 16/17 groups about two thirds of the answers were 'A' answers with the reminder being 'X' answers. For the English 16/17 group the overwhelming majority of the answers were 'A' answers, with just a few of the 'X' kind, while for the Brazilian 16/17 group the answers were similarly distributed among them.

In the factor space (Figure 9.24) the Brazilian 16/17 group located this event at very end of the 'not happen' extremity and towards the 'by itself' side. The English 16/17 in opposition, locates it towards the 'happen' and 'needs an action' sides, while the other groups located it less extremely, in the quadrant 'not happen' and 'needs an action'. All groups see this event as having no goal, with the English 13/14 and Chilean 13/14 placing it most towards the 'no goal' extremity.

Although the location of the events in the factor space might seem to contradict the answers to the open-ended questions, the frequency of replies to phrases in Figure 9.25 can shed some light on this aspect. The English 16/17 group are quite positive about the idea that through an action, this process can be reversed (significant positive frequency of replies to Phrase 10 - 'action ', and high negative frequencies of replies to phrases expressing the impossibility of something to happen, Phrase 2 - 'law prevents it happening', Phrase 5 - 'possible, but difficult', Phrase 8 - 'It could never happen in principle', and Phrase 12 - 'could happen but hardly ever will'), perhaps because for them what matters is 'getting the same appearance'. These responses lead to it being located in the quadrant 'happens' and 'needs an action'.

The Brazilian 16/17 group is the most pragmatic, in the sense that, although giving a relatively positive frequency of replies to the 'action' phrases (Phrase 7 and Phrase 10), which can be understood as them thinking of an action which could reverse the process, the frequency of replies to the phrases expressing the impossibility of something to happen, just cited above, are definitely not very negative, therefore locating it at the very end of the 'not happen' extremity.

In between come the English 13/14, Chilean 13/14 and Chilean 16/17 groups with a relatively positive profile of replies to the 'action' phrases and with a frequency of replies to the phrases expressing the impossibility of something to happen more prominently negative than the Brazilians and less so than the English 16/17 group.

Regarding the 'NH' answers, it seems that although considering this event as not possible to happen, when the students give this sort of answer, they are conceiving the process of dying as a way of reversing it. In the case of the Brazilian 16/17 group this situation is slightly clearer when just a very few students declare 'dying' as a way of reversing it, or in the specific case of a student who explain, 'there is no way of getting the plant as it was before, but it is going to decrease'. Yet, there is a student suggesting the action of 'killing it' as a means of reversing it.

9.2.12.3 Reversibility

This is mainly a natural process, sometimes started by action, and not reversible, except by an external action. However, the reversibility by means of an action is related to the restoring of the original shape/appearance. Some considered the process of dying as a means of reversing. Time reversal is mentioned.

9.2.13 SWING - 'the swing comes back'

9.2.13.1 Forwards

All answers were about a natural process, seeing it either as just happening (NH), e.g. 'let it swing', or as started by an action (AN), e.g. 'push the swing'. In the first type, causes were basically associated with entities such as 'gravity', 'momentum', while in the second, causes were mostly a description of the action itself, e.g. 'force applied'. Over half of the answers given by the English 16/17 group were in terms of 'NH', with the remainder being in terms of 'AN' answers, while the reverse happened with the English 13/14 group. The answers given by the Chilean 13/14 and Chilean 16/17 groups were similarly divided between these two types. For the Brazilians, most of the answers were in terms of 'AN' type.

In the factor space (Figure 9.26) the English 16/17 group locates it at the very end of the 'happens' extremity towards the 'action' side. The others located it as more happening by itself, although the Brazilian 16/17 group sees it as less likely to happen than do the others. They all locate it towards the goal side, with the Brazilian 16/17 group seeing it as more goal-oriented.

Figure 9.27 shows that the goal-like feature given by the Brazilian 16/17 group is explained by the high profile of responses to Phrase 7 - 'forced to go to B', Phrase 10 - 'action', Phrase 13 - ' law makes it happen', and Phrase 14 - 'getting to B is the reason for the change'.

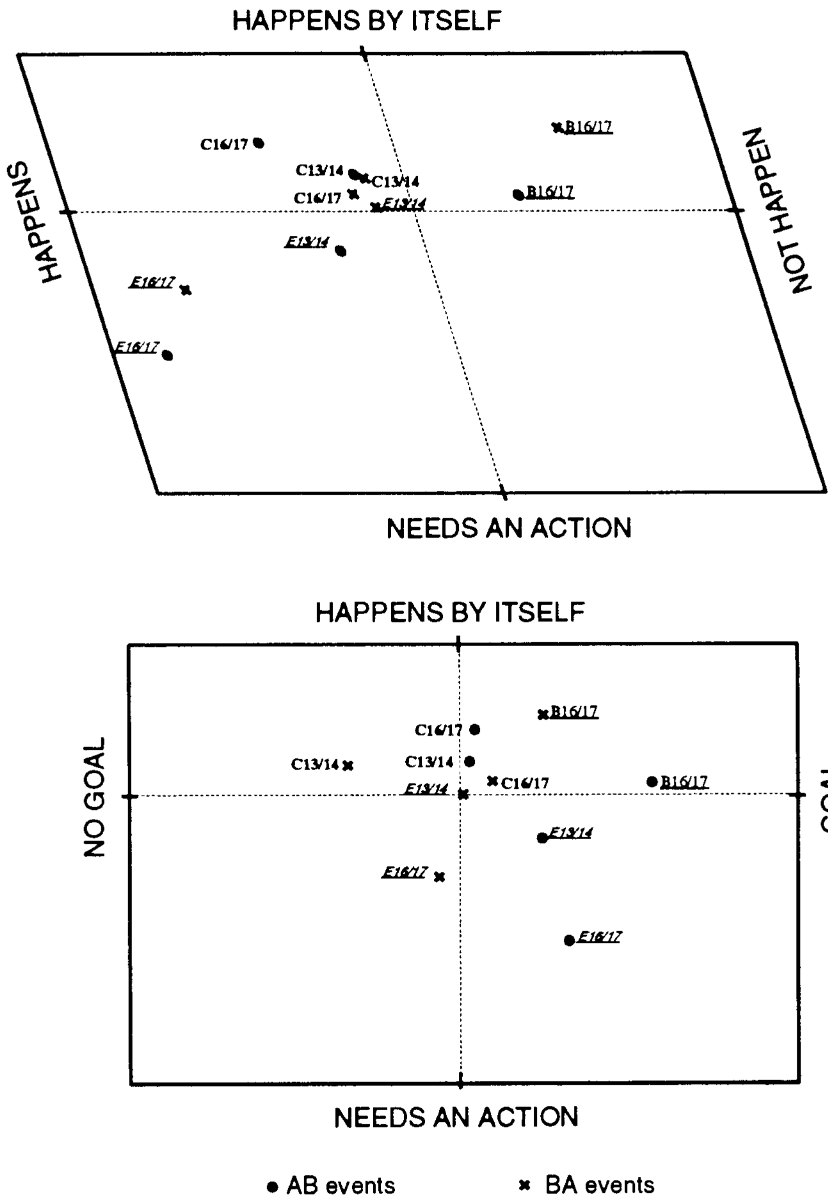


Figure 9.26 - *Plot of the events Swing AB (•) and Swing BA (x) in the common factor space*

Again in this case, the profile of replies to Phrase 2 - 'There is a law which prevents it happening', Phrase 5 - 'It is possible, but difficult to do in practice', Phrase 8 - 'It could never happen in principle', and Phrase 12 - 'It could happen but hardly ever will', reveals that the English 16/17 group is more positive about the fact that it is possible to take an action to reverse this process, while the Brazilians are more sceptical with their low negative profile on these phrases.

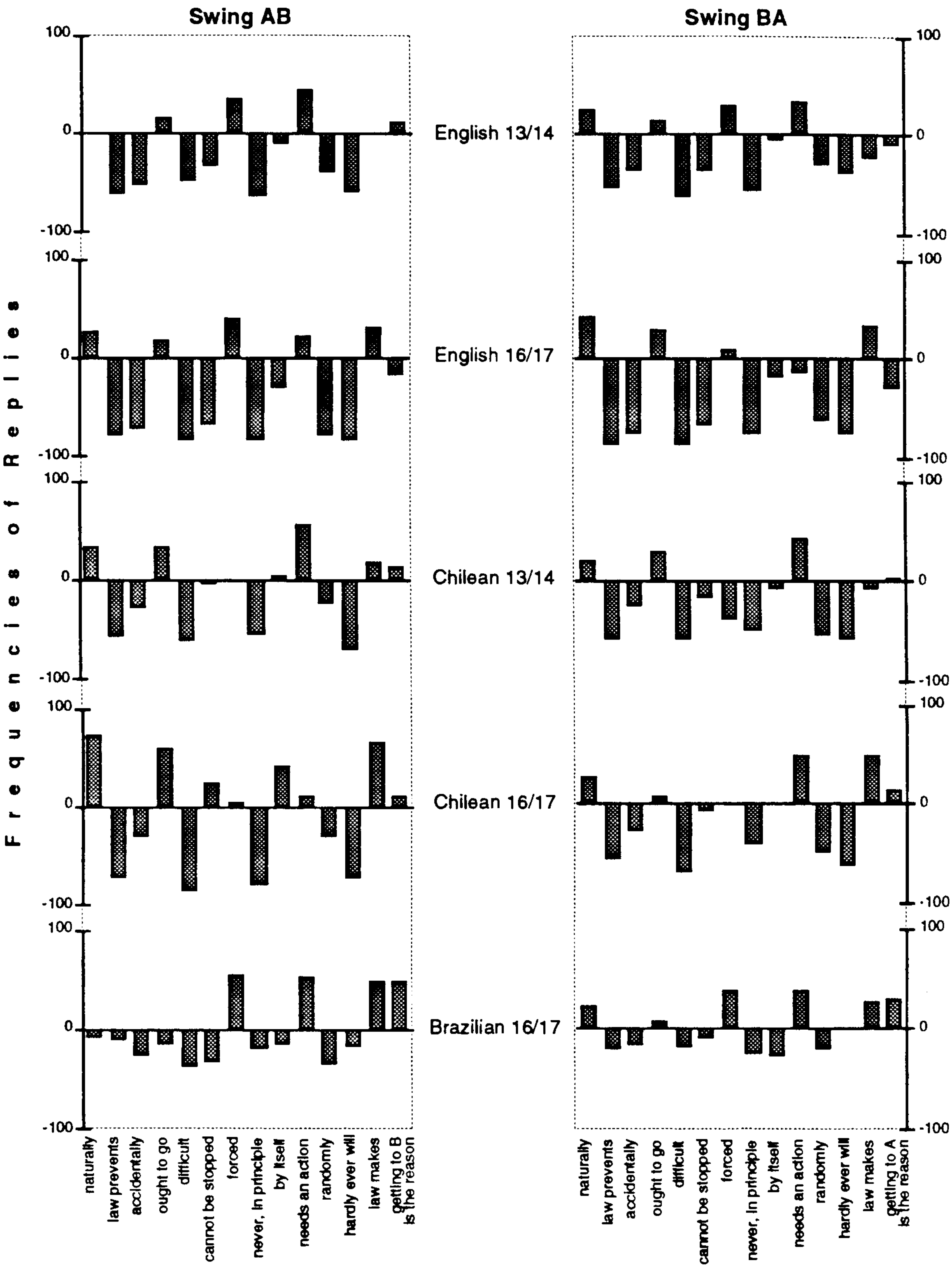


Figure 9.27 - *Frequencies of replies to each phrase for each group for the events Swing AB and Swing BA*

9.2.13.2 Backwards

Similarly to the event Falling Ball, the general description of this phenomenon happening backwards is very analogous to the description of it happening forwards. All answers were about a natural process seen as either a just happening (**NH**), e.g. 'let it swing', or triggered by an action (**AN**), e.g. 'give it a push', 'by propelling the swing with your body'. As in the forward process, in the first case, cause were basically associated with entities, while in the second causes were mostly a description of the action itself. The distribution of answers among the groups were very similar to that described when the phenomenon was happening forward, and yet, on average, the same subjects gave the same kind of answers in both directions.

In the factor space (Figure 9.26) the location of this event for each group is rather similar to the location of the same phenomenon happening forwards. The English 16/17 group sees it as happening due to an action while the others see it happening more by itself. Regarding the goal dimension, there is a overall shift towards the 'no goal' side, excepting for the Chilean 16/17 group, with the Brazilian 16/17 group still seeing it as more goal-oriented than do the others. Comparing the AB and BA events at the same time, the English 13/14, English 16/17, and Brazilian 16/17 groups tend to see it as happening more naturally than when happening forwards.The Chilean 13/14 group places them very close together.

Likewise, to certain extent the profile of responses to phrases is similar (Figure 9.27). Therefore, the way this event is seen when happening backwards is similar to the situation when it is happening

9.2.13.3 Reversibility

This is a reversible process involving natural changes in both directions. Sometimes it is considered as started by an action. In the factor space the AB and BA event are placed close together by each group, thus considered as happening in a similar way.

9.2.14 SPRING - 'the spring is stretched a little'

9.2.14.1 Forwards

Most of the answers of all groups were related to a subject's intervention (**A**). Answers were of two kinds:

• 1. the addition of some *weight* on the existing weight such as 'put more weight on';

• 2. the application of a *force* on the weight, such as 'pull the spring'.

Causes were mainly a description of what would happen such as 'increase of weight', or 'the stretch of the spring', with some related to entities such as 'gravity', 'applied force'. There were some answers in terms of a non-intervention, e.g. 'gravity pulls the weight down', 'the weight stretches it.

For the English 16/17 group most of the answers were of type 1 above, while for the Chilean 13/14 group they were of type 2. For the English 13/14 group answers were equally distributed between the two types. For the Chilean 16/17 and Brazilian 16/17 groups most of the answers were of type 2. In relation to the non-intervention answers, for the English 13/14, English 16/17 and Chilean 13/14 groups there were a few, while for the Chilean 16/17 and Brazilian 16/17 groups there were a significant proportion.

In the factor space (Figure 9.28) the English 16/17 group locates this event in the quadrant 'happens' and 'needs an action', in opposition to the Brazilian 16/17 group who locate it in the quadrant 'happens by itself' and 'not happen'. The English 13/14, Chilean 13/14 and Chilean 16/17 groups place this event in the middle of the plot, with the latter seeing it as more happening by itself than do the others. They all locate it towards the goal side, with the Brazilian 16/17 group placing it as more goal-oriented than do the others.

The frequencies of replies to phrases (Figure 9.29) reveal that the phrases which define the dimension 'by itself-action', Phrase 1 - 'It is something which happens naturally', Phrase 3 - 'It happens accidentally', Phrase 9 - 'It happens spontaneously, all by itself', and Phrase 11 - It happens by some random process', have a low negative profile of answers for the Brazilian 16/17 group, and some positive frequencies for the Chilean 16/17 group, which explains their location towards the 'happens by itself' side. Yet, the low negative profile of answers to phrases connected with the impossibility of something happening, Phrase 2 - 'There is a law which prevents it happening', Phrase 5 - 'It is possible, but difficult to do in practice', Phrase 8 - 'It never happens, in principle', and Phrase 12 - 'It could happen but hardly ever will', explains their location as less likely to happen than the others.

The goal-like feature for Brazilian 16/17, English 16/17, and Chilean 16/17 groups are explained by the positive frequency of replies to the 'action' phrases (Phrases 7 and 10) and the positive or nil frequency of replies to Phrase 13 - 'There is a law which makes it happen', and Phrase 14 - 'It happens because getting to B is the reason for the change'

9.2.14.2 Backwards

The distribution of answers for this case is very similar to those given for this phenomenon happening forwards: most answers were in terms of an action (**A**), with some related to a non-intervention. Similarly to the event See-Saw, the action answers were in terms of the inversion of the answers given for the forward direction. This inversion was in terms of the *reverse of the action* taken to go forwards, such as 'remove the weight', 'push it up', with causes being a description of what would happen. There were some answers related to a non-intervention, 'let it go'.

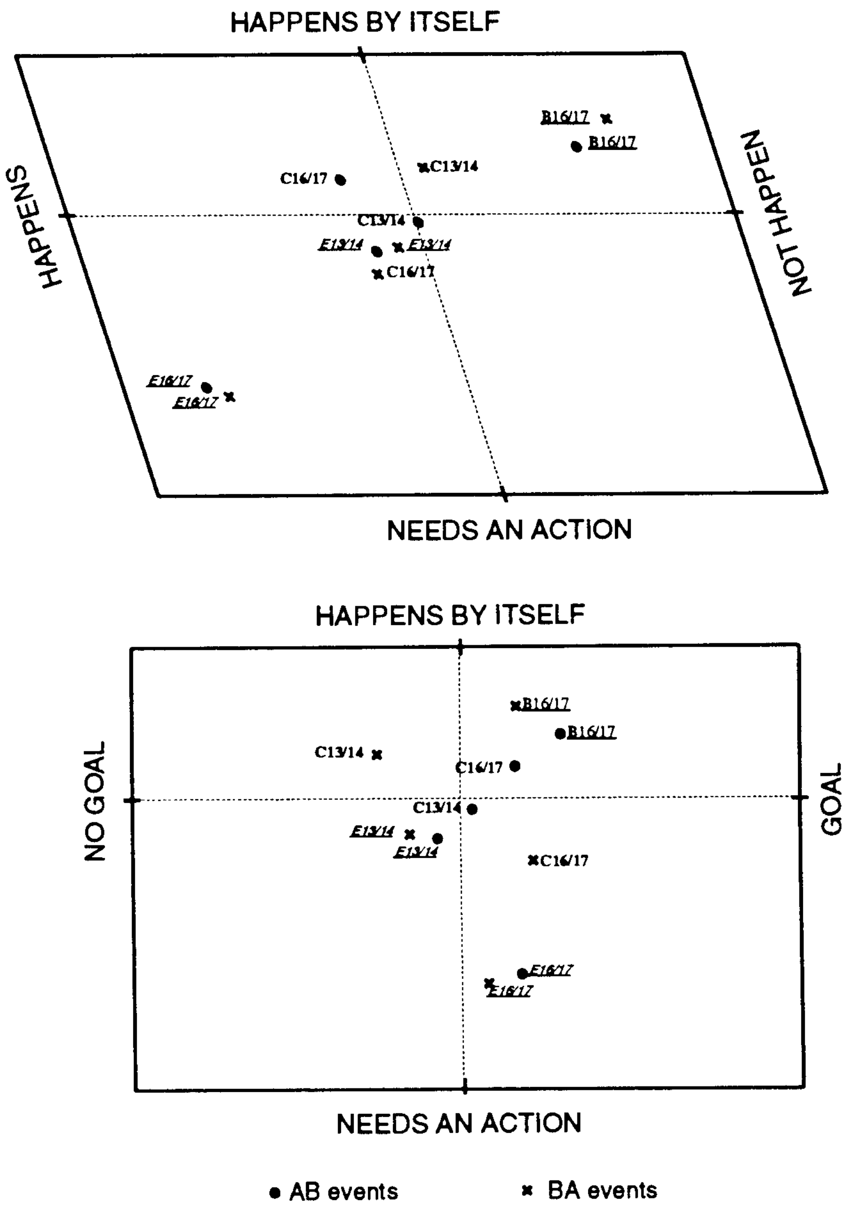


Figure 9.28 - *Plot of the events Spring AB (•) and Spring BA (x) in the common factor space*

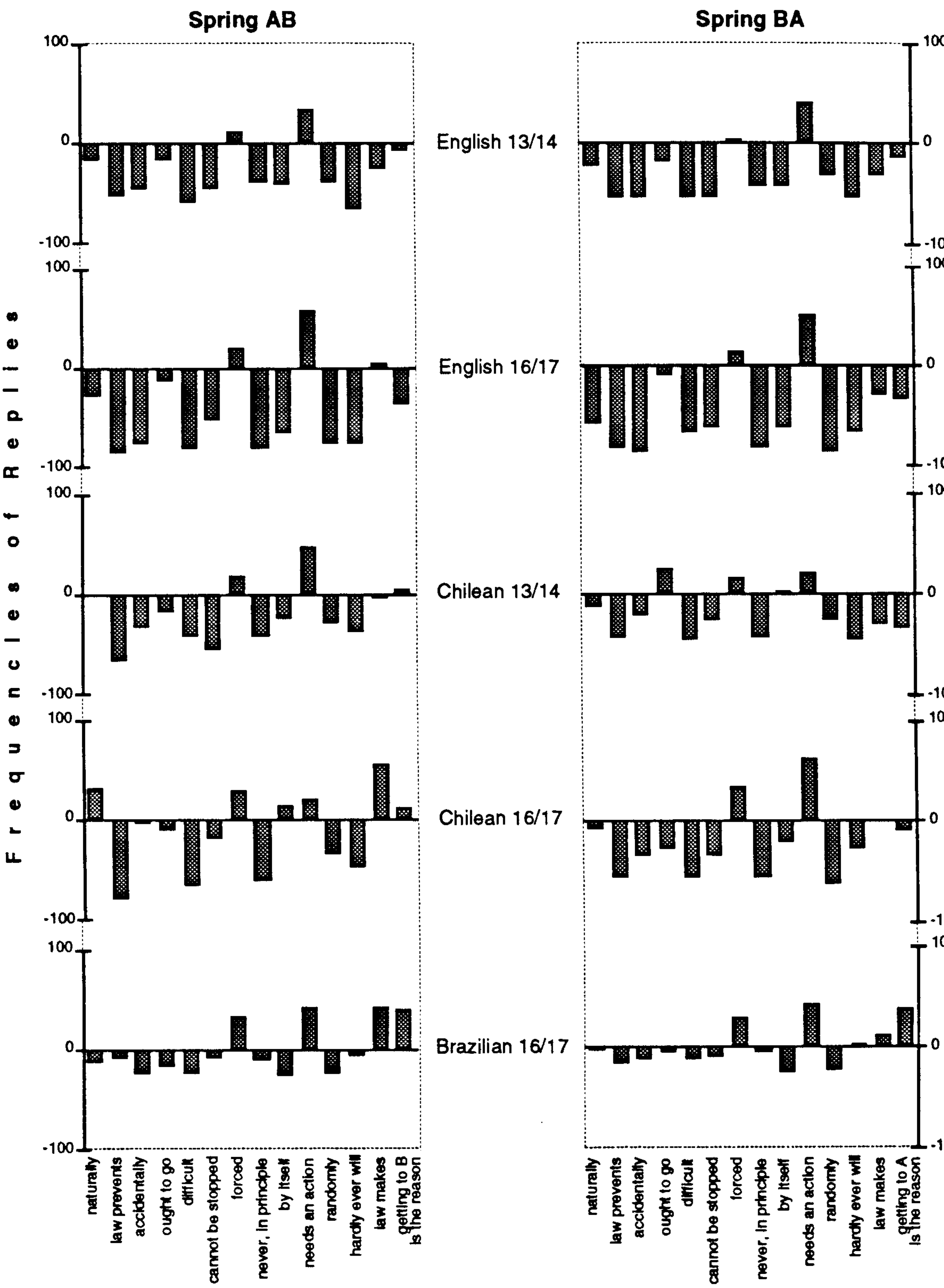


Figure 9.29 - *Frequencies of replies to each phrase for each group for the events Swing AB and Swing BA*

The location of this event in the factor space shown in Figure 9.28 is very similar to the location of the same phenomenon happening forwards, as are the frequencies of replies to phrases shown in Figure 9.29. The English 16/17 group seeing it as happening due to an action, the Brazilian 16/17 group as less likely to happen, but by itself, and the others locate it in the middle of the plot. Similar to the Swing, there is a slight shift in its location towards the no-goal side. Comparing the AB and BA events at the same time, the English 13/14, English 16/17, and Brazilian 16/17 groups locate them very close together while the Chilean 13/14 and Chilean 16/17 groups put them a little apart. Therefore, this phenomenon happening forwards and backwards has the same basic structure of description.

9.2.14.3 Reversibility

This is a process seen as started by an action, and reversed by an external action to restore the initial configuration. The action taken to go back is the reverse of the action taken to go forwards. Likewise the events Falling Ball, See-Saw and Swing, the AB and BA events are placed close together by each group.

9.3 Summary of Description of Events

Table 9.1 presents a summary of the description of each event given by each group of students, in which the majority view is described by the symbols used in the systemic network shown in Figure 9.1.

When different views are equally important, they are all represented, as for the extreme case of the event Candle BA (**I/R/A**), where the answers were roughly distributed among the three kinds of answers, i.e., 'I' for impossible, 'R' for renew, and 'A' for subject's action. In the case of the event Boy/Man, although there is a different distribution of 'I', 'R', and 'Im' answers, they are all 'X' (not possible) answers, and are therefore classified as such. In the case of the events Falling Ball and Swing, besides having two equally important views (**NH** and **AN**), the same group of students gave the same kind of answer to the forward and backward process, thus represented differently by **NH-AN**.

Table 9.1 - *Summary of the description of the events in both questionnaires for each group in separate*

EVENT	FORWARDS - AB					BACKWARDS - BA				
	E13/14	E/1617	C13/14	C16/17	B16/17	E13/14	E/1617	C13/14	C16/17	B16/17
PENDULUM	NH	NH	A	NH	A	A	A	A	A	A
ICE-CREAM	NC	NC	NC	NC	NC	A	A	A	A	A
PUDDLE	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
CAR	NC	NC	NC	NC	NC	A/R	A/R	A	A	A
BOY/MAN	NH	NH	NH	NH	NH	X	X	X	X	X
FALLING BALL	NH-AN	NH-AN	NH-AN	NH-AN	NH-AN	NH-AN	NH-AN	NH-AN	NH-AN	NH-AN
SEE-SAW	A	A	A	A	A	A	A	A	A	A
SLOPE	NH	NH	NH	NH	NH	A	A	A	A	A
TEA	NH	NH	NH	NH	NH	A	A	A	A	A
CHAMPAGNE	NH	NH	NH	NH	NH	A	A	A	A	A
CANDLE	NH	NH	NH	NH	NH	I/R/A	I/R/A	I/R/A	I/R/A	I/R/A
PLANT	NH	NH	NH	NH	NH	A/X	A	A/X	A/X	NH/A/R
SWING	NH-AN	NH-AN	NH-AN	NH-AN	NH-AN	NH-AN	NH-AN	NH-AN	NH-AN	NH-AN
SPRING	A	A	A	A	A	A	A	A	A	A

* NH = happens naturally
NC = happens naturally under circumstances
A = action process
AC = action triggers natural process
X and I = not possible
R = renew

Considering the five groups of students as a whole group, and looking at the average pattern of answers described in Table 9.1, an overall summary of the description of each event is presented in Table 9.2. This table also includes the students' view about the reversibility of each phenomenon.

The events Pendulum, Car, Candle, Falling Ball, Swing and Plant are described in more than one way. The event PENDULUM is seen as happening forwards either naturally or by means of a subject's action. However, even when seen as happening naturally, action seems to play an implicit important role, inasmuch as causes are associated with external agents such as 'gravity'. This fact might explain the location of this event in the factor space towards the 'needs an action' extremity (Figure 9.2). Thus, action, associated with either the subject or any other entity, seems to be the main aspect underlying these two kinds of view.

The event CAR is seen as happening backwards through a subject's action, or as not possible to happen (via '**R**' answers). However, 'R' responses are very like 'A' responses, in the sense that the former also demand a subject's action to renew the elements involved in the event. Yet, although a subject's action to reverse the process is involved in both kinds of responses, considering the location of this event in the factor space towards the 'not happens' extremity (Figure 9.8), it seems that there is a tendency to consider the reversal as not likely to happen.

Table 9.2 - *Overall summary of the description of the events*

EVENT	DIRECTION		REVERSIBILITY	
	AB	BA	√ or x **	Description
PENDULUM	NH/A*	A	√	action reverses natural process, action reverses action process
ICE-CREAM	NC	A	√	action reverses natural process
PUDDLE	NH	NH	√	reversible natural process
CAR	NC	A/R	√/x	action reverses natural process/ irreversible natural process
BOY/MAN	NH	X	x	irreversible natural process
FALLING BALL	NH-AN	NH-AN	√	reversible natural process, action reverses action process
SEE-SAW	A	A	√	action reverses action process
SLOPE	NH	A	√	action reverses natural process
TEA	NH	A	√	action reverses natural process
CHAMPAGNE	NH	A	√	action reverses natural process
CANDLE	NH	I/R/A	√/x	irreversible natural process/ action reverses natural process
PLANT	NH	A/X	√/x	action reverses natural process/ irreversible natural process
SWING	NH-AN	NH-AN	√	reversible natural process, action reverses action process
SPRING	A	A	√	action reverses action process

** √ = reversible, x = irreversible

* NH = happens naturally A = action process X and I = not possible

NC = happens naturally under circumstances AC = action triggers natural process R = renweal

A similar analysis can be done for the event CANDLE. Although, 'R' answers are like 'A' answers, they are associated with the impossibility of reversing the process. Together with the 'I' answers, they represent the major part of the responses and seem to account for the location of this event towards the 'not happens' extremity in the factor space shown in Figure 9.22. Therefore, they are better characterised as indicating an irreversible natural process.

The events FALLING BALL and SWING have a similar pattern of description. Although characterised by two kinds of answers, 'NH' and 'AN', both are about a natural process either just happening or triggered by an action.

The event PLANT is seen either as irreversible or reversible by an action. However its location in the factor space (Figure 9.24) shows that is better characterised as irreversible. The picture presented in the questionnaire may have lead the students to visually consider it as reversible.

The next step is to seek different ways in which the events could be grouped, based upon the way they are described. A first aspect to consider is whether an event is seen as reversible or not, and how it happens. A second aspect is concerned with the naturalness of the process, i.e., whether it happens naturally with no necessity of either taking any external action or providing necessary 'natural' circumstances.

9.4 Action: what is the role played by action in the process?

The description of the events summarised in Table 9.1 and Table 9.2 shows that most of the events happening forwards are seen as natural processes, when the subject makes no intervention in the process. However, when happening backwards, the subject plays an important and decisive role in the process, because it is seen as being caused by the subject's action. Therefore, the role played by action can be described more in detail, firstly in the process happening forwards, secondly happening backwards and finally considering both directions so as to describe the event as a whole, and try to group the events according their similarities.

9.4.1 Events happening forwards: the envisaging of events involving action

9.4.1.1 The Subject: The First Agent

Some of the events included in the questionnaires were represented by drawings showing a situation as if it were already happening: the pendulum and the swing were already swinging, the ball in the event Falling Ball was already falling down, while in the event Slope it was about to roll down. Therefore, in principle, none of the drawings would lead the student to think of an action as a means of causing the events the drawings were representing.

However, many subjects answered these questions in terms of an action, for instance: 'push the pendulum', 'push the swing', 'push the ball' or 'drop the ball from your hand'. Therefore, it seems that although it is not necessary to think of any action to cause these events, these subjects envisage the happening of these events by means of an action.

9.4.1.2 The Implicit Action of "Natural Causal Agents"

The summary of the description of the events in Table 9.2 shows that the events PENDULUM, ICE-CREAM, PUDDLE, CAR, SLOPE, TEA, and CANDLE are all basically considered as happening naturally, with no subject's intervention.

However, the detailed description of each event in section 9.2 reveals that this does not mean that there is no action involved in the process. When the students associate the causes of the events with entities such as 'gravity', 'heat energy', it seems that they are considering these entities as implicit external agents causing these events, in that the profile of replies to the 'action' phrases (Phrases 7 and 10) are significantly positive.

As already pointed out, this is clearly revealed in a few cases when the subjects gave explicit responses such as 'due to the action of the heat of the sun', 'do nothing, let it happen naturally (due to gravity)', 'action of water', 'action of time'. Therefore, although the subject seems to be the major causal agent of events, it seems that these entities are also considered as 'natural causal agents'.

9.4.2 Events happening backwards: reversibility through an action

Half of the phenomena included in the questionnaires were seen as possible to be reversed just through a subject's action on the object. They were basically the physical changes, i.e., PENDULUM, ICE-CREAM, SEE-SAW, SLOPE, TEA, CHAMPAGNE, and SPRING.

The events FALLING BALL, SWING, CAR, CANDLE, and PLANT were also seen as possible to be reversed through an action. The events Falling Ball and Swing are seen as naturally reversible, but also as reversed through an action which triggers the natural process. The events Car, Candle and Plant are basically seen as not possible to be reversed, but are also seen as reversible through an action to restore the original shape or appearance. In the case of Car and Candle the 'renew' answers such as 'buy a new car' or buy a new candle', are in fact very much action-like responses.

There were just two events for which the process of reversing was not explicitly explained through a subject's action: BOY/MAN and PUDDLE. The event Boy/Man was considered as not possible to happen, with no possible action to be thought of to reverse it. However there were 'R' responses which are like 'action' answers. Therefore, as already pointed out, it seems that even when an event is openly considered as impossible to happen, there is often some kind of action that can be thought of as a means to reverse it, even if the result of the action does not produce the proposed reversion.

In the case of the event Puddle, no subject's action was considered because it was seen as a reversible natural process. However, action still seems to play an important role, because of the profile of replies to the action phrases (Fig. 9.7) and the few explicit answers related to action such as 'it must have an action in order for the water became liquid' or 'the action by which the water becomes liquid'.

Therefore, it seems that when thinking of reversing a process, in many cases, action is thought of as the means of doing it. Even when the process is not possible, there is often some action that can be thought of as possible to reverse the process, even if it is an imaginative action, such as those related to reversal of time: 'travel back in time'.

9.4.3 Forwards and Backwards: how the whole phenomenon is described

Considering both forward and backward directions, each event can be described as a whole process, and all events can be grouped according their similarities, as summarised in Table 9.2. A number of categories of events are discussed below.

9.4.3.1 Reversible Natural Process

PUDDLE - 'water in a puddle evaporates'
FALLING BALL - 'the ball falls and bounces back up'
SWING - 'the swing comes back'

These events are seen as natural processes with natural reversion. As previously mentioned, the event Puddle is the unique true reversible natural process, when no subject's action is considered in both forward and reverse directions. The events Falling Ball and Swing are also classified in other categories.

9.4.3.2 Natural Process reversed through an action

PENDULUM - 'a pendulum stops swinging'
ICE-CREAM- 'an ice-cream melts'
CAR - 'a car rusts away'
SLOPE - 'a ball rolls down'
TEA - 'a cup of tea becomes cold'
CHAMPAGNE - 'the champagne goes flat'
CANDLE - 'a candle burns away'
PLANT - 'a plant grows'

These processes are seen as happening forward naturally, i.e. with no subject's intervention, but reversed by a subject's action. The events Pendulum, Car, Candle, and Plant are also considered in other categories. Particularly in the case of Car and Candle, although considered mainly as not possible, the 'renew' replies - **R** - resemble action responses. In the case of Plant the reversal is related to the restoring of the original external appearance/shape.

9.4.3.3 Natural process triggered by an action, reversed through an action which triggers a natural process

FALLING BALL - 'the ball falls and bounces back up'
SWING - 'the swing comes back'

These events are seen as natural phenomena, as classified previously, but in this case seen as triggered by an subject's action in both directions.

9.4.3.4 Non-Natural Process Reversed through an Action

SEE-SAW - 'the see-saw is tilted a little'
SPRING - 'the spring is stretched a little'
PENDULUM - 'a pendulum stops swinging'

These processes are seen as happening forward and backwards by means of a subject's action.

9.4.3.5 Irreversible natural process

BOY/MAN - 'a man grows old'
PLANT - 'a plant grows'
CAR - 'a car rusts away'
CANDLE - 'a candle burns away'

The unique event considered as irreversible is Boy/Man. Even so, there were a significant number of answers suggesting that an action could be taken to reverse this process, e.g., 'plastic surgery', travel back in time', although at the same time they gave some explanations such as 'you cannot change age, but you can make him look younger'. Therefore, it seems that sometimes, even thinking of some events as irreversible, students still consider the possibility of taking any action, either real or imaginative, to 'reverse' the process, which in this case seems to be thought of as getting back to the original external appearance, by any means. A similar analysis can be made for the events Car and Candle, when the students suggested 'buy a new car', which can be understood as more like as a 'start again' than a 'go back'.

A summary of the description of the events according to this categorisation is shown in Table 9.3.

9.5 The whole-part view

Regarding the events considered in section 9.4.1.1 - PENDULUM, SWING, FALLING BALL, and SLOPE -, there is another aspect to be considered. When the subjects answer the questions in terms of an action, it seems that they are not focusing their attention on just the event represented by the drawing, but they are considering the whole phenomenon, as if they were tracing back what would have happened since the beginning.

For instance, considering the event Falling Ball, it appears that they are thinking: the ball is falling down, therefore, before that someone has to have taken the ball in his/her hand, and after holding it from a height, dropped it in the air, thus, acting on the object to have the situation shown in the drawing. Therefore, it seems that, first of all they have to conceive the whole phenomenon so as to envisage the part represented by the drawing, i.e. the event. This fact can be noticed from answers such as 'drop the ball from a height'.

Table 9.3 - *Summary of the Description of Events*

DESCRIPTION OF EVENT	EVENT
NATURAL REVERSIBLE PROCESS	Puddle Falling Ball† Swing†
NATURAL PROCESS REVERSED THROUGH AN ACTION	Pendulum* Ice-Cream Car• Slope Tea Champagne Candle• Plant•
NATURAL PROCESS TRIGGERED BY AN ACTION IN BOTH DIRECTION	Falling Ball† Swing†
NON NATURAL PROCESS REVERSED THROUGH AN ACTION	See-Saw Spring Pendulum*
IRREVERSIBLE NATURAL PROCESS	Boy/Man Plant• Car• Candle•

†•* Events classified in more than one category

9.6 Action, Cause, and Effect: when they are the same

Looking at the answers given to the 'how' question, which is related to possible actions, and to the 'why' question, which is related to causes, it is possible to distinguish a general pattern in them.

When the 'how' question was answered in terms of a subject's action, the 'why' question was answered in terms of a description of either the action itself or of what would happen in the process. It seems that there are two aspects involved in this case:

- firstly, when they associate cause with the action itself, action and cause seem to considered the same, as if they were different views of the same thing;

- secondly, when they associate cause with the description of what would happen, which is the effect of the action, it seems they are seeing cause and effect as the same as well.

On the other hand, when the answers were in terms of a natural process, with no subject's intervention, such as 'leave it', there was always a specific cause related to other entities, or surroundings, or different objects, or even to the object itself. In this case when causes are associated with such entities, it seems that these entities are playing a role as causal agents (they cause the change) AND as something which has the 'power' to make it happen. In these instances, causes are projected onto entities, objects, and seem to be mixed with actions, because as there is no subject's intervention ('leave it), this entity becomes the causal agent which has the power to act and cause the event AND at the same time is considered the cause of the event.

9.7 The Event Happening Forward and Backward: How they are Located in the Factor Space for the Same Phenomena

Looking at the location of each event happening forward and backward in the factor space, for most phenomena the event happening forwards is placed apart from the event happening backwards.

However, for the events FALLING BALL, SEE-SAW, SWING, and SPRING the same group locates them close together, although the location for each group varies all over the factor space. Table 9.2 shows that the description of each of these events is the same when happening forwards as well as backwards. Therefore, it seems that these events are seen as very similar in both directions. They are from this point of view the most reversible processes, in which the path forward and backward has the same basic nature.

10

Discussion and Conclusions

This chapter presents the conclusions of this research, describing them in relation to the research questions presented in section 4.1.4., and discusses the conclusions in terms of the broader context set by Chapters 2 and 3.

10.1 Is it possible to find a description of the basic elements which people use in their everyday life, to reason about reversibility?

For the five different age/instructional/cultural groups selected for this research (13/14 year old and 16/17 year old students from England and Chile, and 16/17 year old students from Brazil), it was possible to find a common underlying structure, represented by a three dimensional space of explanation, obtained with factor analysis, after asking people to characterise a number of changes according to a set of fourteen statements describing ways in which it could happen. The changes were represented by events covering mechanical, physical, chemical and life processes. Each event was presented by a picture, first happening in the 'normal direction, and then in the 'reverse' direction. The same set of fourteen statements were presented about each event in each direction, asking students to agree or disagree. An interpretation of the dimensions of the space was:

Dimension I:	HAPPENS vs. DOES NOT HAPPEN
Dimension II:	HAPPENS BY ITSELF vs. NEEDS AN ACTION
Dimension III:	HAPPENS DUE TO A GOAL vs. HAPPENS WITH NO GOAL.

The first and strongest dimension is related to the possibility or impossibility of an event happening; the second dimension, positively correlated to the first, relates to the necessity or not of an action to be taken to make the event happen; and the third and less strong dimension is connected with the idea that an event happens due to a goal or law.

The outcome of this analysis fits into option 3, among the possibilities outlined in section 8.1: that is, the pattern of correlation between responses to the phrases across the range of events shows a similar underlying structure, but groups judge some events differently concerning these common underlying dimensions.

Although some events are judged differently by each group, and are therefore located differently in the factor space, they are all placed similarly in relation to one another within the same group. Thus, their location by each group can be described as:

- The English 13/14 and 16/17 groups are positive towards the possibility of both forward and reverse events happening: most events are considered as likely to happen, with just a few reversing processes seen as less likely to happen;

- The Chilean 13/14 and 16/17 groups make a little more differentiation than the English groups between the forward and backward events: forward processes are seen as more likely to happen while the backward processes are seen as less likely to happen;

- The Brazilian 16/17 group seems less positive about the possibility of any event happening although most forward processes are seen as relatively more likely to happen than most backward processes.

Regarding the location of the events in the space of explanation, the following overall tendencies can be seen:

- most events are seen by all groups as able to happen, with events happening backwards (BA events) generally being considered as less likely to happen;

- many events are seen by all groups as needing an action to happen, particularly but not exclusively the events happening backwards (BA events);

- most events are seen by all groups as not happening accidentally or randomly;

- a few events are seen as driven by a goal;

• some events are seen as reversible, with the forward and backward processes understood in a very similar way.

Considering these basic trends it is possible to understand the positive correlation between dimension I - HAPPENS vs. DOES NOT HAPPEN and dimension II - HAPPENS BY ITSELF vs. NEEDS AN ACTION: since most events are seen as possible to happen and many as needing an action to happen, the majority of the events are seen as possible to happen anyway either by themselves or due to an action. Those seen as less likely to happen demand an action to happen.

The methodology also involved qualitative analysis of answers to the open-ended questions given by the subjects in their own terms, and the fair degree of consistency between this and the outcome of the statistical model was taken as giving some confidence that the analysis had uncovered meaningful aspects of students' thinking. This thinking is discussed in relation to the four complementary research questions connected with the first research question.

10.2 What are the different ways of reasoning about reversing a process?

Focusing our attention on the events happening backwards, according to the answers given to the open-ended questions related to actions and causes, it is possible to describe basically two ways of thinking about reversing a process:

• subject's intervention - when the event is seen as a result of a *subject's action*;

• non-intervention - when the event is seen as *naturally reversed*; sometimes a subject's action is considered, but in these cases just to trigger the process which is not seen as result of a subject's intervention.

Regarding the processes thought of as reversed through an intervention, there are mainly two kinds of action involved:

• in the first case the action is essentially the same as the one which caused the forward process, but inverted. It is thought of in two ways: it is either the reverse of the initial action or an action which compensates the initial one. Examples of this kind of action are seen in the events SEE-SAW - 'the see-saw is tilted a little' and SPRING - 'the spring is stretched a little';

• in the second case the action has no relation to that which caused the process to happen forwards. It can also be thought of in two ways. Firstly, it is any action that would re-establish the original state using the same kind of elements involved in the process, such as in the case of the events PENDULUM - 'a pendulum stops swinging', ICE-CREAM - 'a ice-cream melts', SLOPE - 'a ball rolls down', TEA - 'a cup of tea becomes cold', CHAMPAGNE - ' the champagne goes flat', PLANT - 'a plant grows', CAR - 'a car rusts away' and CANDLE - 'a candle burns away'. Secondly, although the reversal is fundamentally considered as not possible, an action is still thought of, but in this case to renew or replace the object in question, such as in the case of the events CAR and CANDLE.

The events explained as being naturally reversed were PUDDLE - 'water in puddle evaporates', FALLING BALL - 'the ball falls and bounces back up' and SWING - 'the swing comes back', given that sometimes the last two events were seen as naturally reversed but triggered by an action. Although considered as naturally reversed with no subject's intervention, in these events action is projected onto entities which are seen as an active object. The event BOY/MAN - 'a man grows old' was considered as irreversible.

These different ways of reasoning about reversing a process can be summarised in terms of a systemic network as shown in Figure 10.1

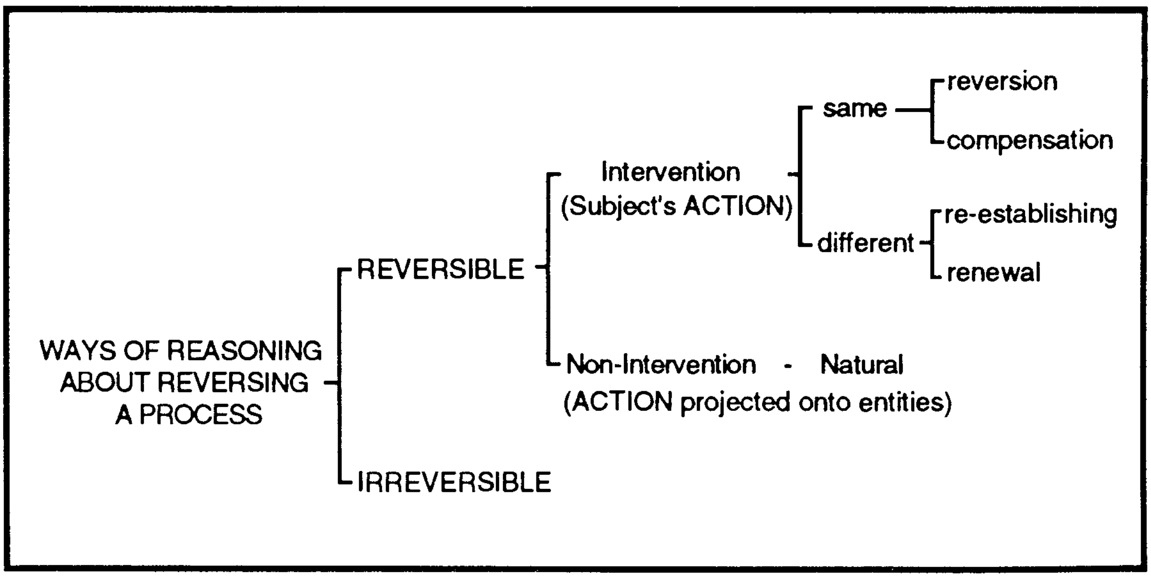


Figure 10.1 - *Ways of reasoning about reversing a process*

10.3 What is the relation between commonsense reasoning and scientific reasoning?

To answer this question, the next two sections present, first a discussion of the relation between the scientific typology of processes and the commonsense grouping of processes and thereafter how commonsense and scientific reasoning describe processes.

10.3.1 What is the relation between a scientific typology of process and commonsense groupings?

Looking at the way the students described processes happening forwards and backwards, it was possible to devise five kinds of groupings of processes in commonsense reasoning as presented in section 9.4.3. They are summarised in Table 10.1.

Table 10.1 -*Groupings of Processes in Commonsense Reasoning*

COMMONSENSE GROUPINGS	EVENTS
Reversible natural process	PUDDLE - water in a puddle evaporates
	FALLING BALL - the ball falls and bounces back up†
	SWING - the swing comes back†
Natural process reversed through an action	PENDULUM - a pendulum stops swinging*
	ICE-CREAM - an ice-cream melts
	CAR - a car rusts away •
	SLOPE - a ball rolls down
	TEA - a cup of tea becomes cold
	CHAMPAGNE - the champagne goes flat
	CANDLE - a candle burns away •
	PLANT - a plant grows •
Natural process triggered by an action in both directions	FALLING BALL - the ball falls and bounces back up†
	SWING - the swing comes back†
Non-natural process reversed through an action	SEE-SAW - the see-saw is tilted a little
	SPRING - the spring is stretched a little
	PENDULUM - a pendulum stops swinging*
Irreversible natural process	BOY/MAN - a man grows old
	PLANT - a plant grows •
	CAR - a car rusts away •
	CANDLE - a candle burns away •

† * • Events classified in more than one category

However, the phenomena can also be grouped as physical, chemical and biological changes, as outlined in section 7.2. Thus from this 'scientific' point of view, the phenomena might be described as shown in Table 10.2.

Now bearing in mind the scientific typology and at the same time looking at the overall summary of the description of the events presented in Table 9.2, it is possible to see that it was the mechanical and physical changes which were considered as reversible, either through an action or naturally.

From a scientific point of view, the mechanical phenomena could be regarded as symmetrical with respect to reversal, in the sense that the reasons for events happening forwards and backwards are the same. However, they are not always seen in this way from a commonsense point of view: if the forward process is natural (PENDULUM, SLOPE, FALLING BALL and SWING) the reverse may be by means of an action. Two (SEE-SAW and SPRING) are symmetrical, but both are seen as requiring actions in both directions.

Table 10.2 - *Scientific Typology of Processes*

SCIENTIFIC TYPOLOGY	EVENTS	
Mechanical Processes	PENDULUM	SLOPE
	FALLING BALL	SWING
	SEE-SAW	SPRING
Physical Change	ICE-CREAM	TEA
	PUDDLE	CHAMPAGNE
Chemical Change	CAR	CANDLE
Life Processes	BOY/MAN	PLANT

One of the physical changes (PUDDLE) is seen as a naturally reversible natural process, but the others (ICE-CREAM, TEA, CHAMPAGNE) are seen as natural processes reversed by action, not naturally.

The events CAR and CANDLE, grouped as chemical changes, are seen as natural processes. The backwards process is seen as not possible, unless considered as reversed by an action, but in this case to re-establish the original shape/form.

Life processes are seen as the most irreversible. The event BOY/MAN is seen as an irreversible natural process. The other, PLANT is seen as irreversible but also as reversible by means of an action, but in this case to merely re-establish the original appearance.
Overall, chemical changes and life processes are more seen as irreversible than are mechanical and physical changes. It is relevant that the latter can be seen as changing basically position or arrangement, while the former can be seen as changing the *nature* of substance or object. Similar results were reported by Stavridou and Solomonidou (1989) and Kruger and Summers (1989). Table 10.3 summarises the categorisation of the events according to the commonsense groupings and the scientific typology.

Table 10.3 - *Summary of the Categorisation of Events according to the Commonsense Groupings and Scientific Typology*

COMMONSENSE GROUPINGS	EVENT	SCIENTIFIC TYPOLOGY
Reversible natural process	PUDDLE	Physical Change
	FALLING BALL	Mechanical Process
	SWING	Mechanical Process
Natural process reversed through an action	PENDULUM	Mechanical Process
	SLOPE	Mechanical Change
	ICE-CREAM	Physical Change
	TEA	Physical Change
	CHAMPAGNE	Physical Change
	CAR	Chemical Change (Renewal)
	CANDLE	Chemical Change (Renewal)
	PLANT	Life Process (Renewal)
Natural process triggered by an action in both directions	FALLING BALL	Mechanical Change
	SWING	Mechanical Change
Non-natural process reversed through an action	SEE-SAW	Mechanical Change
	SPRING	Mechanical Change
	PENDULUM	Mechanical Change
Irreversible natural process	BOY/MAN	Life Process
	PLANT	Life Process
	CAR	Chemical Change
	CANDLE	Chemical Change

10.3.2 Commonsense and Scientific Reasoning: How processes are described.

The scientific account adopted in this research is largely based upon Classical Thermodynamics and Classical Mechanics. As presented in Chapter 2, this account demands a clear boundary between what is considered the system and the surroundings in order to describe the behaviour of the system and its possible interactions with the surroundings. Moreover, the initial conditions of the process taking place in the system are considered as already existing. Establishing or changing these conditions is not considered as part of the process to be described (but as part of a different process, demanding a different boundary between system and surroundings).

In Classical Equilibrium Thermodynamics reversible processes happen as a continuous series of equilibrium states - quasi-static processes -, which means that the system goes through well-defined states where the properties are uniform throughout the system. In these cases, the departure from equilibrium can just as well be in one direction as the opposite. Thus reversibility implies equilibrium or being close to equilibrium. Another aspect is the naturalness of a process, which is related to change towards a state of equilibrium. At equilibrium, the system reaches a state of maximum disorder, when there is no further change. In this case, there is no natural reversal, and an outside intervention (i.e. change of conditions) is required to create conditions to reverse the process. Given that the scientific account does not include establishing the conditions for a process to happen, a natural process is considered as irreversible.

Classical Mechanics deals with systems made up of frictionless pulleys, weightless strings, point masses and processes happening with no dissipation of energy, that is, processes which are perfectly reversible. As the process of establishing the initial conditions is not included in the scientific account, motion is considered as having no first cause and as lasting forever.

On the other hand, the commonsense reasoning about processes described in the present research gives evidence that people adopt a different standpoint when reasoning about the physical world in their daily lives. Unlike scientific reasoning, commonsense reasoning makes no distinction between system and surroundings. Furthermore, it is not at all restricted to quasi-static processes. Indeed it typically reasons about processes which need non-equilibrium thermodynamics to account for them scientifically.

Commonsense reasoning about mechanical processes takes friction for granted, so that motions stop naturally, and a cause is always needed to create a motion. Thus *action is seen as the cause of motion*. Alternatively, friction if made explicit, can be seen as another causal agent, which stops motions.

Commonsense reasoning about 'thermodynamic' processes differs from scientific reasoning because, given that there is no restriction about what is the system, the establishing of the conditions to cause the process becomes part of the reasoning about it. This means that any external intervention thought of as necessary for the event to happen is included in the reasoning about the process. Therefore, *action* becomes a basic and important element in this commonsense reasoning.

We may attempt to understand the role of action, albeit necessarily speculatively. It seems that people see themselves as perpetual sources of action that may cause events, more or less as they want. It is supposed, more or less, that people can act at no expense, staying essentially the same (it is recognised that people get tired, but the recuperation is understood as natural). Further, action can also be considered as a source of organisation in that it can create organised movement, such as a person moving himself or other things. This perception is intelligible inasmuch as living organisms grow and change slowly in a slow process, and on short time scales they seem not to be changing. The scientific account of living beings such as people - who are complex open self-organising systems keeping themselves in a steady state far from equilibrium at the expense of producing less availability of energy - as able to act, the driving force of every action being the dispersal of energy or consumption of free-energy, is not of course considered. Furthermore, the local creation of organisation is not perceived as coupled with a larger decay elsewhere.

Thus, when people say that some process is reversible, they often reason in terms of a possible action that can be taken in order to reverse the process. Commonsense reasoning of reversibility is related to *manipulation* in the sense that an action can nearly always be thought of, which could reverse a process. By contrast, scientific reasoning about reversibility is related to *constraints* imposed by given conditions. It also establishes limits to actions. Commonsense reasoning is in some ways less restrictive than scientific reasoning.

10.4 What is the role played by action in reasoning about reversibility?

The answer to this question is given in the next two sections, where the role of action is discussed further and a model is proposed.

10.4.1 Action: The Reversible Element in Commonsense Reasoning about Reversibility

As has already been pointed out, action plays a basic and important role in commonsense reasoning about reversing a change, especially for those changes that seem not able to be easily reversed, including those which are understood scientifically as non-reversible. External action is invoked to make these kinds of processes 'possible'. In fact human beings (and objects) are seen as capable of taking an action to produce changes (Harré, 1988), more or less as they wish. Regarding this, commonsense reasoning takes as obvious what has given non-equilibrium thermodynamics a lot of trouble to explain .

Action is the reversible element in commonsense reasoning about reversibility, in the sense that an *action* can *reverse* and can *be reversed.* In the first case an action can be involved *to reverse* the forward process and in the second the *reverse of the action* involved in the forward process is considered to reverse it. This can be graphically represented as shown in Figure 10.2.

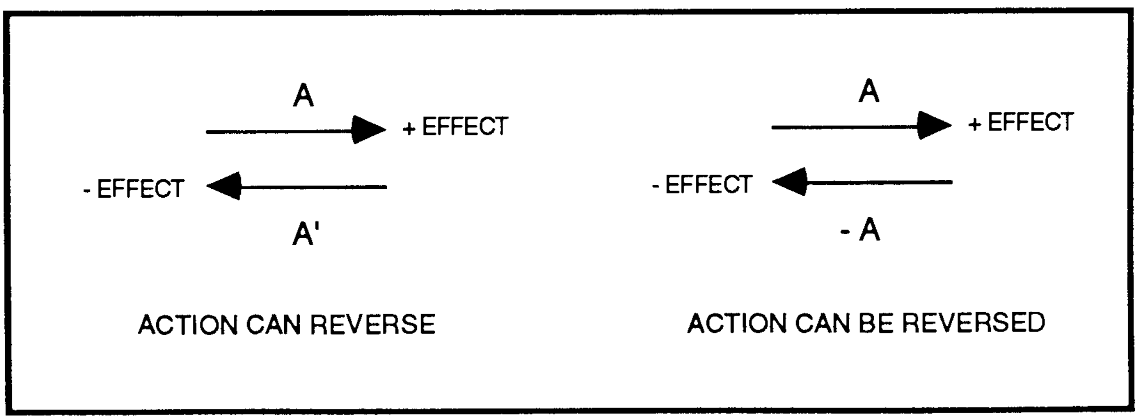


Figure 10.2 - *Action as the Reversible Element in Commonsense Reasoning about Reversibility*

It appears that sometimes, action, cause and effect become mixed. We can say that *an agent* is an object - usually the subject - which can do something - *an action* - to cause an event - *the effect.* An agent has the power to do something, which it may or may not do. For instance, if I (*the agent*) stop a pendulum, *the action* is the fact that I put my hand in the way of the pendulum; the force of my hand being *the cause* for the halt of the pendulum, the halt of the pendulum afterwards being *the effect.*

In this sense, action and cause are mixed. Action is different only in deriving from a purpose of a person, who can act or not. An action is also present behind the notion of goal in that an action can be thought of as making an process happen to fulfil a purpose. For instance, if I (*the agent*) need to stop a pendulum (*the goal*), I can (or cannot) put my hand in its way (*the action*) and the force of my hand (*the cause*) stops it (*the effect*), i.e., I can act on the pendulum so as to fulfil the purpose of halting it.

When cause and action are projected onto inanimate things or entities, they get mixed, since the thing or entity cannot choose to act or not: they are seen as *causal agents* which have the *causal power* to act and cause the event. For instance, if when asked how to stop a pendulum students say 'leave it to stop' and when asked for causes they say 'gravity', there is no distinction between agent, action and cause. If gravity is the cause, the answers to questions such as 'what is the action?' and 'what is the agent?' are mixed with the presumed cause: gravity is the *cause* and also the *'agent'* of actions. Therefore it can be said that in this case, causes are modelled on actions which are projected onto entities.

Cause and effect can also be mixed. Sometimes causes and effects come in chains (Andersson, 1986a) an example of such a situation being represented in Figure 10.3.

CAUSE → EFFECT

CAUSE → EFFECT

Figure 10.3 - *Cause and Effect in Chain*

In this case, the second cause is the first effect. For instance, if I throw a ball, the movement put into the ball (*effect*) can be seen as a cause when the ball hits someone else. Or if I put some weight on the See-Saw, the increase of weight (*effect*) may be seen as the cause for the disequilibrium.

Another situation where cause and effect also seem to be mixed is in processes that are reasoned about in terms of 'leave it', such as 'a cup of tea becomes cold' or 'the champagne goes flat'. When asked for causes some answers are given in terms of the effects - a description of either what would happen or of the process - such as 'loss of heat', 'loss of CO_2' or 'gas escaping'. Thus, it seems that when no action is considered in the happening of the event - no subject's action nor action projected onto entities - causes are projected onto effects.

Taking all the above into account, it seems that causes are frequently considered. Causes are often projected onto entities or objects. Alternatively a description is given in terms of either what would happen, or of the process, or of the action itself, or causes are thought of as an inner cause as in the events 'a man grows old' or 'a plant grows'. Causes were not considered in only a few cases, such as the event 'water in a puddle evaporates', when answers related to causes were in terms of 'it just happens' or 'it happens naturally'.

The way students thought of actions to reverse a process can also be related to Piaget's ideas. Many answers, particularly the renewal answers - 'R' - can be connected with what is called *empirical return* or *revertibility*, which is a mere return to the point of origin, centred on the result of the action and without implying an identity of the paths followed, with actions which occur in a sequential time (Vuyk, 1981). For instance, when students answer 'buy a new car', as a way of reversing the process of a car being rusted, it seems that the central point is the return to the initial state - a car in good condition - which is achieved by the act of buying a car. A similar remark can be made when they give answers such as 'sand rust off + repaint it' or 'take it to repair': there are actions which will recover the initial state.

On the other hand, some answers given in terms of a subject's action - 'A'- can be related to what is called *operational reversibility* or *true reversibility* which is a return that may take place in thought, in which the paths are identical and involves simultaneous co-ordination (Vuyk, 1981). An example of this case is the event when a See-Saw is tilted a little: answers given in terms of the reverse of the action taken to go forwards, 'the man on the right side moves backwards', may indicate that the subject previously realised that this action would initiate the backward process which could follow the forward path in reverse.

10.4.2 Is it possible to model reversibility in terms of action?

Considering the commonsense groupings shown in Table 10.1, the ways of reasoning about reversing a process shown in Figure 10.1 and the fact that *action* is a basic and important element in commonsense reasoning about reversing a process, it is possible to outline a set of models representing processes going forwards and backwards, as shown in Figure 10.4.

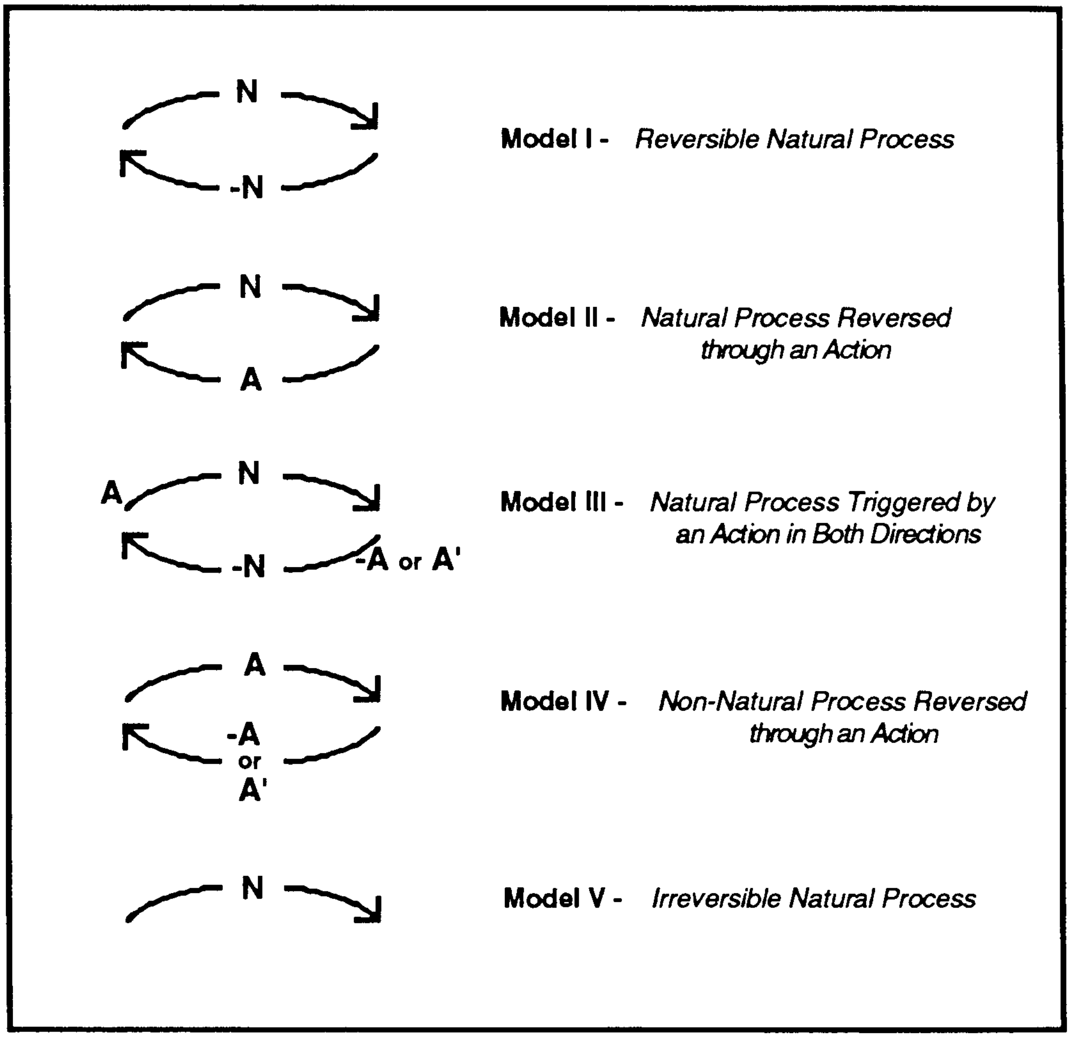


Figure 10.4 - *Models for processes going forwards and backwards*

There are basically five models. In each, a right-pointing arrow represents the forwards direction and a left-pointing arrow represents the reverse direction. The letters **N** or **A** indicate the process happening naturally or due to an action respectively. The minus sign means that the nature of the process is the same, but happening in reverse, i.e., **- N** means that the reverse process happens naturally but in the reverse direction; **-A** means that the same kind of action regarded in the forward process is considered, but is reversed - in this case *action is reversed* to produce the reversal. The label **A'** means that the reverse process happens due to a different kind of action than that considered in the forward process - in this case *a different action reverses the process.*

Models I, III and IV could be considered as 'simply' reversible, where the reverse is basically the negative of the forward process, excepting the case where a different action - **A'** - is considered to reverse the process.

Model II represents a process reversible only by an action, in which the action is not the reverse of the natural process. Action is used to find a way for reversing: it can compensate, re-create or renew.

Model V includes no return nor an action, and represents irreversible natural processes.

10.5 What is the role played by conservation in reasoning about reversibility: to what extent does reversibility involve something being 'conserved'?

10.5.1 Conservation as Constraint

From a scientific point of view, conservation plays a role of constraint. The analysis of any process requires a clear definition of the system being considered. The conservation of some physical quantities such as energy, linear and angular momentum inside an isolated system requires that only those processes occur in which these values remain constant. In another words, conservation limits what processes can occur at all. Processes which would change conserved quantities in an isolated system are impossible. Further, if energy is conserved in any process, it is also conserved in the exact reverse process, and a different principle is needed to decide the direction of a process. This different principle is of course the entropy principle.

However, in commonsense reasoning about processes there is no clear fixing of isolated systems and it is possible to add 'external influences' to make a process happen. In this case there is no mention of conservation or fixed constraints as in scientific reasoning. As the boundary of the system is fluid, the constraint is not connected with conservation of physical quantities, rather it becomes the *possibility of an action* in the sense that a process cannot happen if it cannot be done. Therefore, reversibility becomes a matter of a *possible action* which can be thought of which could reverse the process.

10.5.2 Conservation as 'What stays the same'

The results suggest that to reason about reversibility is to think about the effect of the change, and then to think about a way to restore the original state. Thus, reversibility is thought of in terms of what is expected, or not, to 'stay the same' in a change. A process is not reversible if the reverse process is made impossible by such a conservation principle.

There are many aspects which may or may not stay the same, as seen in the data analysis as well as in the review of literature (for instance Pfundt, 1982; Séré, 1986; Driver, 1985, Stavy and Stachel, 1985b). Features such as position, movement, shape and form, often do *not* have to stay the same for the change to be possible. But it may be that, for example, the amount of matter is thought not to change.

10.5.2.1 Restoration of Configuration - related to the arrangement of the elements of the system. The elements do not suffer any kind of transformation but the configuration of the system as a whole changes. Thus, to reverse a process is to restore the system to the same state of movement or position as it had at the initial state, without using anything from outside excepting action. This situation is observed in mechanical processes:

PENDULUM - 'a pendulum stops swinging'
FALLING BALL - 'the ball falls and bounces back up'
SEE-SAW - 'the see-saw is tilted a little'
SLOPE - 'a ball rolls down'
SWING - 'the swing comes back'
SPRING - 'the spring is stretched a little'

10.5.2.2 Restoration of Shape/Form - related to the shape or form of the of the system as a whole (e.g. Ice-cream). Some elements of the system may have had a structural transformation. However, when reversing the process, what matters is to restore the initial shape or form of the whole system (e.g. Plant). This case is also associated with the impossibility of reversing a process, when the solution is in terms of renewal '**R**'. Restoration is observed in four processes:

ICE-CREAM - 'a ice-cream melts'(physical change)
CANDLE - 'a candle burns away' (chemical change)
CAR - 'a car rusts away' (chemical change)
PLANT - 'a plant grows' (life process)

10.5.2.3 Replacement of Substance - related to replacement of some elements of the system which 'vanished' during the process. It is not required that the same elements which 'vanished' should be used. It is enough that the elements used to reverse are of the same kind and in some cases of the same amount. Processes are mainly related to Physical changes:

CHAMPAGNE - ' the champagne goes flat' (add CO_2)
PUDDLE - 'water in puddle evaporates' (it rains)
TEA - 'a cup of tea becomes cold' (heat it [loss of heat])

10.5.2.4 Conservation of Identity - related to the conservation of the nature of the elements of the system. Despite the process, the elements remains the same. If reversed everything will be the same. In general all mechanical processes and physical changes can be described in this account, and also chemical changes. However there are some remarks in relation to:

CAR 'a car rusts away'
CANDLE 'a candle burns away

The kind of account for these events arises from answers such as 'sand rust off + re-paint it' and 'recollect the wax and reshape it'. The processes of rusting or burning are considered as not affecting the material of the car and of the candle, it being enough to sand the rust off or to 'collect' the wax to get the initial material again. When re-painting the car or reshaping the candle, it would have its initial shape restored, therefore being also described as 'restoration of shape/form'.

10.5.3 Conservation as 'naturalness'

Some processes were considered as natural, just happening with no intervention. In these cases conservation can be thought of as related to 'conserving action' in the sense that no action is needed to make the event happen. However, in the reverse, most often there is no such conservation since an action is required to reverse the process.

10.5.4 Reversibility and Conservation

In a broad view conservation is related to reversibility in that the possibility of reversing a process or not depends upon the possibility of an action being thought of which would reverse the process, so as to have the original state 'conserved' in the end. We might speak of 'conservation' in this case in that if the initial elements and/or features are recovered, 'nothing has been lost or changed'. This 'conservation' can be either natural, when there is no need for any action or as in most cases when the reversal can be caused by an action taken by the subject.

A irreversible process can be one in which it is impossible to restore the initial state, either because doing so is impractical or because during the process of going forwards there is a loss of something as if 'escaping' or 'vanishing'. To the extent that something cannot vanish or be created (i.e. is thought of as conserved), such a process tends to be seen as not possible. The main 'solution' available is to think of 'renewal', which essentially admits the impossibility of a process by proposing to evade it.

10.6 How can the way students reason about processes and their reversibility be related to the review of literature?

The focus of this study is on commonsense forms of reasoning, in which students are considered as using their own commonsense knowledge of the physical world in trying to understand scientific concepts so as to explain them.

The review of literature included reasoning based upon prototypes of reasoning about reversibility such as necessity, contingency, causation, action and teleology (section 3.1).

Regarding the overall results, necessity and contingency underpin commonsense reasoning about reversibility. Necessity - something that either must happen or must not happen - can be associated with events seen as reversible natural processes and as irreversible natural processes in the sense that they are unavoidable: the former as always happening, the latter as never happening. Contingency - as related to something that might or might not happen - can be connected with non-natural processes, natural processes reversed through an action and natural processes triggered by an action in both directions in the sense that *if* an action is provided these events happen.

The role played by action and cause was another important aspect seen in the literature. The present research indicates that action plays a basic and important role in commonsense reasoning about reversing a process, as the reversible element that can reverse and can be reversed. Actions can be considered in different ways.

Action can be seen as related to subjects who are envisaged as the first agent which can act to cause the event, more or less as they want. A similar description is found in Mariani and Ogborn (1991) when they describe the idea of a person as a 'primal source of changes' or as a source of autonomous action from within, able to create or destroy. Stavridou and Solomonidou (1989) and Russel et al. (1989) also describe children thinking of human beings as able to act to cause a phenomenon.

Action can also be related to cause and be projected onto entities or inanimate things. A similar account is given by Stavridou and Solomonidou (1989), Nicholls and Ogborn (1993) and Russel et al. (1989). Time is conceived as something able to act on its own and cause a change, as also pointed by Proverbio and Lai (1989).

The importance of action is also emphasised in situations when it is not necessary to consider any action to cause an event, but in which an action is still mentioned. Similar results are also reported by Prieto et al. (1989), and also by Mariani and Ogborn (1993) in a study about ontology of events.

Causes are often projected onto entities, objects and inanimate things, and are frequently considered. Features of causes such as what would happen (the effect), of the process, of the action itself or as an inner cause (processes of life) are close to what Gutierrez and Ogborn (1991) describe, in their causal framework drawing on de Kleer and Brown (1983, 1985) and Bunge (1959), especially the principle that an effect requires a cause. Answers connected with inner causes such as 'process of life' or 'cell reproduction' seem to be related to proposing *new causal candidates*: in the face of difficulties in giving reasons new causal candidates are sought.

There may be a connection with the linear causal reasoning of Rozier (1991). For example, for the event 'the ball falls and bounces back up', some answers were given in terms of a natural process triggered by an action such as 'drop the ball' or 'throw the ball up', and there were causes related to entities such as 'gravity' or 'the force'. The event unfolds in time in two events. First, the subject acts on the ball initiating the whole process. At a second moment, the phenomenon happens, and the justification is due to a different cause - gravity - as a result of which the ball falls and bounces.

There is a connection between the notion of action in Piaget's work (Piaget, 1937) and the importance of action revealed in the present research. In Piaget's account, the child's actions are the fundamental building element (Piaget and Garcia, 1991): objects acquire meanings from actions, which have their meaning in *what they make happen* (Mariani and Ogborn, 1993) and progressively actions are attributed to objects in that they also become *agents* of actions. The notions of action, reversibility and conservation, closely connected in Piaget's work, may give some guidelines for further research in a commonsense perspective. One such study looked at conservation in relation to actions (Mariani and Ogborn, 1990) and it was reported that from a ontological view conservation and action are closely related, in that to be conserved is to be out of the reach of action.

The results suggest the importance in some cases of teleological thinking. Answers such as 'process of life' and 'cell reproduction' may indicate a means-end relationship peculiar to biological science (Bartov, 1978) instead of a cause-effect relationship. However, the dimension associated with this notion is the least strong and needs further investigation.

Many studies discussed in the literature focused on just one concept at a time and gave broad and general descriptions of conceptions held by students. In contrast, the present research gives accounts of a variety of phenomena. It was possible to devise a model for representing processes going forward and backwards as described in section 10.4.2 and summarised in Table 10.4. By contrast, in the few descriptive studies reporting results related to reversibility such as that by Stavridou and Solomonidou (1989), the analysis was led by a previous assumption that results must fit in either Model I - reversible- or Model V - irreversible. The models given here are more detailed and differentiated.

Certain previous studies support outcomes described here. The importance of the role played by action in a process is also described in Andersson (1990) when reporting pupils' view about changes of matter. Watts (1983) describes students' views about energy where energy is seen as causal agent, source of activity, or even as the action itself, fitting with the idea of action being projected onto entities.

Few studies had reversibility as a central issue and only some of them commented on conservation. A focus on both aspects could facilitate further work on reversibility in which something - matter, substance, properties, perceptual aspects - remains unchanged.

10.7 If a description of the way people reason about processes and their reversibility is possible, what would be the implications for the teaching of scientific ideas about reversibility?

Commonsense reasoning operates in a world in which non-linear, non-equilibrium processes are important. Thus it is likely to have ways of dealing with processes which scientifically speaking:

- *can achieve a (local) decrease of entropy*
- *can reverse a spontaneous (entropy increasing) process*
- *can maintain systems in steady states far from equilibrium*
- *can act as 'driving influences' on other systems (by reason of having a low entropy which increases)*

One of the most important entropy-increasing processes may not be evident to commonsense reasoning, namely the dispersal of energy. It is probably easier to think of the energy of a hot object, or of a moving object, as just naturally 'vanishing'.

In this research, *action* played a fundamental role. Scientifically, an action of an organism is just that organism using some of its free energy - i.e. negative entropy - to achieve a local decrease of entropy, that is, to reverse a natural entropy-increasing process or to disturb an equilibrium state.

Classical reversible thermodynamics does not, and does not need to, give any role to action. It considers only processes close to equilibrium. However, actions do form a covert part of its account of systems and processes, in setting up of initial conditions. For example, Sears & Zemansky (1970) offer the student the following problem, amongst many like it:

> ' A cylinder contains oxygen at a pressure of 2 atm. The volume is 3 l and the temperature is 300°K. The oxygen is carried through the following processes: (1) Heated at constant pressure to 500°K. (2) Cooled at constant volume to 250°K. (3) Cooled at constant pressure to 150°K. (4) Heated at constant volume to 300°K. (a) Show the four processes above in a pV-diagram, giving the numerical values of p and V at the end of each process. (b) Calculate the net work done by the oxygen.' (Sears & Zemansky, 1970; p 282, problem 19.24)

The question is silent about how the oxygen got into the cylinder in the first place, and about how the processes it describes were achieved. It assumes, in effect, that setting up and manipulating the system is not part of the problem. Similarly, hundreds of text-book questions about mechanics tell of masses raised or set in motion, the sources of these initial conditions never being mentioned.

By contrast, commonsense reasoning is likely to be very much concerned with how to achieve states of affairs by human or other 'external' intervention. There *is* a thermodynamic account of such actions, but it is not to be found in (and is carefully concealed in explanations of) classical equilibrium thermodynamics. It belongs to, as discussed above, non-equilibrium (often non-linear) thermodynamics.

To summarise, commonsense reasoning about processes, though the idea of action, deals with processes for which the thermodynamics normally taught cannot account. This is not to say that the commonsense idea of action is a scientifically sophisticated idea. Like free energy (negative entropy), which is its scientific counterpart, it is lost when used. So this much basic structure is in common. But at least to some extent the possibility of action is, unlikely free energy, probably felt by people to be more or less permanently available or at least as being continuously renewed. As mentioned before, this is because people are - thermodynamically speaking - open systems kept in a steady state far from equilibrium, and so have a 'permanent' supply of free energy.

The traditional order of teaching is to deal with quasi-static equilibrium thermodynamics first, to the exclusion of any other considerations, reserving anything more for graduate school or even later. Thus commonsense ideas about processes and their reversibility have to be set aside and ignored. It may be worth thinking about a teaching approach which starts from real, irreversible processes (purely qualitatively) showing how they can drive or act on systems of various kinds, and then to present equilibrium thermodynamics as an idealisation which (on purpose) simplifies the discussion by ignoring them. The real point of the simplification might be explained instead of being tacitly (and implicitly) assumed. It is that *one* value of parameters such as temperature, pressure, etc. can be used to describe the *whole* system, at all times. Where these parameters differ, we divide systems into parts (or into system and surroundings) such that in each *part* one value of any parameter will suffice.

10.8 Design and Methodology

The discussion in this section is related to the design and methodology of the empirical study, looking at the way the results depend on these aspects.

The empirical work was carried out using a questionnaire as the instrument for collecting data. This choice was made so that the main study could include a fairly large sample from two different age groups and from three different countries, thus making the use of interviews impractical. However, the use of interviews would have been helpful, in that it would have been another source of information in which the subjects could have been asked about their ideas concerning each event, and results of the analysis such as the location of events in the factor space could have been tested. This would have helped to shed light on the description of the events, and perhaps on the difference in the way the Brazilian 16/17 year old group located the events in comparison to the other groups.

In the main study the questions related to conservation about what changed and what stayed the same in processes were left out as the questionnaire had proved to be long. The exclusion of these questions was intended to reduce the time to answer it. Although these questions were not included in the main study, the notion of conservation is important and closely related to reversibility in different ways. For this reason, conservation is discussed in these conclusions, but only guided in a general way by the outcome of the analysis (see section 10.5). This is a important topic worth studying further, as is proposed in the final section of this chapter.

As previously described in Chapter 4, the research was based upon two fundamental assumptions: firstly that the way people reason in their everyday lives is not easily available to them by reflection, and secondly that there are regularities and similarities in forms of reasoning shared by groups of individuals, not too much affected by individual differences. This requires a method of investigation which can be used with as wide a range of people as possible and also some means of detecting structures of ideas and of comparing such structures between groups, without knowing in advance whether the structures are in any way comparable.

Factor Analysis (Everitt and Dunn, 1983, Child, 1978) was the multivariate technique used and a conventional view might consider such statistical methods as inadequate for eliciting any deep or significant aspect of thought, especially because they use simple 'yes' or 'no' answers to questions to which seem to need more subtlety of responses.

However, the results reported seem to suggest the potential of this approach for getting in a deep way how people think about processes. People can be directly asked about things they are conscious of thinking or feeling, but deeper and less conscious patterns of thought are less directly accessible, and are to be identified not in individual responses to particular questions, but in *patterns* of responses to many related situations or questions (Ogborn, 1993). Moreover, the study also involved qualitative analysis of extended answers given by the students in their own words, and the fair degree of consistency between this and the results of the statistical analysis helps to support the view that the statistical analysis is meaningful.

In addition the emergence from the analysis of action as a strong feature, either associated with the idea of the necessity of an action to cause an event or associated with the idea that an action can be thought of as a means to fulfil a purpose (goal), seems to be an important outcome: as already emphasised previously, action is the basis of the Piagetian conception of intelligence, appears as fundamental in studies about force and motion, is relevant in the study of energy, is basic to an understanding of conservation as being out of the reach of action, and has appeared as important in studies of 'ontological spaces' for entities and events.

Action can be seen as underlying the notions of:

- *necessity* in that events which are seen as necessary are those which are inaccessible to outside action, sometimes because the process comes from an inner cause which is part of the nature of something;

- *contingency* in that action can be seen as behind the idea of possibility, either as a prevention of something that might not happen, or as supporting something that might happen;

- *cause* in that action may be seen as the source of a notion of cause;

- *teleology* in that an action is seen the source for the fulfilment of a purpose.

10.9 Group Differences

Another point to be raised is the group differences found. Most work on students' conceptions has been done with homogeneous samples so that investigation of differences between groups is only possible by comparing the outcomes of several studies. By carrying out the study with samples from three different countries, the present research allows some group differences to emerge.

The emergence of a reasonably stable common underlying structure represented by the same small number of dimensions for the groups of the three different countries suggests that in fact they all share to a certain extent the same general meanings. However they do interpret the events according their own ideas as seen in the different locations of the events in the factor space.

The main difference is between the Brazilian group and the remainder. Consistently, the Brazilian group rated events, both forward and backward, as less likely to happen, than did other groups. It is difficult to say to what extent these differences are related to cultural, social, educational or instructional aspects. Of the five groups, the Brazilian students seemed most to judge events by their likelihood to occur in practice, rather than by their possibility in principle. Such an interpretation could only be investigated by interview.

The main result is however that, overall, similarities between groups were more striking than were differences between them, sharing a common set of dimensions and broadly giving the same relative ordering to different events in much the same way on the dimensions.

10.10 Further Research

This research has tried to show that it is possible to find some regularities in the way students reason about processes and their reversibility. It is hoped that this study may be of interest for the understanding of commonsense reasoning of processes and for the development of teaching approaches which would take account of this knowledge in the teaching of reversibility.

10.10.1 Commonsense Reasoning Related Research

The present research makes it clear that *action* plays an important and basic role in commonsense reasoning about processes and their reversibility. It would be useful to carry out further research focusing on the role played by action in events in general.

A first approach could be to add to the work done here, interviewing subjects in depth about their ideas concerning each event and its location in the factor space, and about the role played by action in each situation.

Another study could have the focus more directed towards the study of action. In this case, questions could enquire about changes in which action was excluded or included explicitly, instead of leaving it open as in the present study. For example, students could be asked: *'Is there a way to go from A to B without someone or something doing anything?'* which exclude actions, and *'If there is no action, what could be the cause'*

A third approach would focus more attention on the relation between reversibility and conservation. The questions used in the pilot study could be a possible starting point. For instance, students could be asked:
'Is there a way to go from A to B without losing or gaining anything anywhere else?'
'What stays the same in going from A to B?'
'What changes in going from A to B?'

10.10.2 Teaching-Related Research

The discussion in section 10.7 points to the fact that there is a gap between scientific and commonsense reasoning in the sense that each perspective looks at the physical world differently, having a different analysis of the same reality.

The teaching of Thermodynamics is based upon Classical Equilibrium Thermodynamics, and usually non-equilibrium ideas are never even raised. This leads to a situation where after finishing their studies, students do not even know how to think about this sort of problem. It might be sensible to propose a different sequence for teaching these topics. Perhaps, some non-equilibrium ideas could be taken in account from the very beginning, at least so as to see equilibrium thermodynamics as a special case.

Moreover, instead of focusing only on states of equilibrium, the teaching of Thermodynamics could focus more attention on processes that lead to equilibrium so as to try to break the dualism state/process in thermodynamics, which Sciarretta et al. (1990) think is 'partly explicated in the dualism heat/temperature but also in other dualisms such as the one of specific heat/thermal conductivity'. Therefore, an equilibrium state could be focused on as only a particular (though important) happening in the course of the process, and irreversibility as the main characteristic of processes that lead to equilibrium.

A different idea is to explore the notion of *de facto irreversibility* (Horwich, 1987) which is related to the fact that we are dealing with *de facto* one-way processes whose inverses do not happen, although they are not precluded by the laws of Nature.

To conclude, an important aspect would be to include a discussion about the 'positive side' of the Second Law of Thermodynamics despite its appearance of determinism, as emphasised by Sir Arthur Eddington when writing about the foolishness of even thinking about its failure, in his 1928 book 'The Nature of the Physical Word'. An example would be a discussion of Boltzmann's ideas relating the Second Law to natural increase of disorder in contrast to Darwin's ideas about self-reproducing systems (where increase of organisation is a natural tendency) showing that the Second Law plays a decisive role in evolution, creating order.

A different example would be a discussion about the real and important issue of the entropy crisis rather than the misleading discussion of the energy crisis, as pointed out in Chapter 2, in that every slight increase of entropy in the universe means energy becoming less available, so that we should find better ways of using energy so as to avoid a large production of entropy for nothing.

All these suggestions have the purpose of trying to better outline what is here described as commonsense reasoning about processes and their reversibility so as to clarify for students what is or is not included in the scientific account of reversibility, by contrast with commonsense reasoning about reversibility.

10.11 Final Remark

Although this study has been very limited in scope, and leaves many questions open, I believe that it has at least shown that commonsense reasoning about reversibility has a definite structure, very different from scientific reasoning, Even to recognise the existence of the differences may help students. Finally, since action is shown to play such as important role, the research suggests that it should be an important focus of any investigation of reasoning about physical processes.

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* See also end.

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Appendix A

The Questionnaires for the Pilot Study

FORWARDS AND BACKWARDS?

This questionnaire was designed in order to find out how you understand some events in everyday life.

Each question about an event has two parts.
The first part shows a drawing of the event followed by some questions.
The second part shows the same event but in a reverse situation, followed by the same questions.

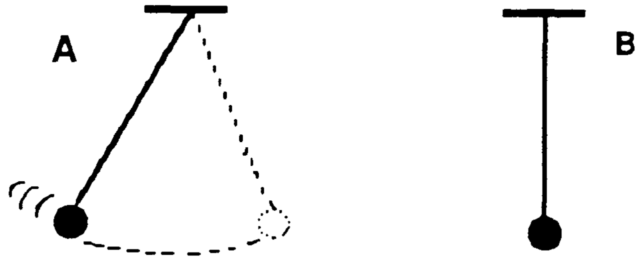
We want you to answer the questions without worrying whether you are "right" or "wrong".

<u>It doesn't matter</u>.

In fact, there are no right or wrong answers.

What's important is your ideas about each event.
So write down whatever comes to your mind as soon as you finish reading each question.

Thank you.



a pendulum stops swinging

Think of - or imagine - some way to go from A to B.

How?

Which of the following phrases describe your idea? √ or ✗ in each box

It happens accidentally		It needs some action to make it happen	
It cannot really happen in practice		It is possible, but difficult to do in practice	
It happens because the system has to go to B		It cannot be stopped from happening	
There is a law which prevents it happening		It is impossible in theory but not in practice	
It happens because the system tends to go to B		It happens by some random process	
There is no cause for it, it just happens		It is possible to imagine but not to do	
It is something which happens naturally		It happens spontaneously, all by itself	
It could never happen, in principle		There is a law which makes it happen	
It happens because getting to B is the reason for the change		It was forced into state A and then just goes back to B.	

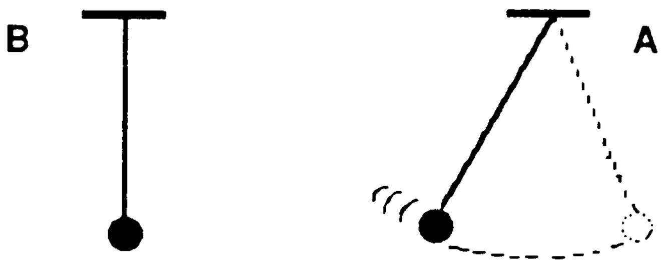
What would you say is the cause of the change from A to B?

In going from A to B, what things CHANGE?

In going from A to B, what things STAY THE SAME?

Is there only one way to go from A to B?

Yes		
No		



Now, think of - or imagine - some way to GO BACK from B to A.

How?

Which of the following phrases describe your idea? √ or ✗ in each box

It happens accidentally	
It cannot really happen in practice	
It happens because the system has to go to B	
There is a law which prevents it happening	
It happens because the system tends to go to B	
There is no cause for it, it just happens	
It is something which happens naturally	
It could never happen, in principle	
It happens because getting to B is the reason for the change	

It needs some action to make it happen	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It is impossible in theory but not in practice	
It happens by some random process	
It is possible to imagine but not to do	
It happens spontaneously, all by itself	
There is a law which makes it happen	
It was forced into state A and then just goes back to B.	

What would you say is the cause of the change from B to A?

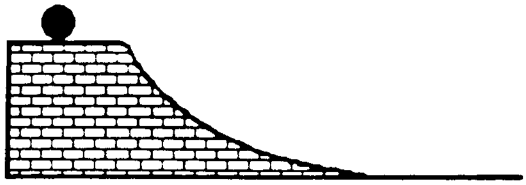
In GOING BACK from B to A , what things CHANGE?

In GOING BACK from B to A, what things STAY THE SAME?

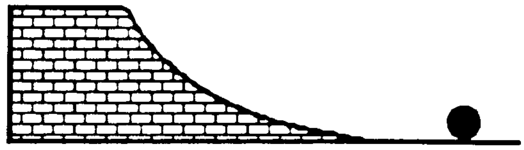
Is there only one way to go from B to A?

Yes		
No		

A



B



a ball rolls down

Think of - or imagine - some way to go from A to B.

How?

Which of the following phrases describe your idea? √ or X in each box

It happens accidentally		It needs some action to make it happen	
It cannot really happen in practice		It is possible, but difficult to do in practice	
It happens because the system has to go to B		It cannot be stopped from happening	
There is a law which prevents it happening		It is impossible in theory but not in practice	
It happens because the system tends to go to B		It happens by some random process	
There is no cause for it, it just happens		It is possible to imagine but not to do	
It is something which happens naturally		It happens spontaneously, all by itself	
It could never happen, in principle		There is a law which makes it happen	
It happens because getting to B is the reason for the change		It was forced into state A and then just goes back to B.	

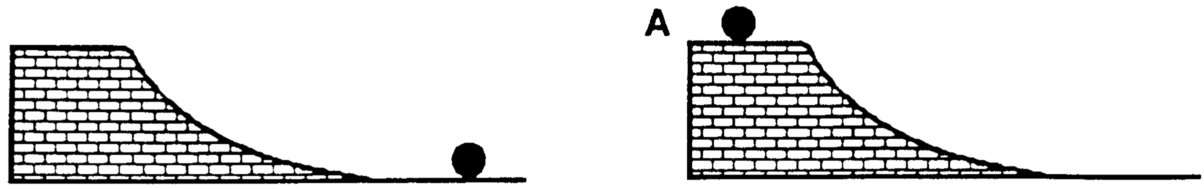
What would you say is the cause of the change from A to B?

In going from A to B, what things CHANGE?

In going from A to B, what things STAY THE SAME?

Is there only one way to go from A to B?

Yes		
No		



Now, think of - or imagine - some way to GO BACK from B to A.

How?

Which of the following phrases describe your idea? √ or X in each box

It happens accidentally		It needs some action to make it happen	
It cannot really happen in practice		It is possible, but difficult to do in practice	
It happens because the system has to go to B		It cannot be stopped from happening	
There is a law which prevents it happening		It is impossible in theory but not in practice	
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It could never happen, in principle		There is a law which makes it happen	
It happens because getting to B is the reason for the change		It was forced into state A and then just goes back to B.	

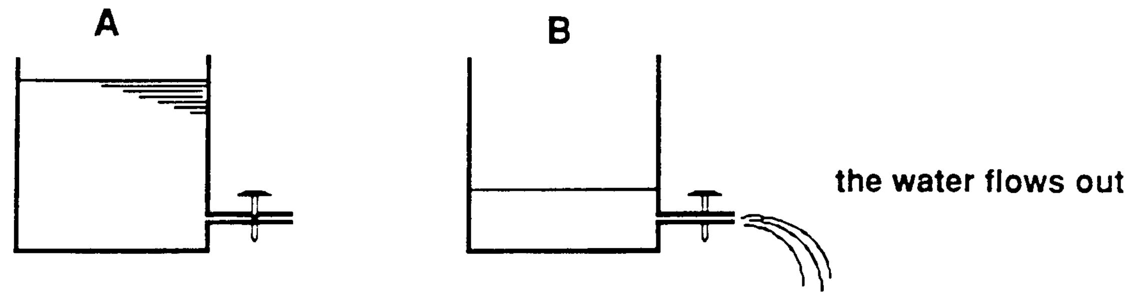
What would you say is the cause of the change from B to A?

In GOING BACK from B to A, what things CHANGE?

In GOING BACK from B to A, what things STAY THE SAME?

Is there only one way to go from B to A?

Yes		
No		



Think of - or imagine - some way to go from A to B.

How?

Which of the following phrases describe your idea? √ or X in each box

It happens accidentally		It needs some action to make it happen	
It cannot really happen in practice		It is possible, but difficult to do in practice	
It happens because the system has to go to B		It cannot be stopped from happening	
There is a law which prevents it happening		It is impossible in theory but not in practice	
It happens because the system tends to go to B		It happens by some random process	
There is no cause for it, it just happens		It is possible to imagine but not to do	
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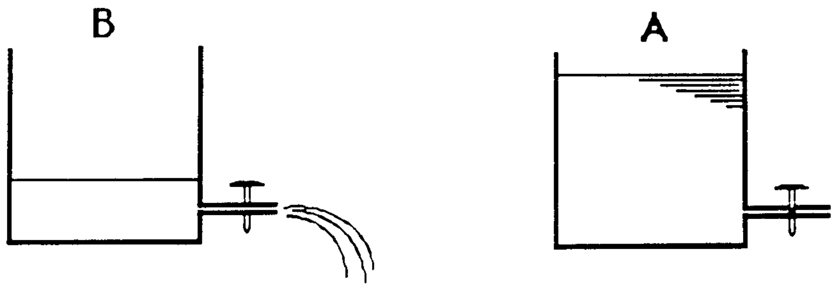
What would you say is the cause of the change from A to B?

In going from A to B, what things CHANGE?

In going from A to B, what things STAY THE SAME?

Is there only one way to go from A to B?

Yes		
No		



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How?

Which of the following phrases describe your idea? √ or X in each box

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It cannot really happen in practice		It is possible, but difficult to do in practice	
It happens because the system has to go to B		It cannot be stopped from happening	
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What would you say is the cause of the change from B to A?

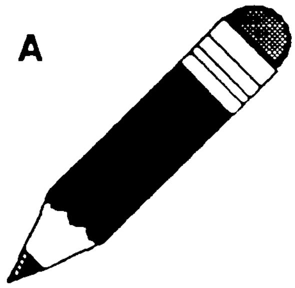
In GOING BACK from B to A, what things CHANGE?

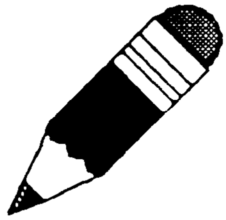
In GOING BACK from B to A, what things STAY THE SAME?

Is there only one way to go from B to A?

Yes		
No		

A





B

a pencil is worn out

Think of - or imagine - some way to go from A to B.

How?

Which of the following phrases describe your idea? √ or ✕ in each box

It happens accidentally		It needs some action to make it happen	
It cannot really happen in practice		It is possible, but difficult to do in practice	
It happens because the system has to go to B		It cannot be stopped from happening	
There is a law which prevents it happening		It is impossible in theory but not in practice	
It happens because the system tends to go to B		It happens by some random process	
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What would you say is the cause of the change from A to B?

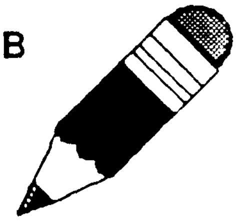
In going from A to B, what things CHANGE?

In going from A to B, what things STAY THE SAME?

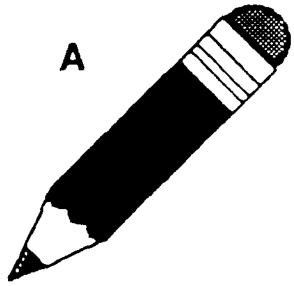
Is there only one way to go from A to B?

Yes		
No		

B



A



Now, think of - or imagine - some way to GO BACK from B to A.

How?

Which of the following phrases describe your idea? √ or X in each box

It happens accidentally	
It cannot really happen in practice	
It happens because the system has to go to B	
There is a law which prevents it happening	
It happens because the system tends to go to B	
There is no cause for it, it just happens	
It is something which happens naturally	
It could never happen, in principle	
It happens because getting to B is the reason for the change	

It needs some action to make it happen	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It is impossible in theory but not in practice	
It happens by some random process	
It is possible to imagine but not to do	
It happens spontaneously, all by itself	
There is a law which makes it happen	
It was forced into state A and then just goes back to B.	

What would you say is the cause of the change from B to A?

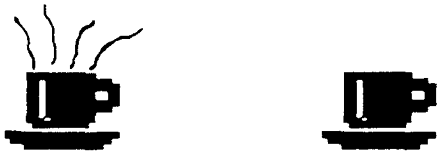
In GOING BACK from B to A , what things CHANGE?

In GOING BACK from B to A, what things STAY THE SAME?

Is there only one way to go from B to A?

Yes		
No		

A B



a cup of tea becomes cold

Think of - or imagine - some way to go from A to B.

How?

Which of the following phrases describe your idea? √ or X in each box

It happens accidentally		It needs some action to make it happen	
It cannot really happen in practice		It is possible, but difficult to do in practice	
It happens because the system has to go to B		It cannot be stopped from happening	
There is a law which prevents it happening		It is impossible in theory but not in practice	
It happens because the system tends to go to B		It happens by some random process	
There is no cause for it, it just happens		It is possible to imagine but not to do	
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It could never happen, in principle		There is a law which makes it happen	
It happens because getting to B is the reason for the change		It was forced into state A and then just goes back to B.	

What would you say is the cause of the change from A to B?

In going from A to B, what things CHANGE?

In going from A to B, what things STAY THE SAME?

Is there only one way to go from A to B?

Yes		
No		

B

A

Now, think of - or imagine - some way to GO BACK from B to A.

How?

Which of the following phrases describe your idea? √ or × in each box

It happens accidentally		It needs some action to make it happen	
It cannot really happen in practice		It is possible, but difficult to do in practice	
It happens because the system has to go to B		It cannot be stopped from happening	
There is a law which prevents it happening		It is impossible in theory but not in practice	
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There is no cause for it, it just happens		It is possible to imagine but not to do	
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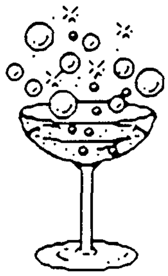
What would you say is the cause of the change from B to A?

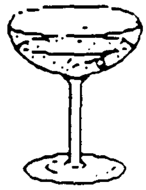
In GOING BACK from B to A , what things CHANGE?

In GOING BACK from B to A, what things STAY THE SAME?

Is there only one way to go from B to A?

Yes		
No		

A 

B 

the champagne goes flat

Think of - or imagine - some way to go from A to B.

How?

Which of the following phrases describe your idea? √ or X in each box

It happens accidentally		It needs some action to make it happen	
It cannot really happen in practice		It is possible, but difficult to do in practice	
It happens because the system has to go to B		It cannot be stopped from happening	
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It could never happen, in principle		There is a law which makes it happen	
It happens because getting to B is the reason for the change		It was forced into state A and then just goes back to B.	

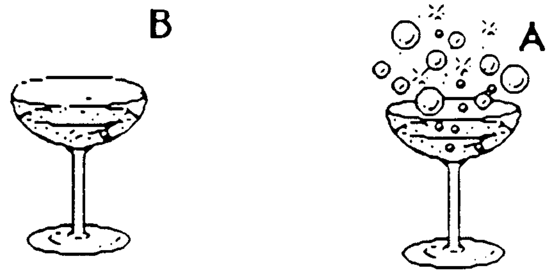
What would you say is the cause of the change from A to B?

In going from A to B, what things CHANGE?

In going from A to B, what things STAY THE SAME?

Is there only one way to go from A to B?

Yes		
No		



Now, think of - or imagine - some way to GO BACK from B to A.

How?

Which of the following phrases describe your idea? √ or X in each box

It happens accidentally	
It cannot really happen in practice	
It happens because the system has to go to B	
There is a law which prevents it happening	
It happens because the system tends to go to B	
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It is something which happens naturally	
It could never happen, in principle	
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It needs some action to make it happen	
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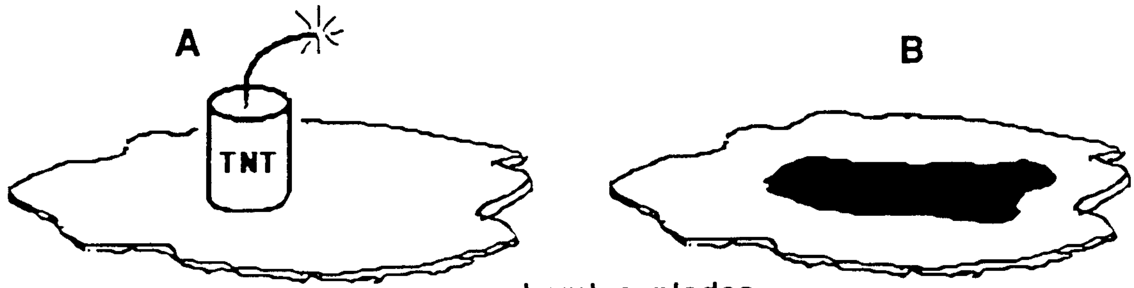

a bomb explodes

Think of - or imagine - some way to go from A to B.

How?

Which of the following phrases describe your idea? √ or X in each box

It happens accidentally		It needs some action to make it happen	
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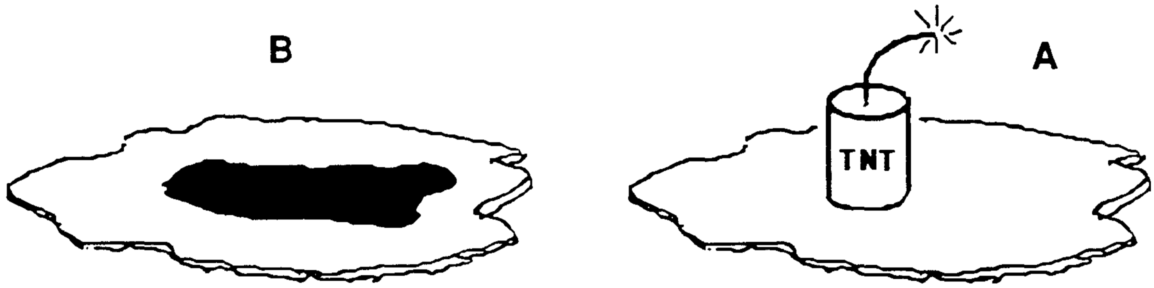

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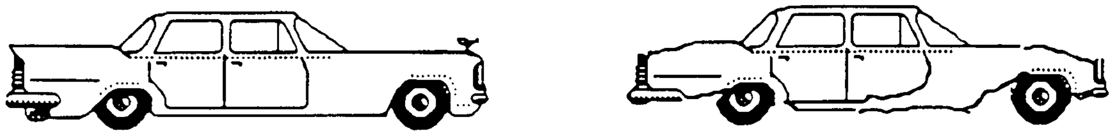
A **B**



a car rusts away

Think of - or imagine - some way to go from A to B.

How?

Which of the following phrases describe your idea? √ or × in each box

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It happens because the system has to go to B	
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Is there only one way to go from A to B?

Yes		
No		

B A

Now, think of - or imagine - some way to GO BACK from B to A.

How?

Which of the following phrases describe your idea? √ or X in each box

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Is there only one way to go from B to A?

Yes		
No		

a car battery runs down

Think of - or imagine - some way to go from A to B.

How?

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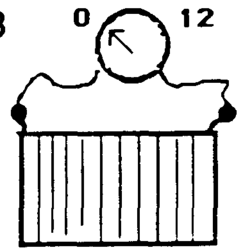
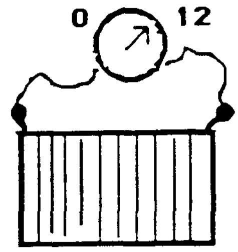
Is there only one way to go from A to B?

Yes		
No		

B



A



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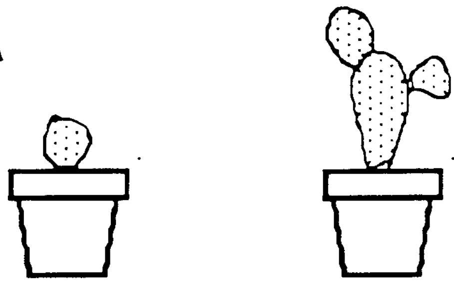
A B



a plant grows

Think of - or imagine - some way to go from A to B.

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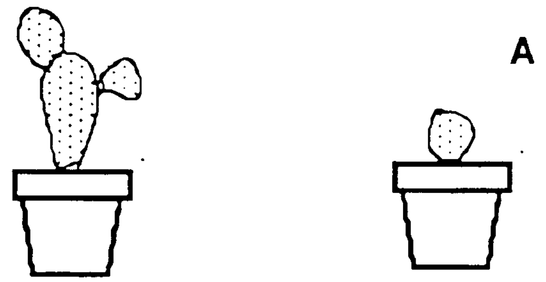

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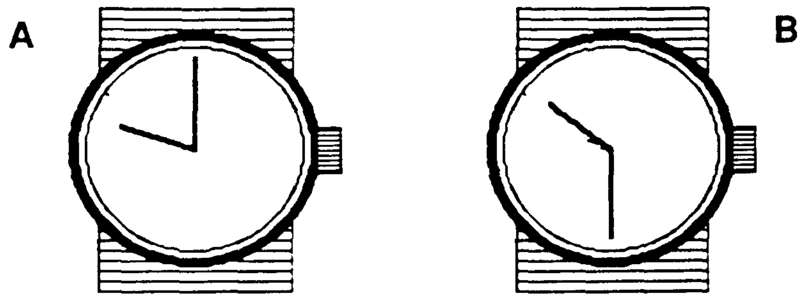

the time goes by

Think of - or imagine - some way to go from A to B.

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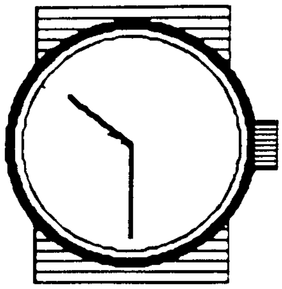
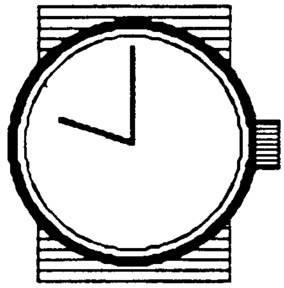
Yes		
No		

B   A

Now, think of - or imagine - some way to GO BACK from B to A.

How?

Which of the following phrases describe your idea? √ or X in each box

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Is there only one way to go from B to A?

Yes		
No		

FORWARDS AND BACKWARDS?

This questionnaire was designed in order to find out how you understand some events in everyday life.

Each question about an event has two parts.
The first part shows a drawing of the event followed by some questions.
The second part shows the same event but in a reverse situation, followed by the same questions.

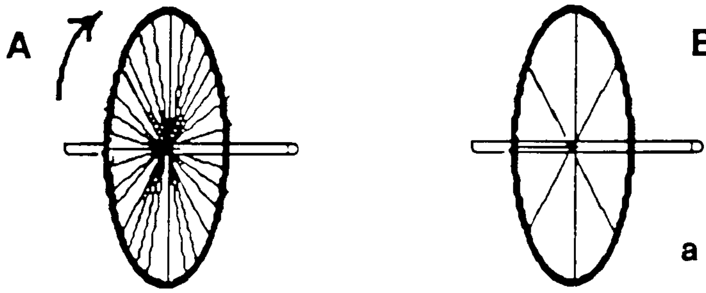
We want you to answer the questions without worrying whether you are "right" or "wrong".

It doesn't matter.

In fact, there are no right or wrong answers.

What's important is your ideas about each event.
So write down whatever comes to your mind as soon as you finish reading each question.

Thank you.



a rotating wheel stops turning

Think of - or imagine - some way to go from A to B.

How?

Which of the following phrases describe your idea? √ or X in each box

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In going from A to B, what things CHANGE?

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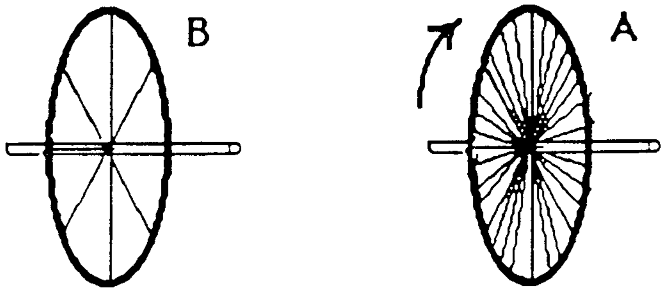
Is there only one way to go from A to B?

Yes		
No		



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Yes		
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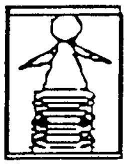
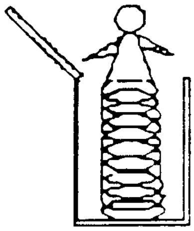
A  B 

a "jack in the box" jumps

Think of - or imagine - some way to go from A to B.

How?

Which of the following phrases describe your idea? √ or X in each box

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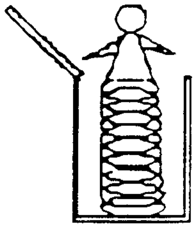
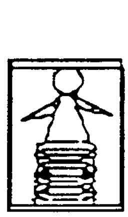
Is there only one way to go from A to B?

Yes		
No		

B



A



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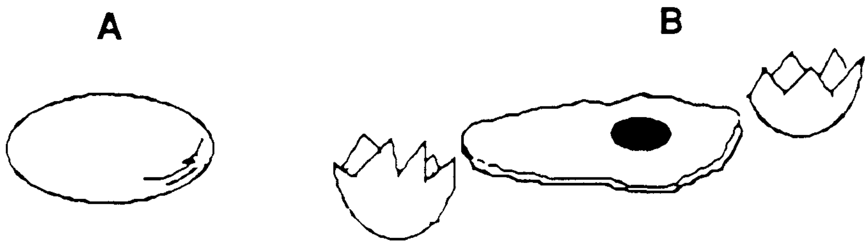

an egg is broken

Think of - or imagine - some way to go from A to B.

How?

Which of the following phrases describe your idea? √ or X in each box

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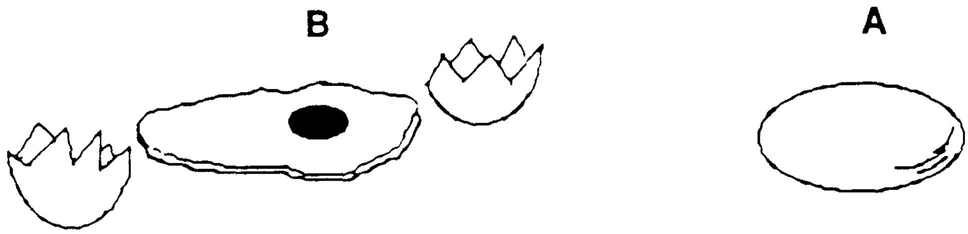

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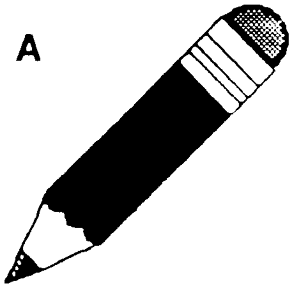
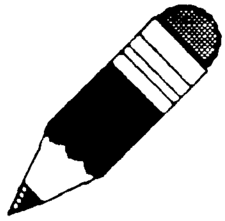
In GOING BACK from B to A, what things STAY THE SAME?

Is there only one way to go from B to A?

Yes		
No		

A





B

a pencil is worn out

Think of - or imagine - some way to go from A to B.

How?

Which of the following phrases describe your idea? √ or ✗ in each box

It happens accidentally		It needs some action to make it happen	
It cannot really happen in practice		It is possible, but difficult to do in practice	
It happens because the system has to go to B		It cannot be stopped from happening	
There is a law which prevents it happening		It is impossible in theory but not in practice	
It happens because the system tends to go to B		It happens by some random process	
There is no cause for it, it just happens		It is possible to imagine but not to do	
It is something which happens naturally		It happens spontaneously, all by itself	
It could never happen, in principle		There is a law which makes it happen	
It happens because getting to B is the reason for the change		It was forced into state A and then just goes back to B.	

What would you say is the cause of the change from A to B?

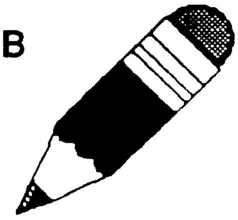
In going from A to B, what things CHANGE?

In going from A to B, what things STAY THE SAME?

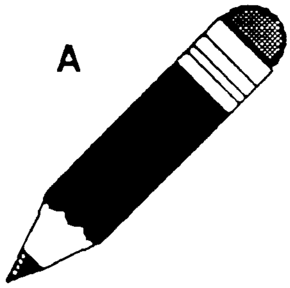
Is there only one way to go from A to B?

Yes		
No		

B



A



Now, think of - or imagine - some way to GO BACK from B to A.

How?

Which of the following phrases describe your idea? √ or X in each box

It happens accidentally		It needs some action to make it happen	
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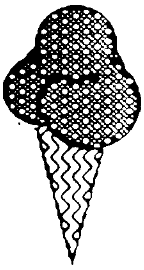
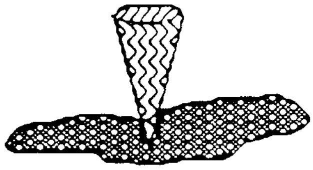
A



B



an ice-cream melts

Think of - or imagine - some way to go from A to B.

How?

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Is there only one way to go from A to B?

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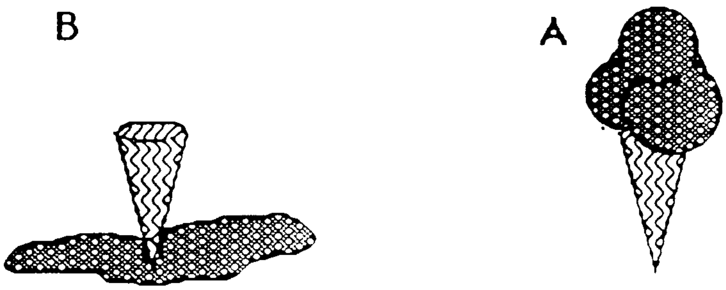

Now, think of - or imagine - some way to GO BACK from B to A.

How?

Which of the following phrases describe your idea? √ or X in each box

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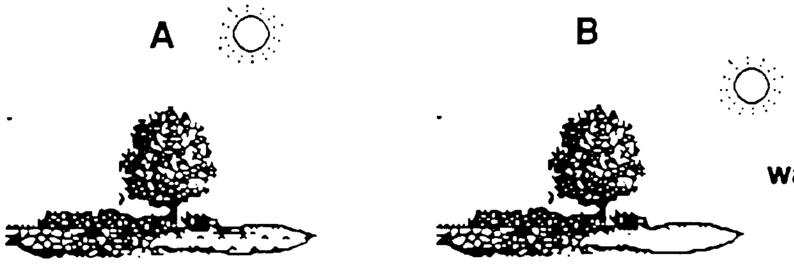

water in a puddle evaporate[illegible]

Think of - or imagine - some way to go from A to B.

How?

Which of the following phrases describe your idea? √ or X in each box

It happens accidentally		It needs some action to make it happen	
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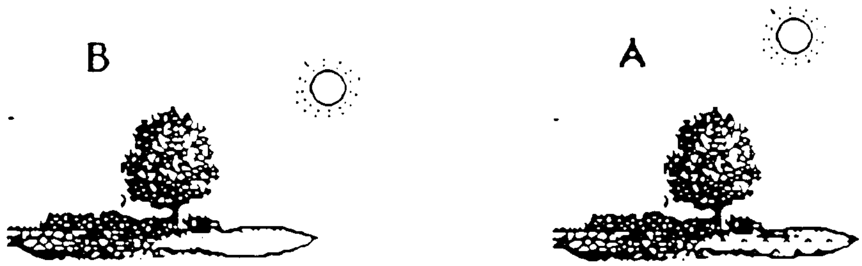

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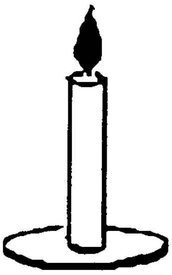
No		

A



B

a candle burns away

Think of - or imagine - some way to go from A to B.

How?

Which of the following phrases describe your idea? √ or X in each box

It happens accidentally		It needs some action to make it happen	
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It happens because the system has to go to B		It cannot be stopped from happening	
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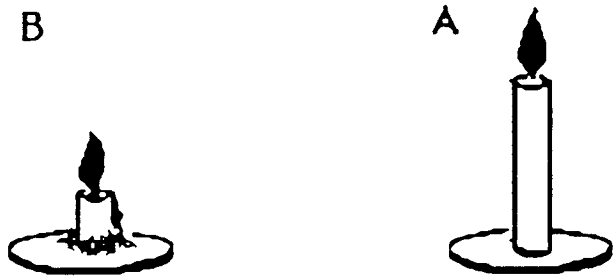

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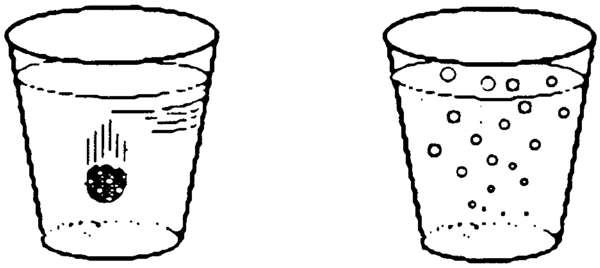
No	

A B



an alka-seltzer tablet dissolves

Think of - or imagine - some way to go from A to B.

How?

Which of the following phrases describe your idea? √ or X in each box

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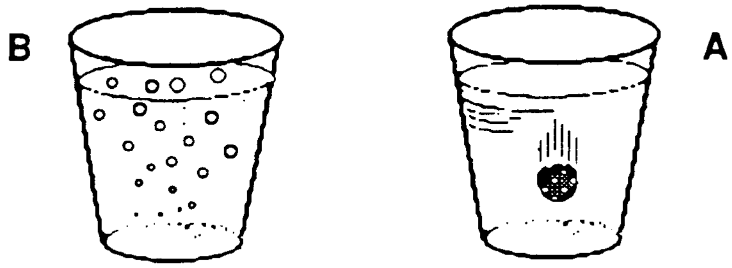
No		



Now, think of - or imagine - some way to GO BACK from B to A.

How?

Which of the following phrases describe your idea? √ or ✗ in each box

It happens accidentally		It needs some action to make it happen	
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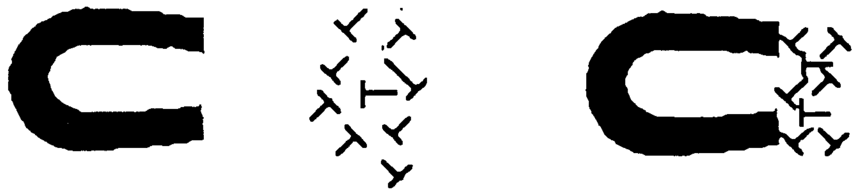
Yes		
No		

A B



a magnet attracts nails

Think of - or imagine - some way to go from A to B.

How?

Which of the following phrases describe your idea? √ or X in each box

It happens accidentally		It needs some action to make it happen	
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In going from A to B, what things CHANGE?

In going from A to B, what things STAY THE SAME?

Is there only one way to go from A to B?

Yes		
No		

B A

Now, think of - or imagine - some way to GO BACK from B to A.

How?

Which of the following phrases describe your idea? √ or X in each box

It happens accidentally		It needs some action to make it happen	
It cannot really happen in practice		It is possible, but difficult to do in practice	
It happens because the system has to go to B		It cannot be stopped from happening	
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In GOING BACK from B to A, what things STAY THE SAME?

Is there only one way to go from B to A?

Yes		
No		

A

B

a man grows old

Think of - or imagine - some way to go from A to B.

How?

Which of the following phrases describe your idea? √ or X in each box

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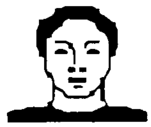
Is there only one way to go from A to B?

Yes		
No		

B

A



Now, think of - or imagine - some way to GO BACK from B to A.

How?

Which of the following phrases describe your idea? √ or ✗ in each box

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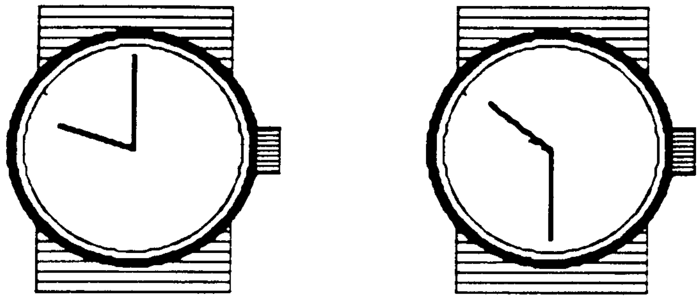
Yes		
No		

A B



the time goes by

Think of - or imagine - some way to go from A to B.

How?

Which of the following phrases describe your idea? √ or X in each box

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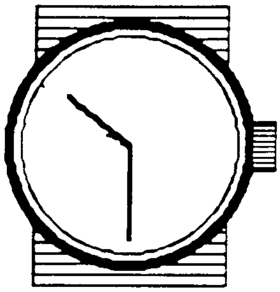
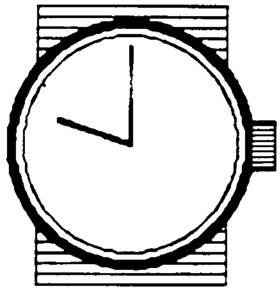
Is there only one way to go from A to B?

Yes		
No		

B





A

Now, think of - or imagine - some way to GO BACK from B to A.

How?

Which of the following phrases describe your idea? √ or X in each box

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In GOING BACK from B to A, what things STAY THE SAME?

Is there only one way to go from B to A?

Yes		
No		

Appendix B

Statistical Techniques

This Appendix briefly describes the meaning of the statistical terms used in the thesis, and indicates the nature of the statistical methods employed. (Everitt and Dunn, 1983, Child, 1978 and Everitt, 1980).

APPENDIX B.1 - Factor Analysis

Multivariate Analysis - is for this purpose of this thesis the investigation of how several dependent variables vary together, looking for patterns or underlying structure in order to establish a smaller number of fundamental factors or dimensions. The techniques used in this research were Factor Analysis, Cluster Analysis and Multidimensional Scaling.

Factor Analysis - assumes a model in which part of the variance of each variable is explained by a linear combination of relatively small number of factors or dimensions.

Factor Extraction - The initial step in factor analysis. The technique used is principal components.

Principal Component Analysis is a method of re-expressing multivariate data of 'n' variables by 'n' factors. The first factor is that linear combination of variables which explains the maximum variance. Having removed this factor, the second is the linear combination which explains the maximum amount of the remaining variance. The factors are also all constrained to be orthogonal to one another.

Rotating Factors - is a method of simplifying the factor structure. The commonest method (Varimax) rotates the factors so that each variable tends to load highly on only one factor.

Orthogonal Rotation - in this case the factors remain uncorrelated (orthogonal).

Oblique Rotation - in this case factors are allowed to correlate with one another.

Orthotran (Oblique) Solution - is a general algorithm that refines the simple structure of an orthogonal solution. It refines the simple structure by allowing the factors to be correlated, giving an oblique solution. This is the transformation used to produce the oblique rotation in the statistics package StatView 512+™, used in this research.

Factor Structure Matrix - matrix representing a oblique solution where the loadings are correlations between the variables and the factor.

Factor Pattern Matrix - matrix representing a oblique solution where the loadings are regression coefficients of each variable for each factor produced when the variable is regressed on the factors.

Eigenvalue - a coefficient that represents the total variance explained by each factor

Bartlett Test of Sphericity - is the multivariate analogue of the statistical test that is frequently applied to a single correlation coefficient to see if it is significantly different from zero. The test of Sphericity is used to determine if, in general, the collection of correlations in the correlation matrix are different from zero.

Factor - hypothesised, unmeasured, and underlying variables which are presumed to be the sources of the observed variables; often divided into unique factors - a factor containing only one significant loading for a particular variable - and common factor - a factor containing two or more variables with significant loadings.

Factor Loading - a general term referring to a coefficient in a factor pattern - when it is the correlation between a variable and a factor - or in a factor structure matrix - when it is the regression between the variable and the factor.

Factor Score - indicates for a case how the pattern of responses across variables correlates with a factor. Factor scores can be regarded as coordinates in a factor space.

Variable Complexity - refers to the factor density of a variable. Usually for ideal simple structure, each variable is accounted for by no more than one factor, and the average variable complexity is one. To the extent that simple structure is not achieved, each variable is defined by more than one factor, and the average variable complexity will be greater than unity.

APPENDIX B.2 - Cluster Analysis

Cluster Analysis - a statistical procedure which examines a collection of variables to see if individuals can be formed into any natural system of groups according to their similarities. The objective of cluster analysis is to identify homogeneous groups or clusters.

Agglomerative Hierarchical Clustering - a commonly method used where clusters are formed by grouping cases into bigger and bigger clusters until all cases are members of a single cluster.

Complete Linkage - criterion for deciding which cases or clusters should be combined at each step. In this method, the distance between two clusters is calculated as the distance between their two furthest points.

APPENDIX B.3 - Multidimensional Scaling (MDS)

Multidimensional Scaling (MDS) - is a technique designed to analyse distance-like data called dissimilarity data, or data that indicates the degree of dissimilarity (or similarity) or two things. MDS analyses the dissimilarity data in a way that displays the structure of the distance-like data as a geometrical picture. If correlations are used as similarities, and distance is defined as Euclidean distance, MDS is equivalent to principal components.

MDS Model - each object or event is represented by a point in a multidimensional space. The points are arranged in this space so that the distances between pairs of point have the best possible relation to the similarities among pairs of objects. That is, two similar objects are represented by two points that are close together, and two dissimilar objects are represented by two points that are far apart. The space is usually a two- or three-dimensional Euclidean space but may have more dimensions.

Appendix C

Statistical Summary of the Factor Analysis for the Pilot Study

APPENDIX C -Statistical Summary of the Factor Analysis for the Pilot Study

The Factor Analysis was performed on a Macintosh computer using the statistic package called StatView 512+™ available at the Institute of Education.

- **Factor Extraction Method**: Principal Component Analysis
- **Transformation Method**: Orthotran/Varimax
- **Number of Factor**: 4
- **Factor Scores**: Oblique Solution
- **Bartlett Test of Sphericity** - DF: 152 Chi-Square: 897.441 p: .0001

- **Eigenvalues and Proportion of Original Variance**

FACTOR	EIGENVALUE	VARIANCE PROP.	CUMULAT. PROP.
1	7.849	.462	.462
2	3.181	.187	.649
3	1.452	.085	.734
4	1.106	.065	.799

Eigenvalues represent the total variance explained by each factor, and the variance proportion is the ratio of the total variance attributable to each factor. The cumulative proportion indicates the fraction of variance attributable to that factor and those that precede it in the table. Therefore, the four factors jointly explain 79.9% of the total variance. Any remaining factors would account for only 20.1% of the variance.

The criterion for deciding the number of factors to be extracted was Kaiser's criterion (Child, 1978), which says that only factors having eigenvalues (or latent roots) greater than unity should be considered.

- **Primary Intercorrelation-Orthotran/Varimax**

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
FACTOR 1	1.000			
FACTOR 2	-.26	1.000		
FACTOR 3	-.407	.491	1.000	
FACTOR 4	-.203	.067	.233	1.000

• Proportionate Variance Contribution

	OBLIQUE TOTAL
FACTOR 1	.355
FACTOR 2	.349
FACTOR 3	.191
FACTOR 4	.106

The oblique total proportionate variance contribution is the sum of the direct proportionate contribution, which represents the proportion of the common variance that the factor accounts for independent of the other factors, plus the joint proportionate contribution, which deals with shared variance or variance that is common to more than one factor.

• 'Factor Scores' for Phrases

Phrases	Factor 1	Factor 2	Factor 3	Factor 4
1- It happens accidentally	-0.034	**1.021**	-0.211	-0.008
2- It cannot really happen in practice	**2.054**	-0.005	-0.053	-0.017
3- It happens because the system has to go to B	-0.405	0.487	**1.150**	0.012
4- There is a law which prevents it happening	**1.316**	-0.076	0.062	-0.052
5- It happens because the system tends to go to B	-0.649	**1.140**	0.524	0.391
6- There is no cause, it just happens	0.429	0.185	**0.570**	-0.340
7- It is something which happens naturally	-1.104	**1.843**	0.464	-0.013
8- It could never happen, in principle	**1.712**	-0.087	0.185	0.016
9- It happens because getting to B is the reason	-0.030	-0.446	**1.301**	0.085
10-It needs some action to make it happen	-0.272	**-2.086**	-0.276	0.117
11-It is possible, but difficult to do in practice	**0.683**	0.012	**-0.847**	0.097
12-It cannot be stopped from happening	-0.326	**0.728**	0.582	-0.667
14-It happens by some random process	0.093	**1.249**	-0.543	0.340
15-It is possible to imagine but not to do	**1.312**	0.057	0.024	0.008
16-It happens spontaneously, all by itself	-0.116	**1.859**	-0.004	0.137
17-There is a law which makes it happen	**-1.116**	0.647	0.244	0.621
18-It was forced into state A and then just goes back	-0.037	0.274	-0.043	**1.568**

Ob.: Phrase 13 was not considered in the Factor Analysis, as explained in section 5.1.

These 'factor scores' are explained in section 5.2.1.

• Factor Scores of Events

EVENT	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
PendulumAB - a pendulum stops swinging	-0.009	0.934	0.519	1.241
PendulumBA - backwards	-0.347	-0.374	-0.575	1.013
SlopeAB - a ball rolls down	-0.463	-0.402	0.081	1.226
SlopeBA - backwards	0.053	-0.755	-0.520	-0.036
TankAB - the water flows out	-0.245	-0.762	0.572	1.700
TankBA - backwards	-0.043	-0.124	-1.109	0.169
PencilAB1 - a pencil is worn out	-0.386	-1.511	1.920	-0.645
PencilBA1 - backwards	2.472	0.008	0.704	-0.017
TeaAB - a cup of tea becomes cold	-0.007	2.749	-1.031	2.043
TeaBA - backwards	-0.812	-0.560	-1.128	0.557
ChampagneAB - the champagne goes flat	0.168	3.099	-1.158	1.943
ChampagneBA - backwards	0.550	-0.004	-1.012	0.373
BombAB - a bomb explodes	-0.862	-0.977	0.627	-0.347
BombBA - backwards	3.149	0.324	1.302	0.321
CarAB - a car rusts away	-0.923	3.146	-2.202	-0.687
CarBA - backwards	-0.003	0.220	-1.480	-0.484
BatteryAB - a car battery runs down	0.106	1.566	-0.561	0.446
BatteryBA - backwards	-0.937	-0.682	-0.614	-0.659
PlantAB - a plant grows	-0.127	-0.164	1.398	-0.515
PlantBA - backwards	0.805	0.678	-0.448	0.057
WatchAB1 - the time goes by	1.563	0.917	3.282	-1.721
WatchBA1 - backwards	1.134	0.354	0.853	-0.906
WheelAB - a rotating wheel stops turning	-0.303	-1.355	1.331	1.409
WheelBA - backwards	-0.984	-1.339	-0.199	0.443
JackAB - a 'jack in the box' jumps	0.436	-2.350	2.982	1.895
JackBA - backwards	-0.709	-1.307	-0.677	0.744
EggAB - an egg is broken	-1.038	-0.165	-0.557	-1.186
EggBA - backwards	1.759	0.374	-0.615	-0.453
PencilAB2 - a pencil is worn out	-0.820	-1.348	0.919	-0.827
PencilBA2 - backwards	2.678	-0.167	0.647	0.229
IceCreamAB - an ice-cream melts	-0.735	0.914	-0.556	0.787
IceCreamBA - backwards	0.031	-0.134	-1.732	0.593
PuddleAB - water in a puddle evaporates	-1.307	1.559	-1.641	-0.387
PuddleBA - backwards	-0.829	0.871	-2.076	-0.334
CandleAB - a candle burns away	-1.656	0.112	-0.383	-1.300
CandleBA - backwards	0.482	-0.316	-0.872	0.015
AlkaSeltAB - an alka-seltzer tablet dissolves	-0.896	-0.070	0.327	0.178
AlkaSeltBA - backwards	1.119	-0.277	-0.131	0.552
MagnetAB - a magnet attracts nails	-1.014	-0.480	0.359	-0.417
MagnetBA - backwards	-0.636	-0.756	-0.225	-1.096
BoyManAB - a man grows old	-0.785	0.538	1.854	-2.808
BoyManBA - backwards	1.808	-0.244	0.506	-0.470
WatchAB2 - the time goes by	-0.455	-0.973	1.613	-1.419
WatchBA2 - backwards	-0.980	-0.764	-0.296	-1.222

Appendix D

Cluster Analysis for Events for the Pilot Study

APPENDIX D - Cluster Analysis for Events for the Pilot Study

This Appendix describes the interpretation of the clusters of events. Clusters were sought among the events plotted in the factor space when their factor scores were cluster analysed using the complete linkage method. The analysis was performed on a Macintosh computer using the statistics package called Data Desk® Professional available at the Institute of Education. Figure D.1 shows the result with the interpretations. The clusters appear to be:

D.1.1 First Cluster: HAPPEN BY THEMSELVES, NATURALLY RULED BY SOME LAW - SPONTANEOUS CAUSAL LAW

The events fitting in this cluster were:

Champagne AB	Car AB	Puddle AB
Tea AB	Puddle BA	Candle AB

Looking at the plots of Figure D.2, these events can be described as having the following features:

- they do not need any action to happen, and as they have a substantial coordinate on phrases 7 - 'it is something which happens naturally', and phrase 17 - 'there is a law which makes it happen', it seems they are ruled by some law which makes them happen naturally;

- they do not have/need any goal, but they have/need a cause inasmuch they are around the negative contribution of phrase 6 - 'there is no cause, it just happens';

- while most of them have a substantial coordinate on phrase 14 - 'it happens by some random process', they can be interpreted as happening by themselves but without any planning.

Therefore, it seems they happen by themselves, are ruled by some law which makes them happen naturally, and need a cause, but happen randomly, with no planning. As no action is necessary to be taken, perhaps the causes are related to some external conditions which cannot be foreseen, and a description of this cluster would be: event ruled by a spontaneous causal law.

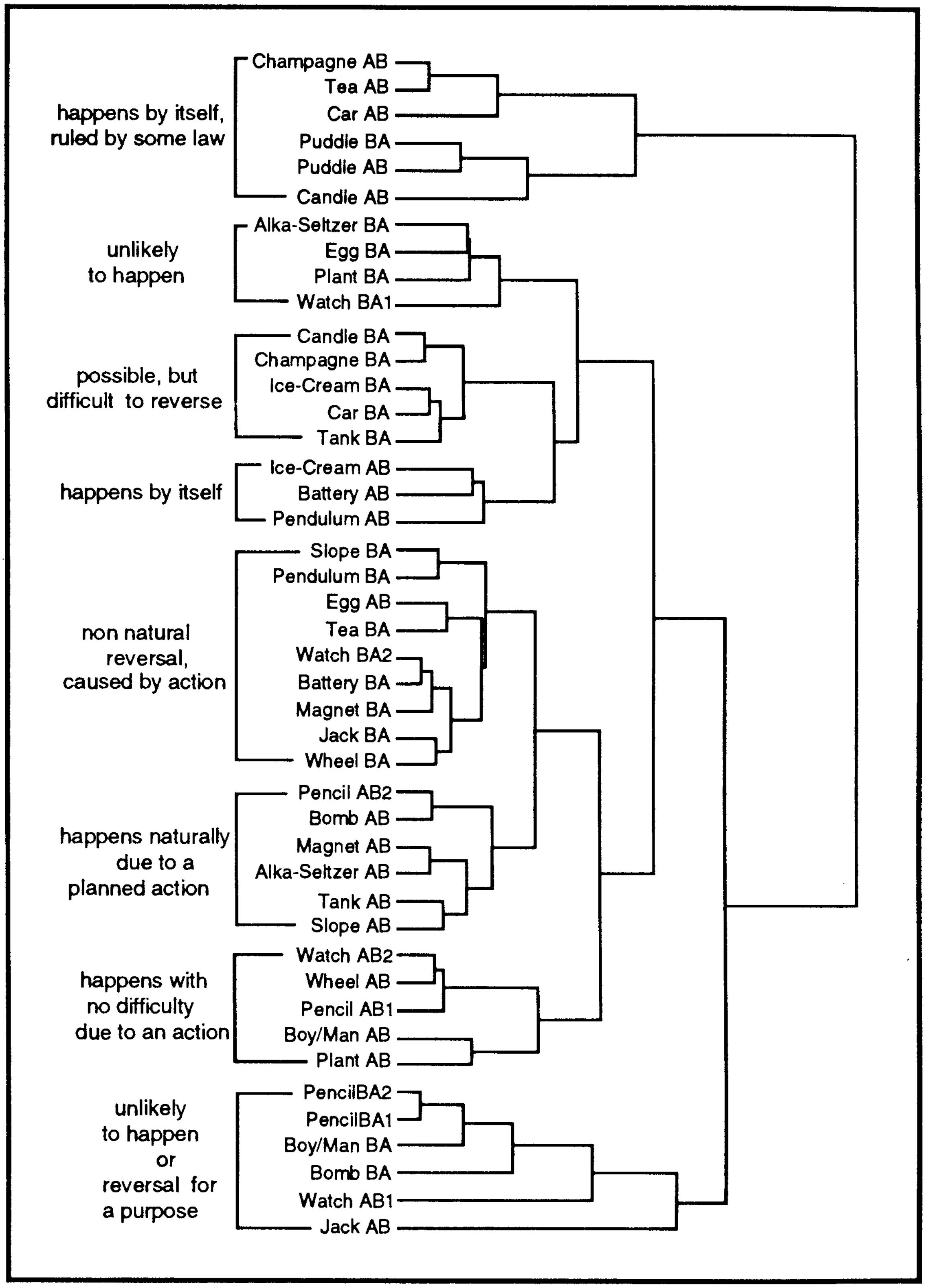


Figure D.1 - Cluster of events in the factor space

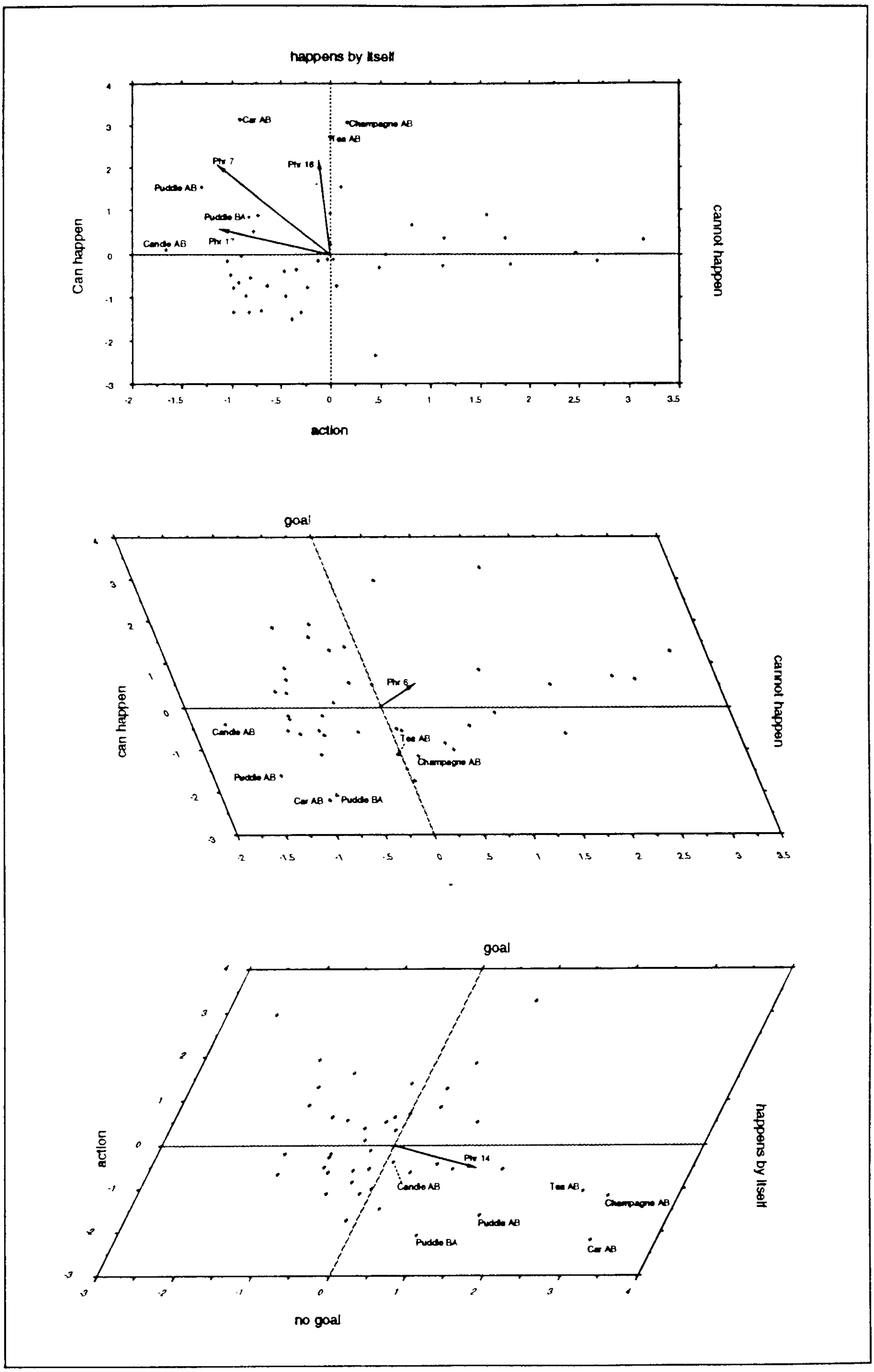


Figure D.2 - *First Cluster: Happens by itself, ruled by some (causal) law*

D.1.2 Second Cluster: UNLIKELY TO HAPPEN

The events met in this cluster were:

Alka-Seltzer BA	Plant BA	Watch BA1
Egg BA		

They are all BA events, and looking at the plots of Figure D.3 it is noticed these events can be basically described as the ones which cannot happen, with almost no discrimination in relation to the other dimensions.

D.1.3 Third Cluster: POSSIBLE, BUT DIFFICULT

In this case the events included were:

Candle BA	Ice-Cream BA	Tank BA
Champagne BA	Car BA	

Again, these events are all BA, and from their location shown in Figure D.4 it can be observed that they mainly cluster around phrase 11 - 'it is possible, but difficult to do in practice', and they do not need/have any goal. There is no clear distinction whether they happen by themselves or they need an action.

D.1.4 Fourth Cluster: HAPPEN BY THEMSELVES, NATURALLY AND SPONTANEOUSLY

The events fitting in this cluster were:

Ice-Cream AB	Battery AB	Pendulum AB

Looking at Figure D.5 it is noticed these events do not need any action to happen, and can be basically described as happening by themselves, with no other remarkable discrimination. They are located around phrase 7 - 'it is something which happens naturally' and phrase 16 'it happens spontaneously, all by itself', thus supporting this analysis. Unlike the events of the first cluster, it seems they have/need no causes.

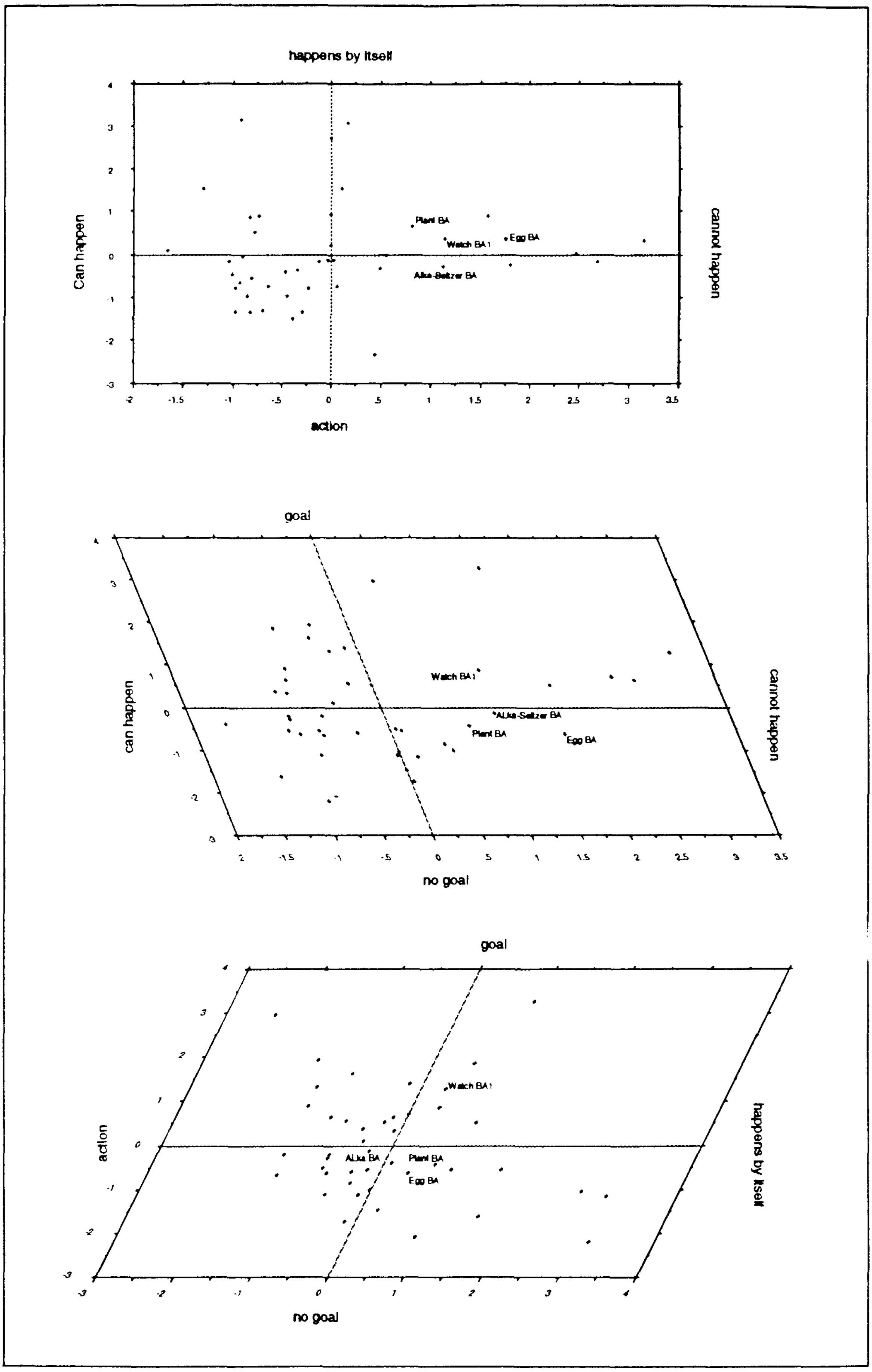


Figure D.3 - *Second Cluster: Unlikely to happen*

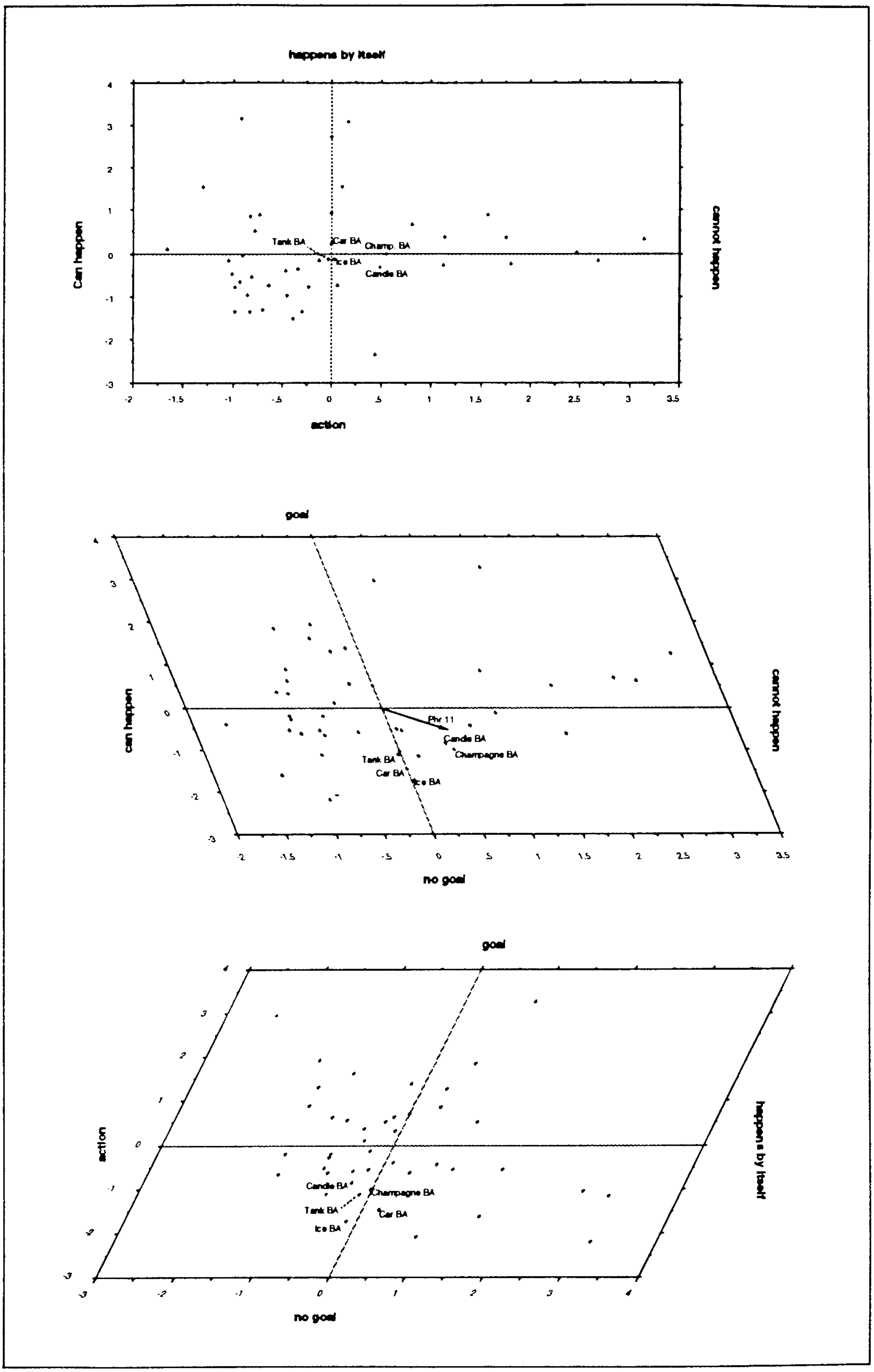


Figure D.4 - *Third Cluster: Possible, but difficult to happen*

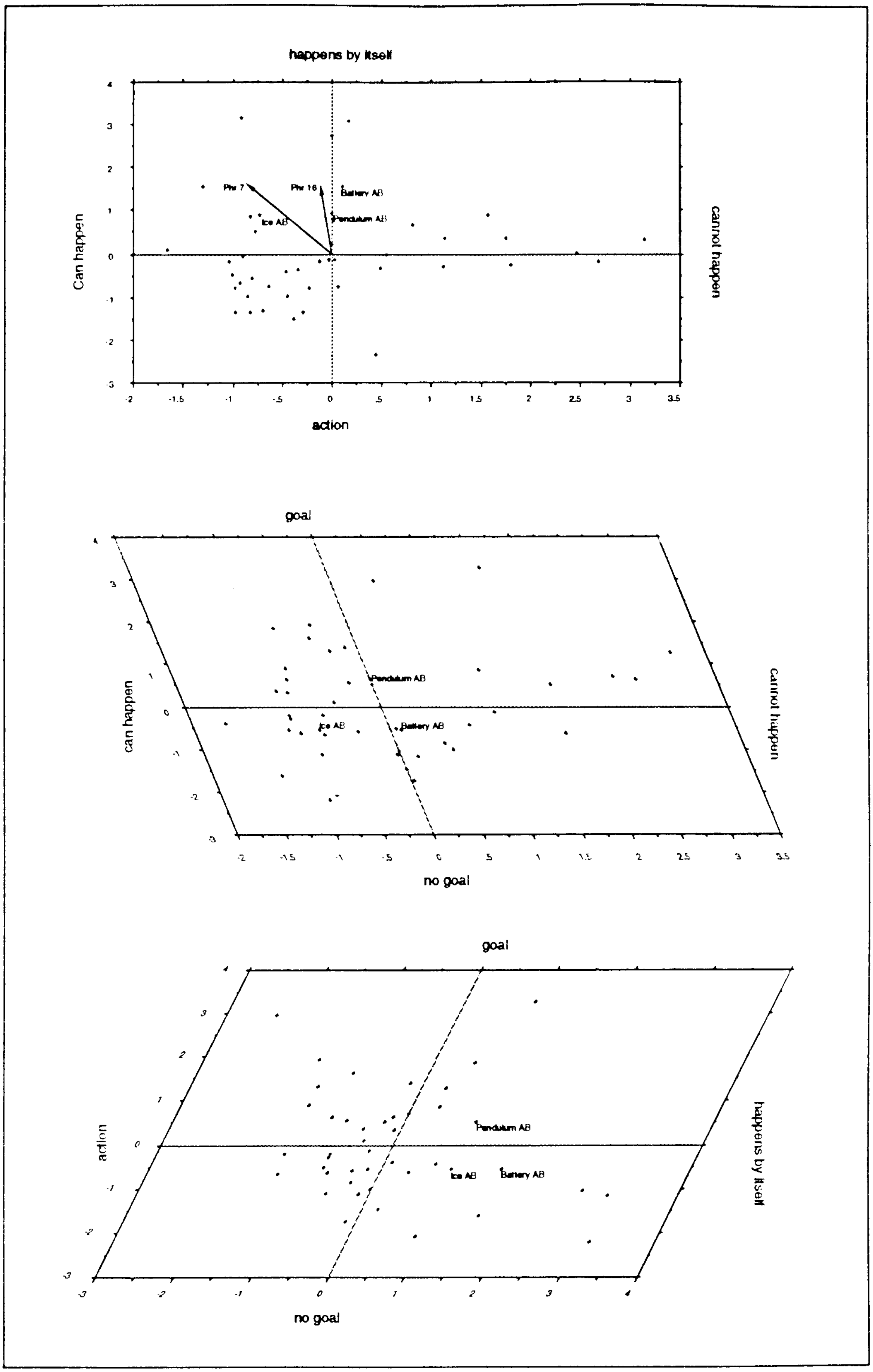


Figure D.5 - *Fourth Cluster: Happens by itself*

D.1.5 Fifth Cluster: NON NATURAL REVERSAL CAUSED BY AN ACTION

The events belonging to this cluster were:

Slope BA	Tea BA	Magnet BA
Pendulum BA	Watch BA2	Jack BA
Egg AB	Battery BA	Wheel BA

All except Egg AB are BA events, and considering Figure D.6, these events can be described as having the following features:

- they need an action to happen, a view supported by their location around phrase 10 - 'it needs some action to make it happen';

- they do not need/have any goal, but they need/have a cause insofar as they are located around the negative contribution of phrase 6 - 'there is no cause, it just happens';

- they can happen, but not naturally, insofar as they are located around the negative contribution of phrase 7 - 'it is something which happens naturally', and the positive contribution of phrase 10 - 'it needs some action to make it happen'.

Therefore, they can be characterised as able to happen, but not naturally, due to an action, that is non natural reversal, caused by an action.

D.1.6 Sixth Cluster: HAPPEN NATURALLY WHEN A PLANNED ACTION IS TAKEN

In this case the events included were:

Pencil AB2	Magnet AB	Tank AB
Bomb AB	Alka-Seltzer AB	Slope AB

From the location of these events in Figure D.7, they can be described as:

- they need an action to happen, characterised by their location around phrase 10 - 'it needs some action to make it happen';

- they can happen and they do so naturally due to a law which makes them happen, according to their location around phrase 7 - 'it is something which happens naturally' and phrase 17 - 'there is a law which makes it happen';

- they have/need a external goal, a view supported by the negative contribution of phrase 14 - 'it happens by some random process'. If something doesn't happen randomly, maybe it is because it was previously planned, and when the action was taken by the subject it was because s/he had already a goal in mind.

Therefore they could be described as events which happen naturally when a planned action is taken. Excepting for the event Pencil AB2, an planned action could be thought of to trigger the event.

D.1.7 Seventh Cluster: HAPPEN WITH NO DIFFICULTY DUE TO AN ACTION TAKEN WITH A GOAL

In this cluster the events were:

Watch AB2	Pencil AB1	Plant AB
Wheel AB	Boy/Man AB	

Looking at the plots of Figure D.8 it is noticed that the main characteristics of these events are:

- all except Boy/Man AB need an action to happen;

- they have a strong goal and happen with no difficulty, once the are located around the negative contribution of phrase 11 - 'it is possible, but difficult to do in practice';

- their location around the negative contribution of phrase 14 - 'it happens by some random process', also support the feature that they have a strong goal.

Thus, they need a planned action to happen with no difficulty, that is happen with no difficulty due to an action taken with a goal.

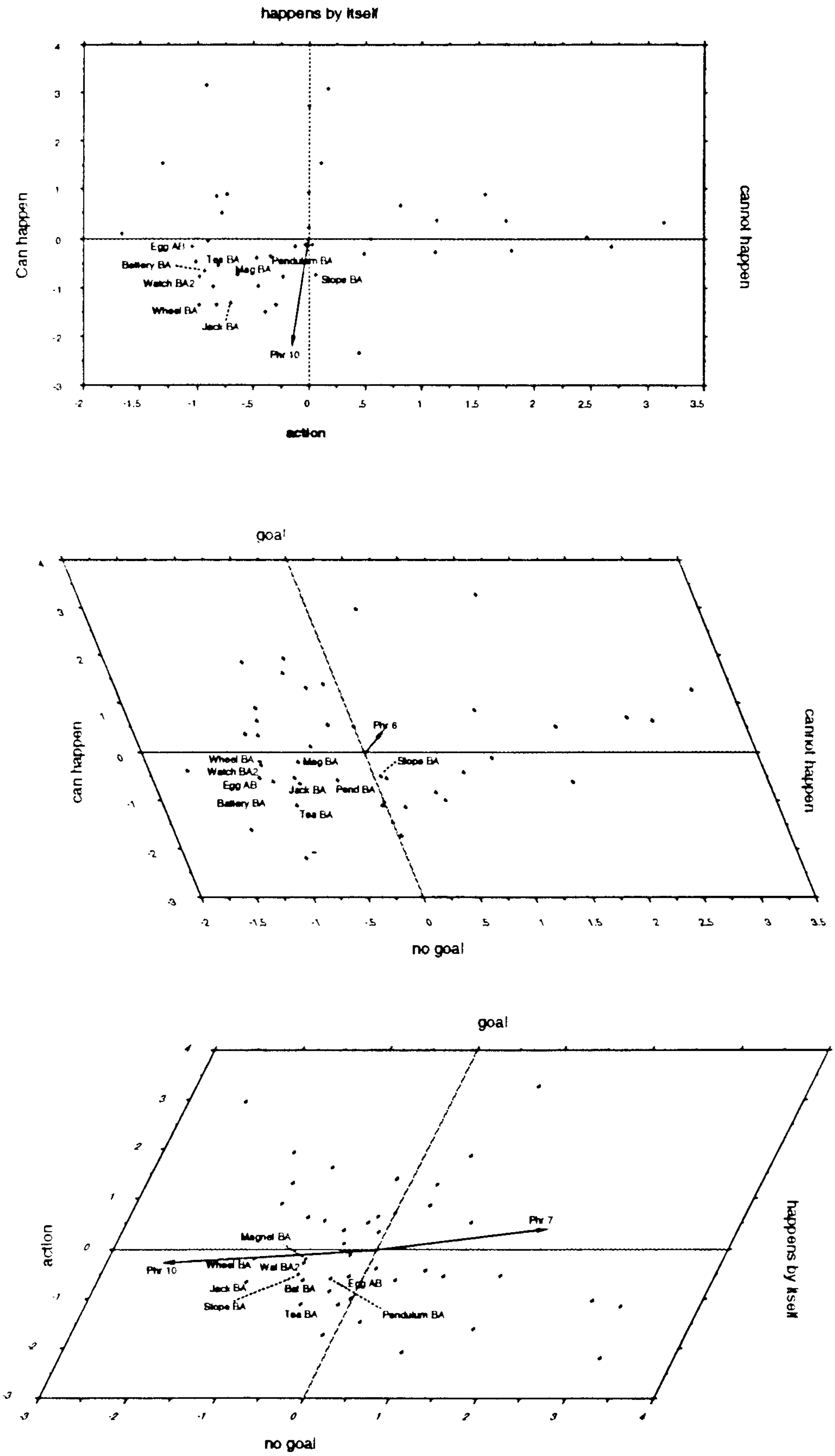


Figure D.6 - *Fifth Cluster: Non natural reversal, caused by action*

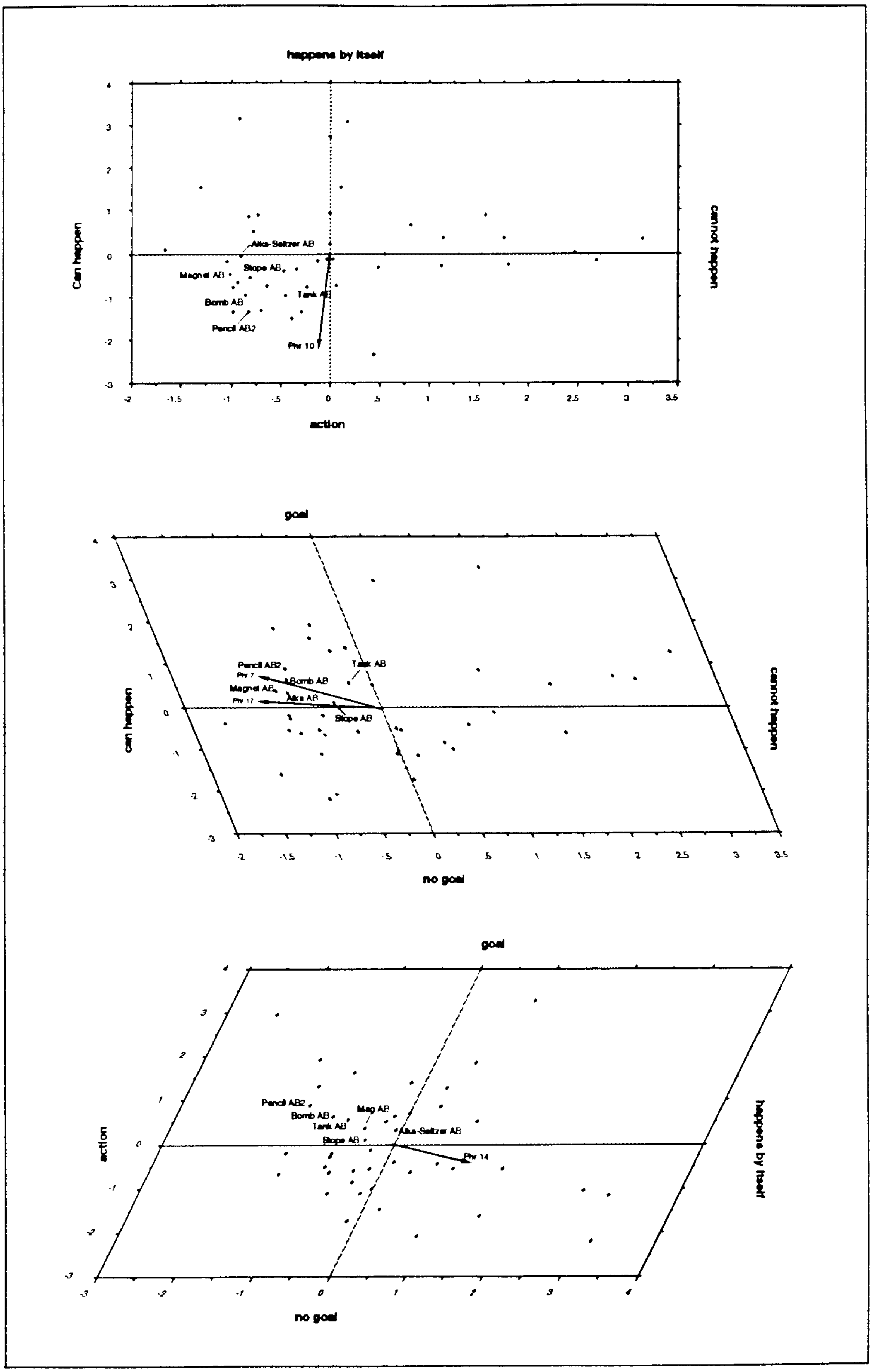


Figure D.7 - *Sixth Cluster: Happens naturally due to a planned action*

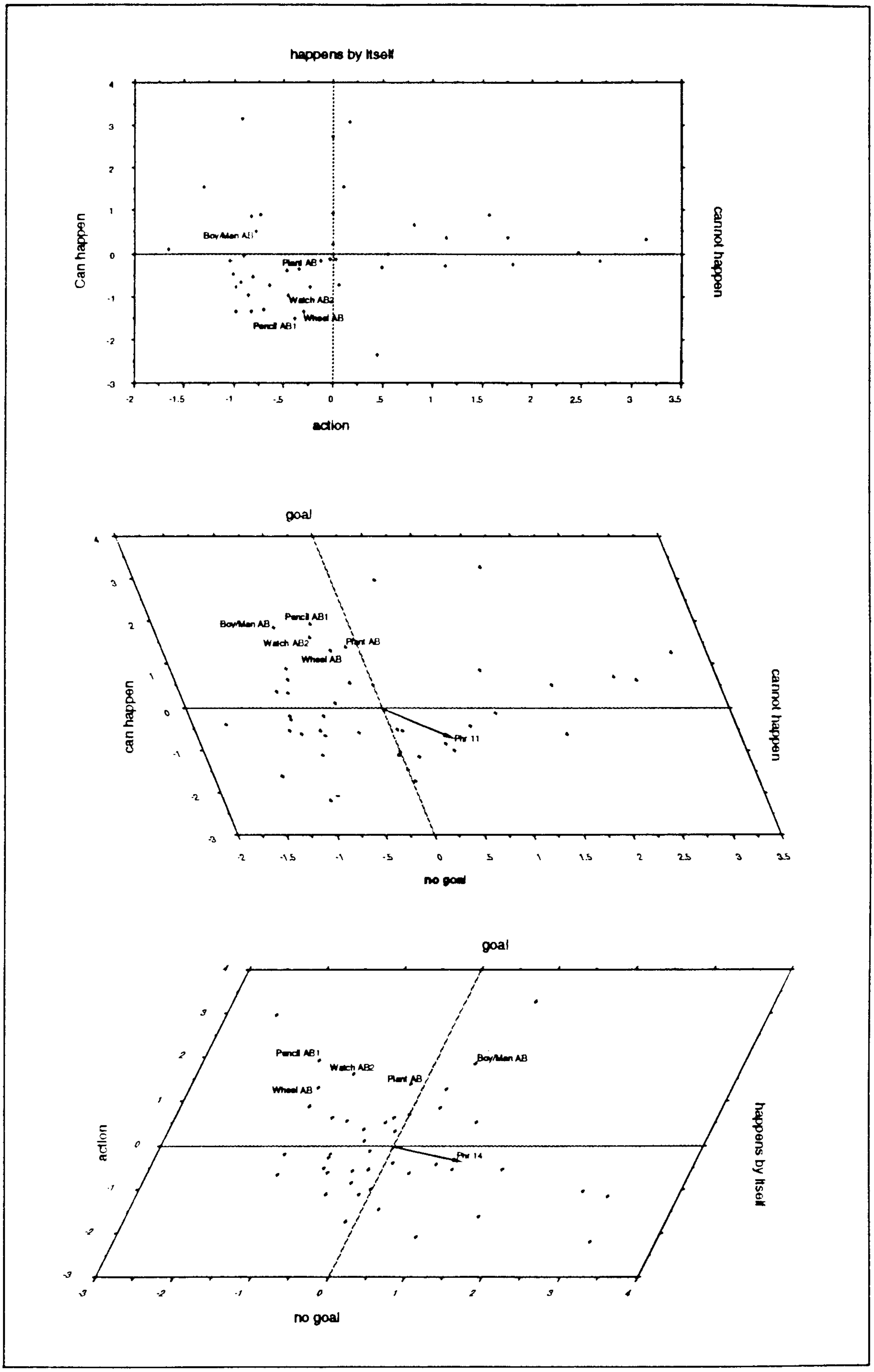


Figure D.8 - *Seventh Cluster: Happens with no difficulty due to an action*

D.1.8 Eighth Cluster: UNLIKELY TO HAPPEN OR POSSIBLE REVERSAL FOR A PURPOSE, BUT LACKING A POSSIBLE CAUSE

In the last cluster the events included were:

Pencil BA2	Boy/Man BA	Watch AB1
Pencil BA1	Bomb BA	Jack AB

These mainly BA events are basically understood as not able to happen, perhaps due to the absence of cause indicated by phrase 6 - 'there is no cause, it just happens'. However they are acknowledged to have/need a goal, which could lead them to happen (Figure D.9). Therefore, it seems that the student needs to imagine a cause or goal, which is known to be impossible (when it is thought of as impossible), just to make the events to happen (when it is thought of as a possible reversal).

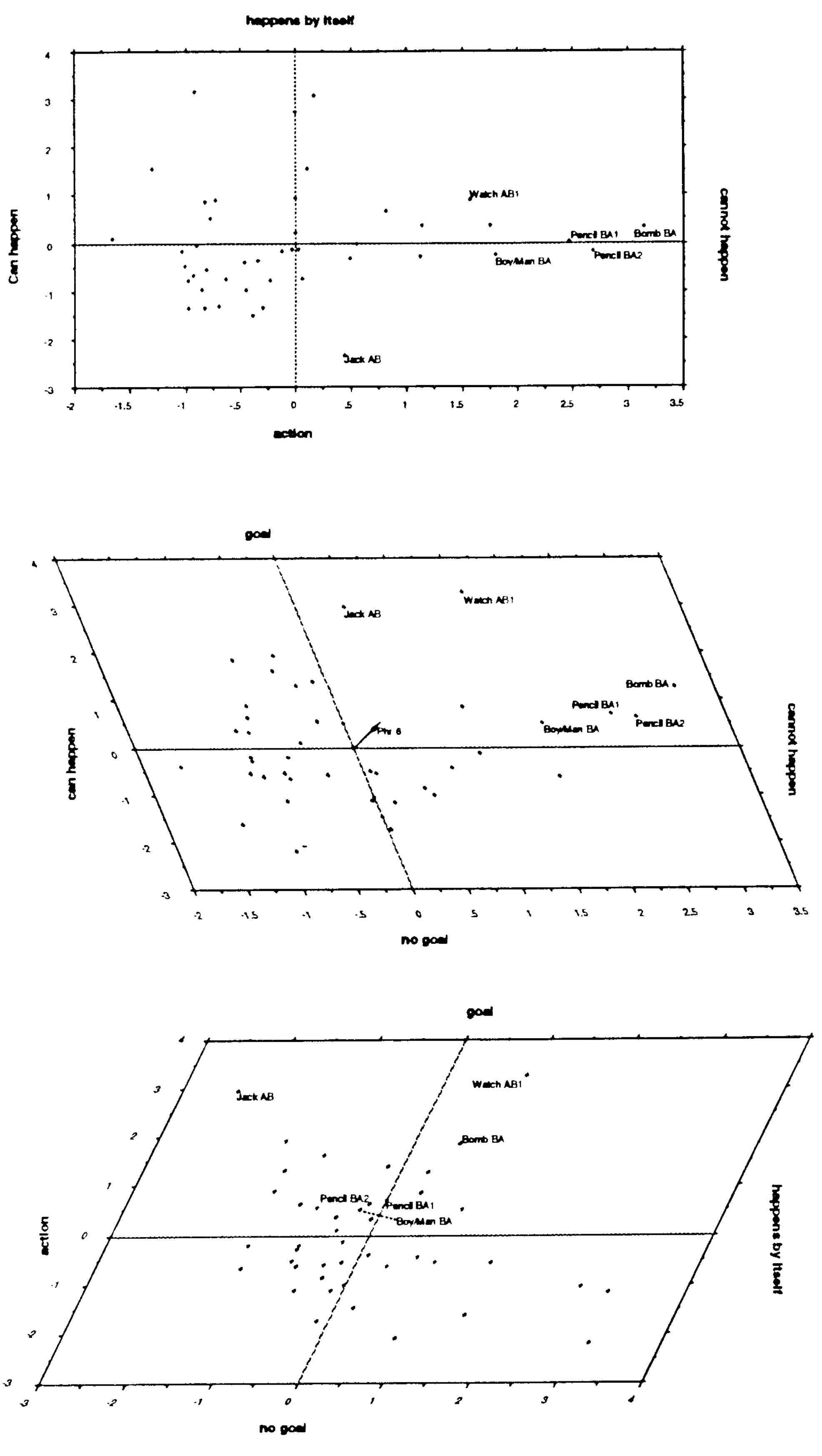


Figure D.9 - *Eighth Cluster: Unlikely to happen or reversal for a purpose*

Appendix E

The Questionnaires for the Main Study

FORWARDS AND BACKWARDS ?

This questionnaire was designed in order to find out what you think about some events in everyday life.

Each question about an event has two parts.
The first part shows a drawing of the event, and the second one shows the same event but in reverse.
Each part is followed by similar questions.

We want you to answer the questions without worrying whether you are "right" or "wrong".

It doesn't matter.

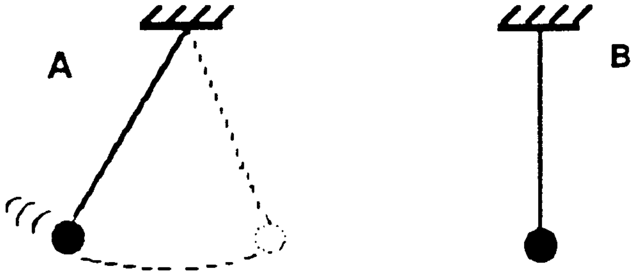
In fact, there are no right or wrong answers.

What's important is your ideas about each event.
So write down whatever comes to your mind as soon as you finish reading each question.

Thank you.

Age: _______

Sex: M ☐ F ☐
Tick as appropriate



a pendulum stops swinging

1. Think of some way to go from A to B.

How?

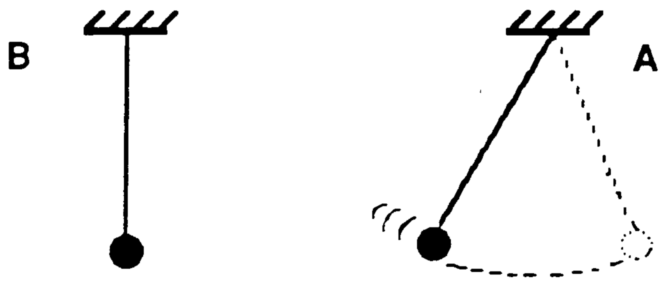
2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **B**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **B**	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **B** is the reason for the change	

3. What, if anything, would you say is the cause of the change from A to B?

Questionnaire 1



1. Now, think of some way to GO BACK from B to A.

How?

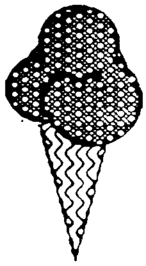
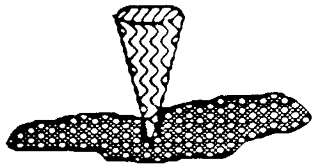
2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **A**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **A**	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **A** is the reason for the change	

3. What, if anything, would you say is the cause of the change from B to A?

Questionnaire 1

A  B  an ice-cream melts

1. Think of some way to go from A to B.

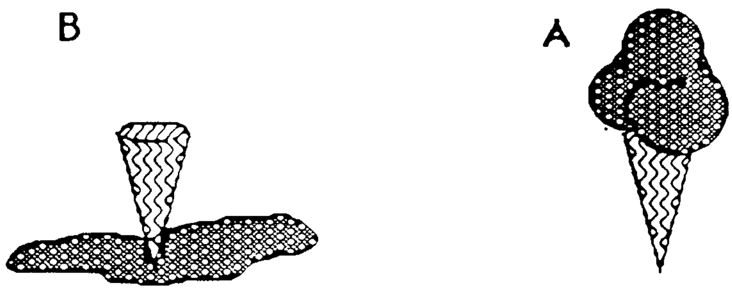
How?

2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **B**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **B**	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **B** is the reason for the change	

3. What, if anything, would you say is the cause of the change from A to B?



1. Now, think of some way to GO BACK from B to A.

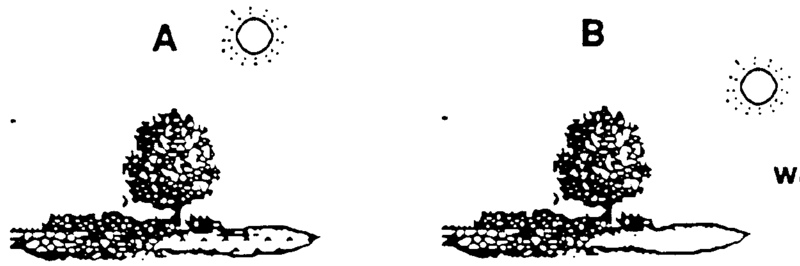
How?

2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **A**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **A**	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **A** is the reason for the change	

3. What, if anything, would you say is the cause of the change from B to A?



water in a puddle evaporates

1. Think of some way to go from A to B.

How?

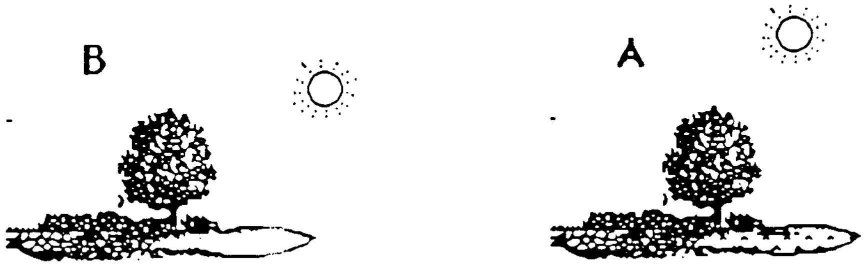
2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **B**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **B**	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **B** is the reason for the change	

3. What, if anything, would you say is the cause of the change from A to B?

Questionnaire 1



1. Now, think of some way to GO BACK from B to A.

How?

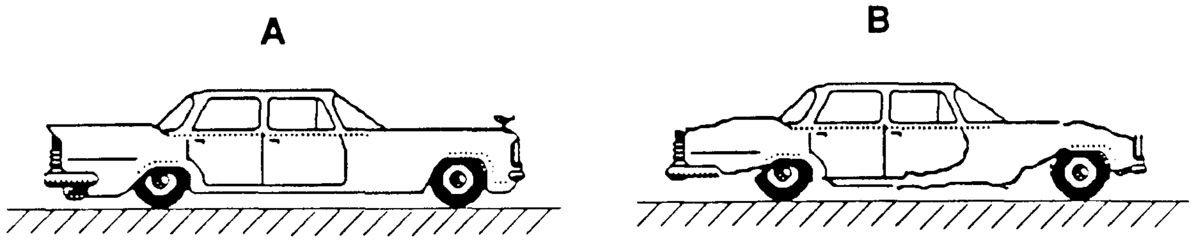
2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **A**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **A**	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **A** is the reason for the change	

3. What, if anything, would you say is the cause of the change from B to A?

Questionnaire 1



a car rusts away

1. Think of some way to go from A to B.

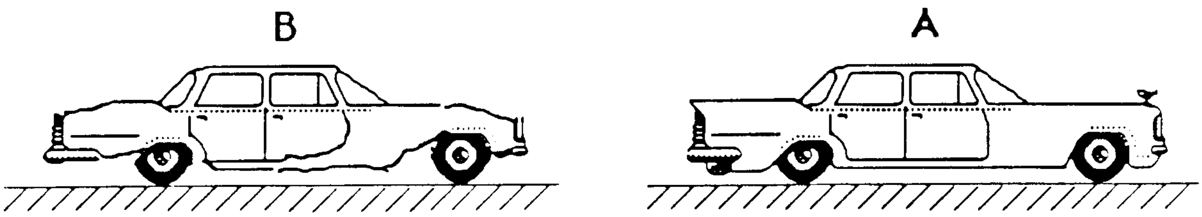
How?

2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **B**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to B	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **B** is the reason for the change	

3. What, if anything, would you say is the cause of the change from A to B?



1. Now, think of some way to GO BACK from B to A.

How?

2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **A**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **A**	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **A** is the reason for the change	

3. What, if anything, would you say is the cause of the change from B to A?

A 

B 

a man grows old

1. Think of some way to go from A to B.

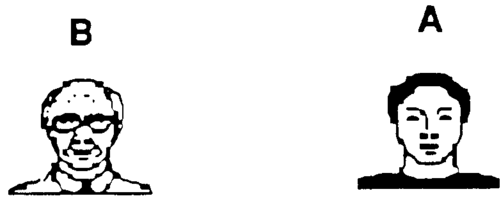
How?

2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **B**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **B**	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **B** is the reason for the change	

3. What, if anything, would you say is the cause of the change from A to B?



1. Now, think of some way to GO BACK from B to A.

How?

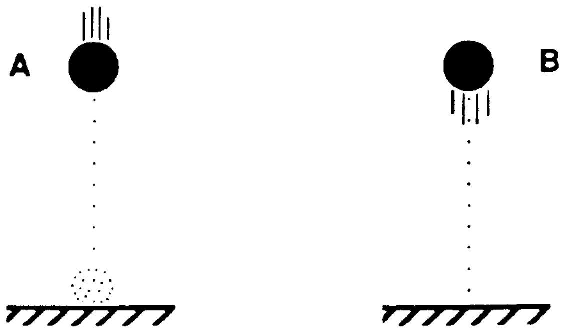
2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **A**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **A**	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **A** is the reason for the change	

3. What, if anything, would you say is the cause of the change from B to A?

Questionnaire 1



the ball falls and bounces back up

1. Think of some way to go from A to B.

How?

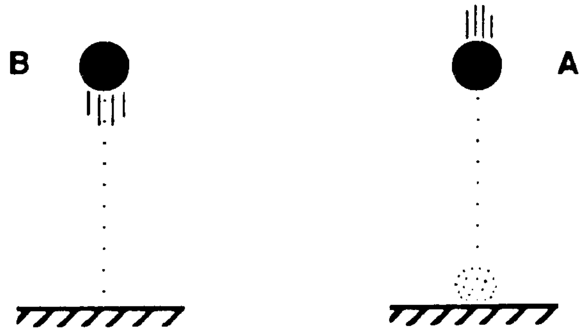
2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **B**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **B**	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **B** is the reason for the change	

3. What, if anything, would you say is the cause of the change from A to B?

Questionnaire 1



1. Now, think of some way to GO BACK from B to A.

How?

2. Which of the following phrases describe your idea?

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It is something which happens naturally	
There is a law which prevents it happening	
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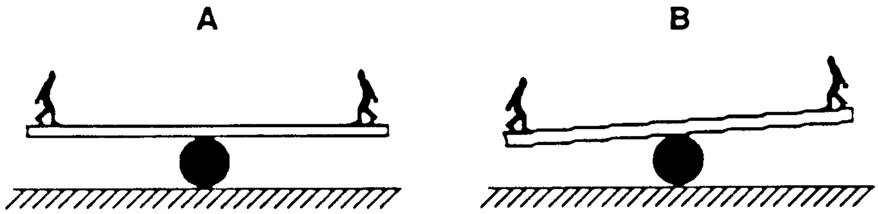
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **A** is the reason for the change	

3. What, if anything, would you say is the cause of the change from B to A?

Questionnaire 1



the see-saw is tilted a little

1. Think of some way to go from A to B.

How?

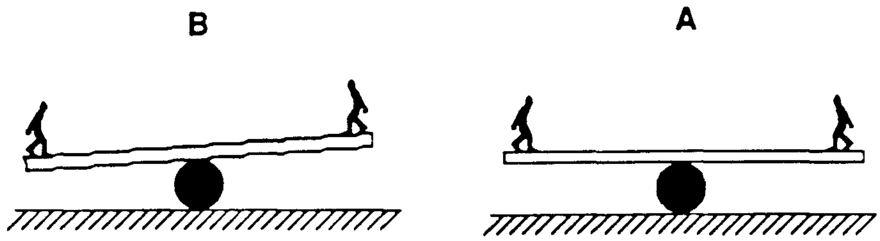
2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **B**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **B**	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **B** is the reason for the change	

3. What, if anything, would you say is the cause of the change from A to B?

Questionnaire 1



1. Now, think of some way to GO BACK from B to A.

How?

2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **A**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **A**	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **A** is the reason for the change	

3. What, if anything, would you say is the cause of the change from B to A?

FORWARDS AND BACKWARDS ?

This questionnaire was designed in order to find out what you think about some events in everyday life.

Each question about an event has two parts.
The first part shows a drawing of the event, and the second one shows the same event but in reverse.
Each part is followed by similar questions.

We want you to answer the questions without worrying whether you are "right" or "wrong".

<u>It doesn't matter</u>.

In fact, there are no right or wrong answers.

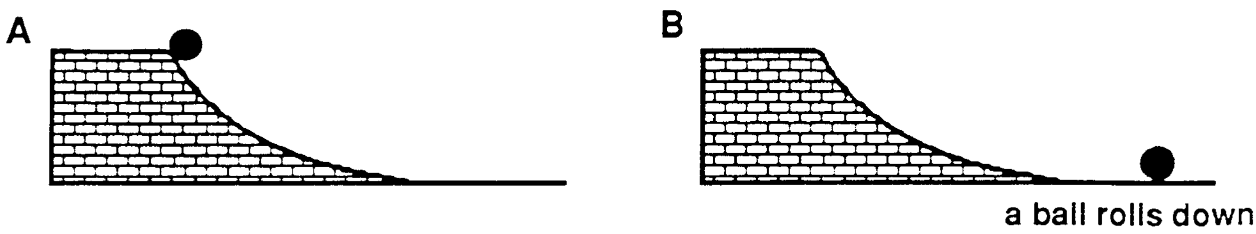
What's important is your ideas about each event.
So write down whatever comes to your mind as soon as you finish reading each question.

Thank you.

Age: _______

Sex: M ☐ F ☐
Tick as appropriate

Questionnaire 2



1. Think of some way to go from A to B.

How?

2. Which of the following phrases describe your idea?

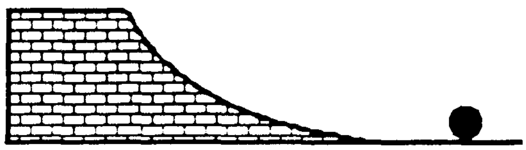
√ or X in each box

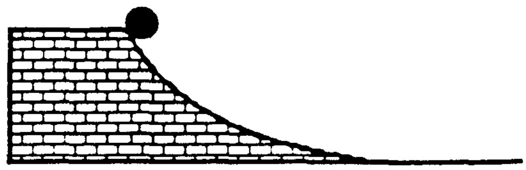
It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **B**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **B**	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **B** is the reason for the change	

3. What, if anything, would you say is the cause of the change from A to B?

B

A





1. Now, think of some way to GO BACK from B to A.

How?

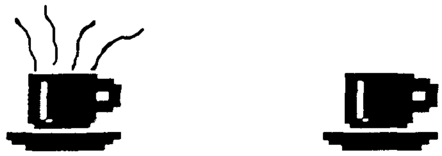
2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **A**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **A**	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **A** is the reason for the change	

3. What, if anything, would you say is the cause of the change from B to A?

A B



a cup of tea becomes cold

1. Think of some way to go from A to B.

How?

2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **B**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **B**	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **B** is the reason for the change	

3. What, if anything, would you say is the cause of the change from A to B?

1. Now, think of some way to GO BACK from B to A.

How?

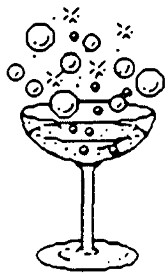
2. Which of the following phrases describe your idea?

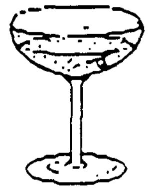
√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **A**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **A**	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **A** is the reason for the change	

3. What, if anything, would you say is the cause of the change from B to A?

A





B

the champagne goes flat

1. Think of some way to go from A to B.

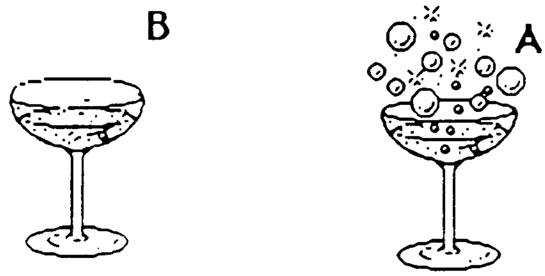
How?

2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **B**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **B**	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **B** is the reason for the change	

3. What, if anything, would you say is the cause of the change from A to B?



1. Now, think of some way to GO BACK from B to A.

How?

2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **A**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **A**	
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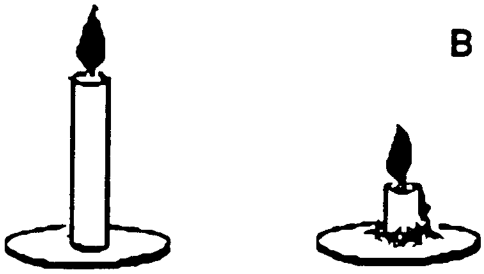
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **A** is the reason for the change	

3. What, if anything, would you say is the cause of the change from B to A?

Questionnaire 2

A B



a candle burns away

1. Think of some way to go from A to B.

How?

2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **B**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **B**	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **B** is the reason for the change	

3. What, if anything, would you say is the cause of the change from A to B?

1. Now, think of some way to GO BACK from B to A.

How?

2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
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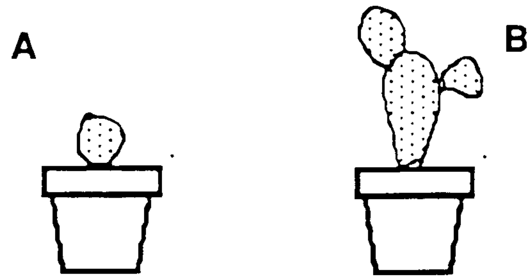
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **A** is the reason for the change	

3. What, if anything, would you say is the cause of the change from B to A?

Questionnaire 2



a plant grows

1. Think of some way to go from A to B.

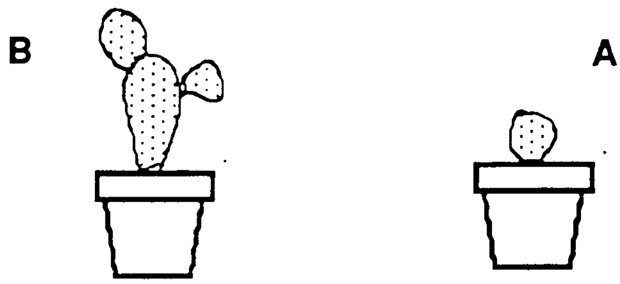
How?

2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **B**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **B**	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **B** is the reason for the change	

3. What, if anything, would you say is the cause of the change from A to B?



1. Now, think of some way to GO BACK from B to A.

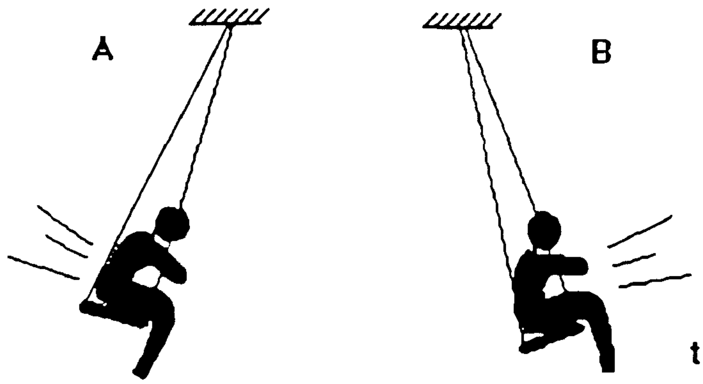
How?

2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **A**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **A**	
It coula never happen, in pnnciple	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **A** is the reason for the change	

3. What, if anything, would you say is the cause of the change from B to A?



the swing comes back

1. Think of some way to go from A to B.

How?

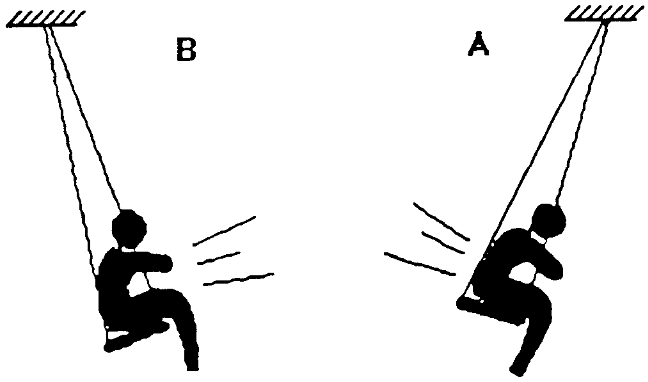
2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **B**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **B**	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **B** is the reason for the change	

3. What, if anything, would you say is the cause of the change from A to B?

Questionnaire 2



1. Now, think of some way to GO BACK from B to A.

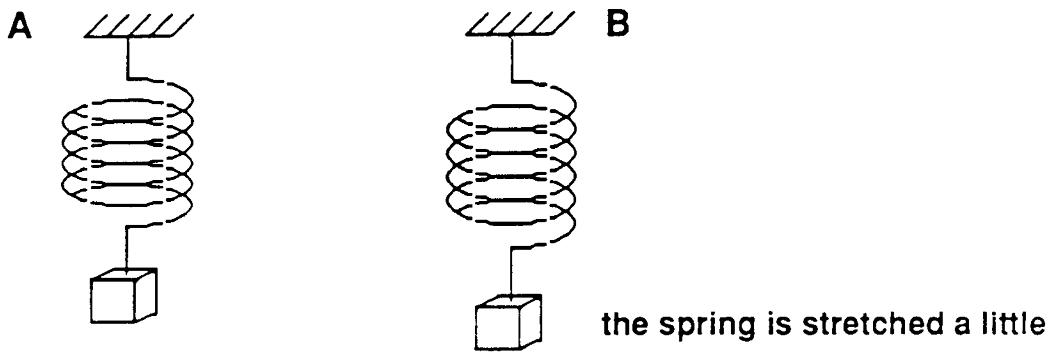
How?

2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **A**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **A**	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **A** is the reason for the change	

3. What, if anything, would you say is the cause of the change from B to A?



1. Think of some way to go from A to B.

How?

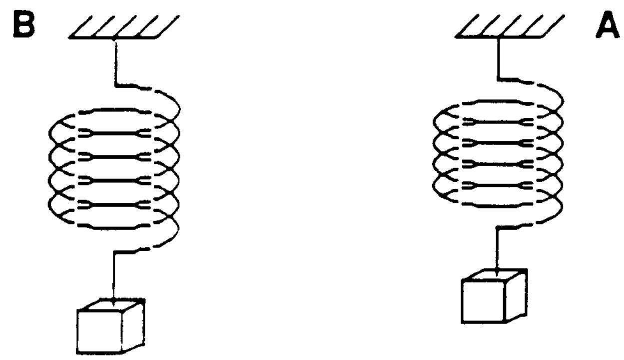
2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **B**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **B**	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **B** is the reason for the change	

3. What, if anything, would you say is the cause of the change from A to B?

Questionnaire 2



1. Now, think of some way to GO BACK from B to A.

How?

2. Which of the following phrases describe your idea?

√ or X in each box

It is something which happens naturally	
There is a law which prevents it happening	
It happens accidentally	
It happens because it ought to go to **A**	
It is possible, but difficult to do in practice	
It cannot be stopped from happening	
It happens because it is forced to go to **A**	
It could never happen, in principle	
It happens spontaneously, all by itself	
It needs an action to make it happen	
It happens by some random process	
It could happen but hardly ever will	
There is a law which makes it happen	
It happens because getting to **A** is the reason for the change	

3. What, if anything, would you say is the cause of the change from B to A?

Appendix F

Statistical Summaries for the Main Study: Factor Analysis by Groups

APPENDIX F.1: Statistical Details for the 13/14 year old English Group

- **Factor Extraction Method**: Principal Component Analysis
- **Transformation Method**: Orthotran/Varimax
- **Number of Factor**: 3
- **Factor Solution**: Oblique Solution
- **Bartlett Test of Sphericity** - DF: 104 Chi-Square: 665.881 p: .0001

- **Eigenvalues and Proportion of Original Variance**

FACTOR	EIGENVALUE	VARIANCE PROP.	CUMULAT. PROP.
1	8.485	0.606	0.606
2	2.512	0.179	0.785
3	1.108	0.079	0.864

The three factors jointly explain 86.4% of the total variance. The remaining factors together account for only 13.6% of the variance.

- **Factor Loadings**

The factor loadings are presented in Table G.1 - *Oblique Solution Reference Structure Orthotran/Varimax*, in Appendix G, together with the description of the interpretation of the factor analysis.

- **Primary Intercorrelation-Orthotran/Varimax**

	FACTOR 1	FACTOR 2	FACTOR 3
FACTOR 1	1.000		
FACTOR 2	-0.726	1.000	
FACTOR 3	- 0.826	.0.706	1.000

- **Proportionate Variance Contribution**

	OBLIQUE TOTAL
FACTOR 1	0.334
FACTOR 2	0.550
FACTOR 3	0.107

• Factor Scores of Events

Event	Factor 1	Factor 2	Factor 3
PendulumAB	-1.811	-2.087	0.817
PendulumBA	-2.673	-2.483	-0.872
Ice-Cream AB	-2.591	1.463	-2.949
Ice-Cream BA	1.132	-0.215	-0.569
Puddle AB	1.958	2.316	0.816
Puddle BA	1.691	2.233	0.182
Car AB	-1.420	2.711	-3.643
Car BA	2.386	-0.346	1.615
Boy/Man AB	3.726	1.035	4.674
Boy/Man BA	2.095	1.453	-1.379
Ball AB	-0.827	-1.514	1.660
Ball BA	0.158	-0.820	1.188
See-Saw AB	-0.384	-0.780	0.578
See-Saw BA	-0.881	-1.068	0.053
Slope AB	-3.610	-1.768	-0.821
Slope BA	-1.645	-2.465	-0.808
Tea AB	-3.078	0.403	-2.558
Tea BA	-1.843	-1.712	-1.187
Champagne AB	-1.421	2.834	-3.258
Champagne BA	2.081	-0.136	0.854
Candle AB	0.017	0.779	0.218
Candle BA	2.041	0.276	0.298
Plant AB	1.531	0.542	2.120
Plant BA	0.163	0.855	-1.747
Swing AB	1.070	-1.015	2.447
Swing BA	1.341	0.045	1.486
Spring AB	0.124	-0.439	0.387
Spring BA	0.670	-0.096	0.396

• 'Factor Scores' for Phrases

Phrases	Factor 1	Factor 2	Factor3
1- It is something which happens naturally	-1.523	4.222	0.218
2- There is a law which prevents it happening	-1.664	-0.022	-0.517
3- It happens accidentally	-0.768	3.063	-2.057
4- It happens because it ought to go to B	0.000	-0.042	3.165
5- It is possible, but difficult to do in practice	2.810	0.457	0.510
6- It cannot be stopped from happening	1.545	2.370	2.083
7- It happens because it is forced to go to B	-0.995	-2.149	2.095
8- It could never happen, in principle	2.421	0.117	0.015
9- It happens spontaneously, all by itself	-0.557	3.710	0.245
10-It needs an action to make it happen	-0.196	-3.945	1.017
11-It happens by some random process	1.739	1.803	0.716
12-It could happen but hardly ever will	1.749	0.315	-0.043
13-There is a law which makes it happen	-1.149	0.167	1.203
14-It happens because getting to B is the reason for the change	0.434	-0.301	2.482

APPENDIX F.2: Statistical Details for the 16/17 year old English Group

- **Factor Extraction Method**: Principal Component Analysis
- **Transformation Method**: Orthotran/Varimax
- **Number of Factor**: 3
- **Factor Solution**: Oblique Solution
- **Bartlett Test of Sphericity** - DF: 104 Chi-Square: 521.366 p: .0001

- **Eigenvalues and Proportion of Original Variance**

FACTOR	EIGENVALUE	VARIANCE PROP.	CUMULAT. PROP.
1	7.393	0.582	0.582
2	2.441	0.174	0.756
3	1.129	0.081	0.0837

The three factors jointly explain 83.7% of the total variance. The remaining factors together account for only 16.3% of the variance.

- **Factor Loadings**

The factor loadings are presented in Table G.2 - *Oblique Solution Reference Structure Orthotran/Varimax*, in Appendix G, together with the description of the interpretation of the factor analysis.

- **Primary Intercorrelation-Orthotran/Varimax**

	FACTOR 1	FACTOR 2	FACTOR 3
FACTOR 1	1.000		
FACTOR 2	-0.437	1.000	
FACTOR 3	0.207	-0.056	1.000

- **Proportionate Variance Contribution**

	OBLIQUE TOTAL
FACTOR 1	0.462
FACTOR 2	0.417
FACTOR 3	0.121

• Factor Scores of Events

Event	Factor 1	Factor 2	Factor 3
PendulumAB	-1.288	-0.747	-0.084
PendulumBA	-0.810	-1.470	0.856
Ice-Cream AB	-1.020	-0.011	0.623
Ice-Cream BA	1.036	-0.286	1.775
Puddle AB	-0.696	1.070	1.427
Puddle BA	0.878	2.010	0.075
Car AB	0.063	1.613	1.707
Car BA	1.414	0.201	0.267
Boy/Man AB	-0.292	1.654	-0.258
Boy/Man BA	3.397	1.272	-0.872
Ball AB	-1.477	-0.698	0.940
Ball BA	-0.857	-0.336	0.742
See-Saw AB	-0.067	-0.606	0.612
See-Saw BA	0.157	-0.171	0.580
Slope AB	-1.537	-0.810	-0.537
Slope BA	0.057	-1.626	-0.307
Tea AB	-0.428	0.997	-0.186
Tea BA	-0.552	-1.794	-1.076
Champagne AB	0.739	1.900	-1.033
Champagne BA	0.735	-0.877	-0.670
Candle AB	-0.348	0.757	0.275
Candle BA	2.292	0.443	-0.653
Plant AB	0.700	1.105	-3.181
Plant BA	0.704	-0.175	0.781
Swing AB	-1.041	-1.097	-1.021
Swing BA	-0.577	-0.178	-0.646
Spring AB	-0.853	-1.099	0.237
Spring BA	-0.331	-1.043	-0.373

• 'Factor Scores' for Phrases

Phrases	Factor 1	Factor 2	Factor3
1- It is something which happens naturally	-2.831	3.700	-0.289
2- There is a law which prevents it happening	-1.664	-0.022	-0.517
3- It happens accidentally	-0.446	1.599	1.339
4- It happens because it ought to go to B	-2.047	1.546	-1.005
5- It is possible, but difficult to do in practice	2.383	0.112	0.925
6- It cannot be stopped from happening	-0.606	1.965	0.250
7- It happens because it is forced to go to B	-1.440	-2.480	0.453
8- It could never happen, in principle	2.133	0.476	0.153
9- It happens spontaneously, all by itself	-1.685	2.645	0.004
10-It needs an action to make it happen	0.597	-3.212	0.450
11-It happens by some random process	0.163	1.507	0.431
12-It could happen but hardly ever will	1.429	-0.120	0.653
13-There is a law which makes it happen	-3.212	-0.116	0.386
14-It happens because getting to B is the reason for the change	-0.137	-0.007	-0.838

APPENDIX F.3: Statistical Details for the 13/14 year old Chilean Group

- **Factor Extraction Method**: Principal Component Analysis
- **Transformation Method**: Orthotran/Varimax
- **Number of Factor**: 3
- **Factor Solution**: Orthogonal Solution
- **Bartlett Test of Sphericity** - DF: 104 Chi-Square: 581.788 p: .0001

- **Eigenvalues and Proportion of Original Variance**

FACTOR	EIGENVALUE	VARIANCE PROP.	CUMULAT. PROP.
1	8.940	0.639	0.639
2	1.637	0.117	0.756
3	1.249	0.089	0.845

The three factors jointly explain 84.6% of the total variance. The remaining factors together account for only 15.5% of the variance.

- **Factor Loadings**

The factor loadings are presented in Table G.3 - *Orthogonal Transformation Solution/Varimax*, in Appendix G, together with the description of the interpretation of the factor analysis.

- **Primary Intercorrelation-Orthotran/Varimax**

	FACTOR 1	FACTOR 2	FACTOR 3
FACTOR 1	1.000		
FACTOR 2	-0.364	1.000	
FACTOR 3	- 0.201	.0.042	1.000

- **Proportionate Variance Contribution**

	ORTHOGONAL-DIRECT
FACTOR 1	0.334
FACTOR 2	0.550
FACTOR 3	0.107

• Factor Scores of Events

Event	Factor 1	Factor 2	Factor 3
PendulumAB	0.330	0.367	-2.471
PendulumBA	-0.610	1.652	-1.464
Ice-Cream AB	0.733	0.367	-0.067
Ice-Cream BA	-1.272	-0.965	-0.863
Puddle AB	1.044	-0.218	0.844
Puddle BA	0.230	-0.496	1.677
Car AB	0.241	1.148	0.865
Car BA	-1.205	-0.774	0.150
Boy/Man AB	1.513	-0.851	0.192
Boy/Man BA	-1.608	-2.056	0.099
Ball AB	0.759	0.952	-0.627
Ball BA	0.342	1.224	-0.272
See-Saw AB	0.190	1.702	1.799
See-Saw BA	-0.121	1.275	0.554
Slope AB	0.814	-0.355	-0.943
Slope BA	-1.367	0.614	-1.176
Tea AB	1.337	-1.135	-1.144
Tea BA	-1.076	0.376	-1.192
Champagne AB	1.222	-1.383	-0.069
Champagne BA	-1.663	0.279	-0.072
Candle AB	1.384	-0.792	-0.560
Candle BA	-1.618	-1.429	0.876
Plant AB	0.784	-0.918	0.582
Plant BA	-0.975	0.148	1.367
Swing AB	0.461	0.458	0.373
Swing BA	0.203	-0.566	0.255
Spring AB	-0.045	0.845	0.244
Spring BA	-0.026	0.531	1.043

• 'Factor Scores' for Phrases

Phrases	Factor 1	Factor 2	Factor3
1- It is something which happens naturally	3.016	-0.219	0.426
2- There is a law which prevents it happening	-0.832	-0.011	-0.259
3- It happens accidentally	0.180	0.683	0.673
4- It happens because it ought to go to B	2.228	0.330	-0.140
5- It is possible, but difficult to do in practice	-1.242	-0.097	0.358
6- It cannot be stopped from happening	2.142	-0.097	0.578
7- It happens because it is forced to go to B	-0.295	1.115	0.060
8- It could never happen, in principle	-1.215	-0.551	-0.151
9- It happens spontaneously, all by itself	2.657	-0.367	0.160
10-It needs an action to make it happen	-2.037	0.943	0.285
11-It happens by some random process	0.004	0.003	0.891
12-It could happen but hardly ever will	-1.377	-0.322	0.028
13-There is a law which makes it happen	1.501	0.588	0.312
14-It happens because getting to B is the reason for the change	0.680	0.466	-0.415

APPENDIX F.4: Statistical Details for the 16/17 year old Chilean Group

- **Factor Extraction Method**: Principal Component Analysis
- **Transformation Method**: Orthotran/Varimax
- **Number of Factor**: 3
- **Factor Solution:** Oblique Solution
- **Bartlett Test of Sphericity** - DF: 104 Chi-Square: 640.933 p: .0001

- **Eigenvalues and Proportion of Original Variance**

FACTOR	EIGENVALUE	VARIANCE PROP.	CUMULAT. PROP.
1	9.272	0.662	0.662
2	1.524	0.109	0.771
3	0.935	0.067	0.838

The three factors jointly explain 83.8% of the total variance. The remaining factors together account for only 16.2% of the variance. The third factor has eigenvalue marginally less than unity, but including it gave a simpler interpretation of the factors.

- **Factor Loadings**

The factor loadings are presented in Table G.4 - *Oblique Solution Reference Structure Orthotran/Varimax*, in Appendix G, together with the description of the interpretation of the factor analysis.

- **Primary Intercorrelation-Orthotran/Varimax**

	FACTOR 1	FACTOR 2	FACTOR 3
FACTOR 1	1.000		
FACTOR 2	0.044	1.000	
FACTOR 3	-0.721	-0.079	1.000

- **Proportionate Variance Contribution**

	OBLIQUE TOTAL
FACTOR 1	0.648
FACTOR 2	0.158
FACTOR 3	0.195

• Factor Scores of Events

Event	Factor 1	Factor 2	Factor 3
PendulumAB	3.057	-0.070	-3.053
PendulumBA	-0.044	2.042	-0.391
Ice-Cream AB	1.553	0.006	-0.819
Ice-Cream BA	-0.827	-0.337	-0.534
Puddle AB	-0.687	-0.126	1.994
Puddle BA	-3.059	-0.901	3.453
Car AB	-1.548	-0.304	2.148
Car BA	-1.162	0.524	-0.271
Boy/Man AB	1.942	-0.537	-0.910
Boy/Man BA	-0.229	-2.672	-1.803
Ball AB	0.004	-0.242	0.706
Ball BA	-0.192	0.041	0.533
See-Saw AB	-0.889	0.598	1.042
See-Saw BA	-1.528	1.065	1.382
Slope AB	2.800	0.308	-2.470
Slope BA	-1.341	1.367	0.012
Tea AB	2.550	-0.149	-1.245
Tea BA	0.495	0.645	-1.826
Champagne AB	1.169	-0.541	0.037
Champagne BA	-1.478	-0.118	-0.002
Candle AB	0.351	-0.792	1.065
Candle BA	0.149	-2.203	-1.990
Plant AB	0.915	-1.020	0.271
Plant BA	-1.575	0.950	0.478
Swing AB	0.531	-0.138	0.475
Swing BA	0.199	0.102	0.110
Spring AB	-0.779	1.132	1.488
Spring BA	-0.376	1.369	0.122

• 'Factor Scores' for Phrases

Phrases	Factor 1	Factor 2	Factor3
1- It is something which happens naturally	2.462	-1.280	0.748
2- There is a law which prevents it happening	-1.664	-0.022	-0.517
3- It happens accidentally	-0.237	0.017	1.288
4- It happens because it ought to go to B	2.019	-0.994	0.770
5- It is possible, but difficult to do in practice	-1.274	0.375	0.000
6- It cannot be stopped from happening	0.542	-0.641	0.420
7- It happens because it is forced to go to B	0.686	0.996	0.265
8- It could never happen, in principle	-0.990	-0.365	-0.210
9- It happens spontaneously, all by itself	1.468	-1.107	0.278
10-It needs an action to make it happen	-0.016	0.986	-0.214
11-It happens by some random process	1.017	-0.607	0.272
12-It could happen but hardly ever will	-1.199	0.530	0.101
13-There is a law which makes it happen	1.298	0.979	0.333
14-It happens because getting to B is the reason for the change	2.187	0.544	-0.469

APPENDIX F.5: Statistical Details for the 16/17 year old Brazilian Group

- **Factor Extraction Method**: Principal Component Analysis
- **Transformation Method**: Orthotran/Varimax
- **Number of Factor**: 3
- **Factor Solution**: Oblique Solution
- **Bartlett Test of Sphericity** - DF: 104 Chi-Square: 699.718 p: .0001

- **Eigenvalues and Proportion of Original Variance**

FACTOR	EIGENVALUE	VARIANCE PROP.	CUMULAT. PROP.
1	8.717	0.623	0.623
2	2.532	0.181	0.804
3	1.354	0.097	0.901

The three factors jointly explain 90.1% of the total variance. The remaining factors together account for only 9.9% of the variance.

- **Factor Loadings**

The factor loadings are presented in Table G.5 - *Oblique Solution Reference Structure Orthotran/Varimax*, in Appendix G, together with the description of the interpretation of the factor analysis.

- **Primary Intercorrelation-Orthotran/Varimax**

	FACTOR 1	FACTOR 2	FACTOR 3
FACTOR 1	1.000		
FACTOR 2	0.850	1.000	
FACTOR 3	0.255	0.331	1.000

- **Proportionate Variance Contribution**

	OBLIQUE TOTAL
FACTOR 1	0.490
FACTOR 2	0.416
FACTOR 3	0.094

• Factor Scores of Events

Event	Factor 1	Factor 2	Factor 3
PendulumAB	3.726	-2.947	-0.991
PendulumBA	4.284	-4.493	-0.399
Ice-Cream AB	2.810	-2.148	1.177
Ice-Cream BA	0.970	-1.996	-1.421
Puddle AB	1.185	0.650	-1.315
Puddle BA	-1.418	1.637	-0.670
Car AB	0.883	-1.278	1.732
Car BA	-0.697	0.112	-1.268
Boy/Man AB	-1.950	4.727	-2.291
Boy/Man BA	-3.653	2.183	-0.676
Ball AB	0.867	-1.101	1.324
Ball BA	-1.412	1.011	0.843
See-Saw AB	-0.073	0.100	0.778
See-Saw BA	-0.705	0.273	0.701
Slope AB	2.124	-1.199	-0.081
Slope BA	0.478	-1.724	-0.167
Tea AB	-1.066	2.313	0.266
Tea BA	1.062	-1.708	-0.945
Champagne AB	-0.579	1.127	1.565
Champagne BA	-1.452	0.373	-0.684
Candle AB	0.400	1.108	-0.545
Candle BA	-3.471	2.086	-0.431
Plant AB	-0.668	2.371	-1.065
Plant BA	-2.087	0.592	1.028
Swing AB	1.915	-2.192	0.742
Swing BA	-0.531	0.209	1.059
Spring AB	0.028	-0.419	0.700
Spring BA	-0.970	0.333	1.033

• 'Factor Scores' for Phrases

Phrases	Factor 1	Factor 2	Factor3
1- It is something which happens naturally	0.825	3.532	0.716
2- There is a law which prevents it happening	-1.664	-0.022	-0.517
3- It happens accidentally	0.036	-0.272	1.483
4- It happens because it ought to go to B	0.584	2.813	0.071
5- It is possible, but difficult to do in practice	-1.931	-0.015	-0.027
6- It cannot be stopped from happening	-0.594	2.464	-0.687
7- It happens because it is forced to go to B	3.059	-1.738	0.275
8- It could never happen, in principle	-2.012	-0.353	-0.189
9- It happens spontaneously, all by itself	-0.391	3.545	-0.071
10-It needs an action to make it happen	2.189	-2.897	-0.026
11-It happens by some random process	-0.554	1.386	0.658
12-It could happen but hardly ever will	-1.496	-0.344	0.255
13-There is a law which makes it happen	3.148	-1.842	0.139
14-It happens because getting to B is the reason for the change	2.180	-0.621	0.006

Appendix G

Interpretation of Factor Analysis by Groups of the Main Study

APPENDIX G - Interpretation of Factor Analysis by Groups of the Main Study

This Appendix presents the interpretation of the dimensions produced by factor analysis performed independently for each group of the main study. The procedure is the same as described in Chapter 5 for the pilot study. The statistical summaries of the factor analysis for each group are presented in Appendix F.

The factor space associated with oblique solutions is non-orthogonal, since the correlation between two variables can be expressed by the cosine between them. However, the plots of the non-orthogonal projections do not represent the real angle between dimension, rather they are a reminder of the non-orthogonality

G.1 The 13/14 year old English Group

The factor loadings for each statement on the three factors are shown in Table G.1. Each factor is interpreted, using these loading.

G.1.1 Dimension I: Does Not Happen vs. Happens

The basic account of this dimension is given by the positive loadings of

Phrase 2 - There is a law which prevents it happening
Phrase 5 - It is possible, but difficult to do in practice
Phrase 8 - It could never happen, in principle
Phrase 11- It happens by some random process
Phrase 12- It could happen but hardly ever will

and the negative loading of

Phrase 13 - There is a law which makes it happen

The positive loadings are high with nearly all having variable complexity approximately 1. They all declare that events do not happen. Although not very high, the negative loading of Phrase 13 endorses this interpretation.

Therefore, this dimension might reasonable be named DOES NOT HAPPEN vs. HAPPENS. Events such as Boy/Man BA, Candle BA, Plant BA are located on the 'not happen' side, whilst events such as Pendulum AB, Slope AB, Tea BA are located on the 'happens' side.

Table G.1 - *Oblique Solution Reference Structure-Orthotran/Varimax 13/14 year old English Group*

Phrases	Factor I	Loadings II	III	Variable Complexity
1- It is something which happens naturally	-0.141	**0.488**	0.020	1.264
2- There is a law which prevents it happening	**0.443**	-0.180	0.070	1.258
3- It happens accidentally	-0.147	**0.746**	**-0.407**	1.888
4- It happens because it ought to go to B	-0.001	-0.006	**0.486**	1.000
5- It is possible, but difficult to do in practice	**0.644**	0.132	0.122	1.123
6- It cannot be stopped from happening	0.262	**0.507**	0.363	2.713
7- It happens because it is forced to go to B	-0.240	**-0.654**	**0.522**	2.401
8- It could never happen, in principle	**0.506**	0.032	0.006	1.005
9- It happens spontaneously, all by itself	-0.067	**0.557**	0.029	1.054
10-It needs an action to make it happen	-0.025	**-0.703**	0.150	1.140
11-It happens by some random process	**0.575**	**0.746**	**0.245**	2.311
12-It could happen but hardly ever will	**0.559**	0.128	-0.010	1.067
13-There is a law which makes it happen	**-0.243**	0.046	**0.262**	2.038
14-It happens because getting to B is the reason for the change	0.111	-0.096	**0.651**	1.091

G.1.2 Dimension II: Happens by Itself vs. Needs an Action

This dimension is basically defined by the positive loadings of

Phrase 1 - It is something which happens naturally
Phrase 3 - It happens accidentally
Phrase 6 - It cannot be stopped from happening
Phrase 9 - It happens spontaneously, all by itself
Phrase 11- It happens by some random process

and the negative loadings of

Phrase 7 - It happens because it is forced to go to B
Phrase 10 - It needs an action to make it happen

They all express the idea of the possibility of events happening, either naturally or spontaneously - positive loadings, or due to an action - but then with negative loadings.

Moreover, something which happen naturally or spontaneously may be considered as unavoidable in the sense that it cannot be stopped from happening - phrase 6.

Thus, an appropriate name for this dimension could be HAPPENS NATURALLY vs. FORCED TO HAPPEN. Events such as Boy/Man AB, Champagne AB, Plant AB are located on the 'natural' side, while Pendulum BA, Slope BA, Tea BA are located on the 'forced' side.

G.1.3 Dimension III: Goal/Planned vs. No Goal/Accidental

This dimension is described by the positive loadings of

Phrase 4 - It happens because it ought to go to B
Phrase 7 - It happens because it is forced to go to B
Phrase 13 - There is a law which makes it happen
Phrase 14 - It happens because getting to B is the reason for the change

and the negative loading of

Phrase 3 - It happens accidentally

All phrases with positive loadings express the idea that something has to happen as if driven by a natural or inner goal or due to some previous plan. This is ratified by the negative loading of Phrase 3 which expresses the idea that something happens with no plan or accidentally.

Therefore, this dimension could be named HAPPENS DUE TO A GOAL OR PLAN vs. HAPPENS DUE TO NO GOAL OR ACCIDENTALLY. Events such as Pendulum AB, Boy/Man AB, Slope AB are located on the 'goal' side, while Car AB, See-Saw AB, Puddle BA are located on the 'accidental' side.

G.1.4 The Factor Space

The non-orthogonal three dimensional factor space is shown projected on two dimensions in turn: Dimension I (horizontal axis) non-orthogonal to Dimension II (vertical axis) in Figure G.1, Dimension I (horizontal axis) non-orthogonal to Dimension III (vertical axis) in Figure G.2, and Dimension II (horizontal axis) non-orthogonal to Dimension III (vertical axis) in Figure G.3. In these plots, the events happening backwards - BA events - are represented by their names underlined.

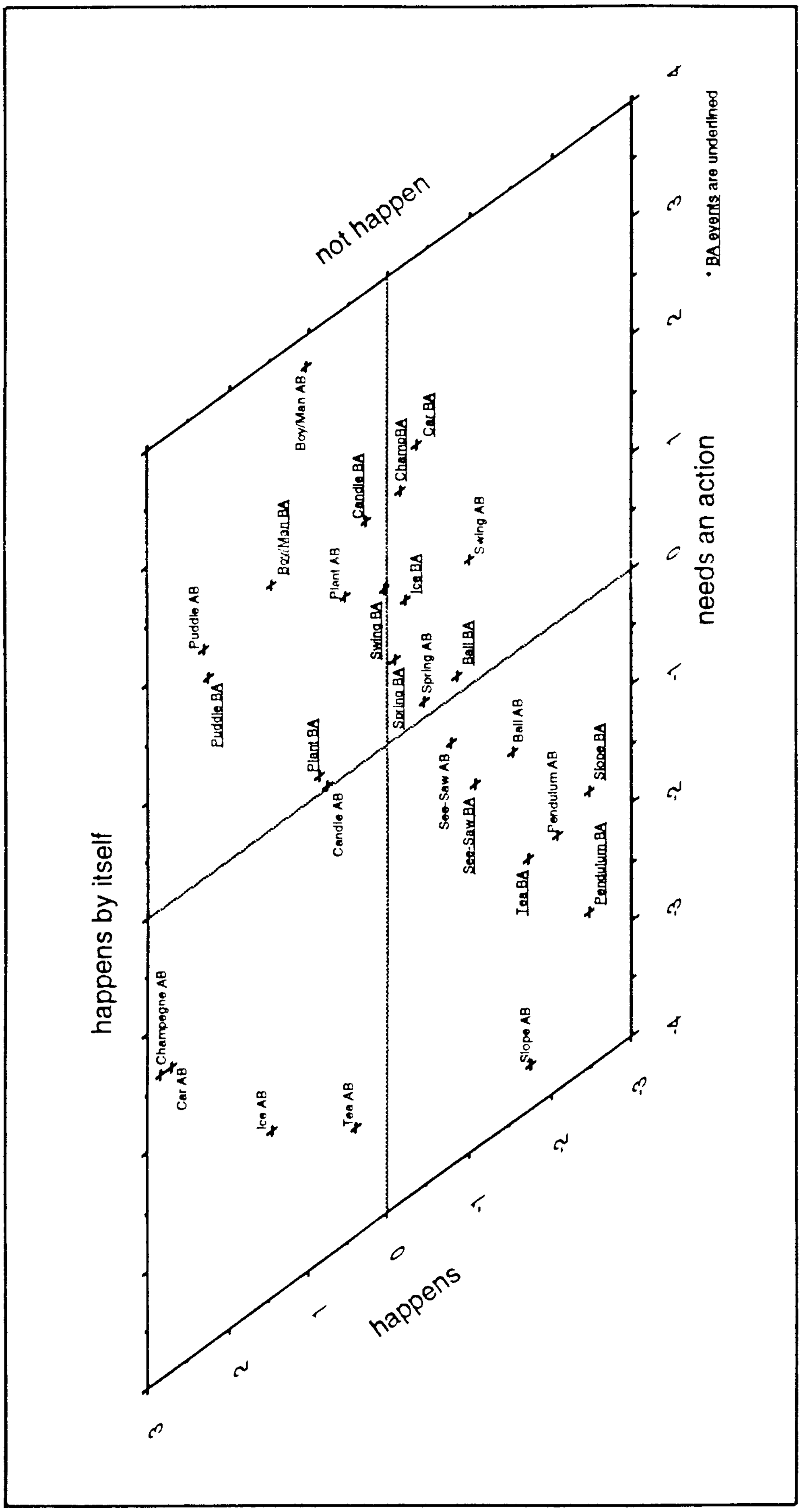


Figure G.1 - *Factor Space of 13/14 year old English Group: Dimension I vs. Dimension II*

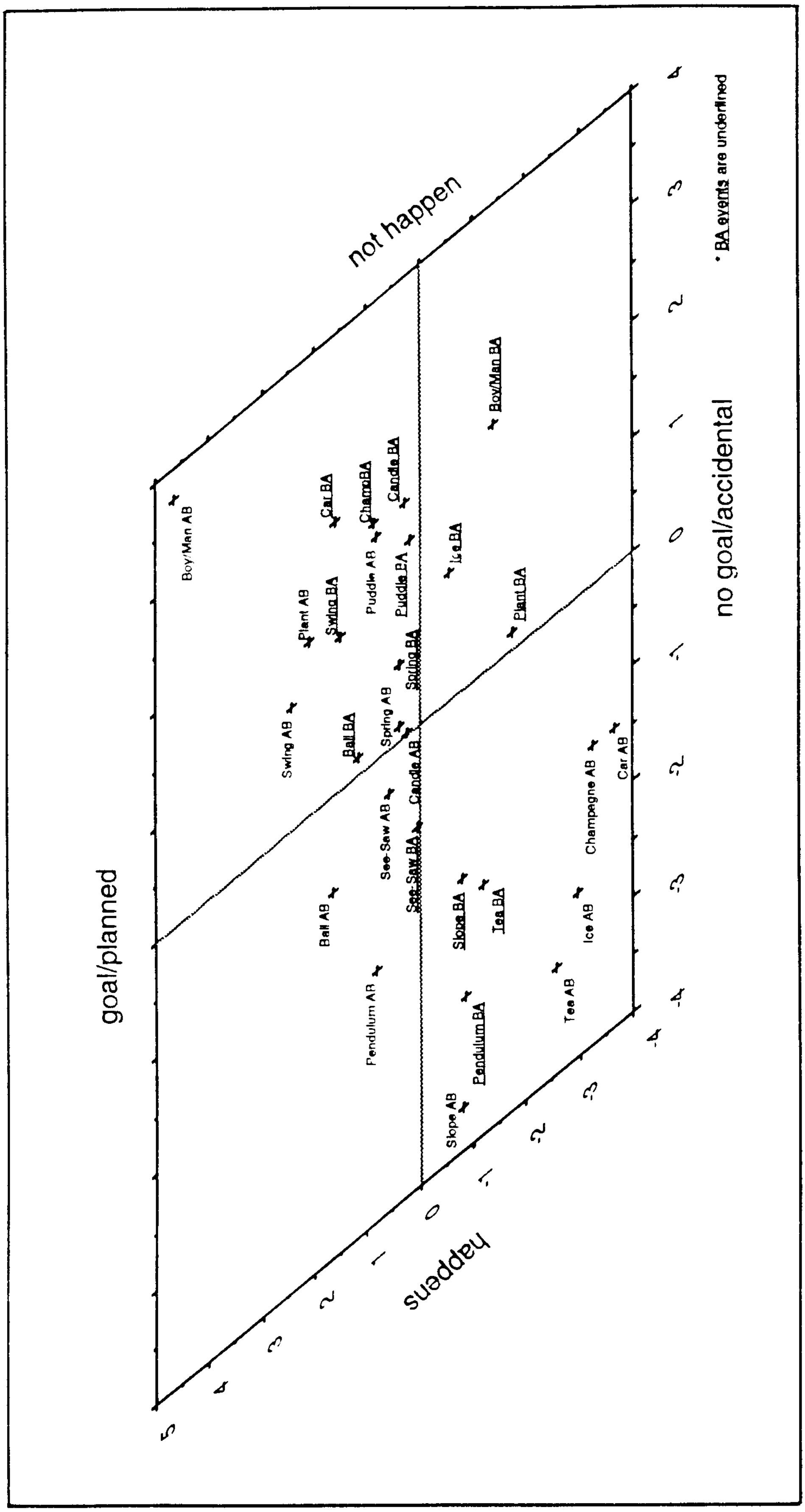


Figure G.2 - *Factor Space of 13/14 year old English Group: Dimension I vs Dimension III*

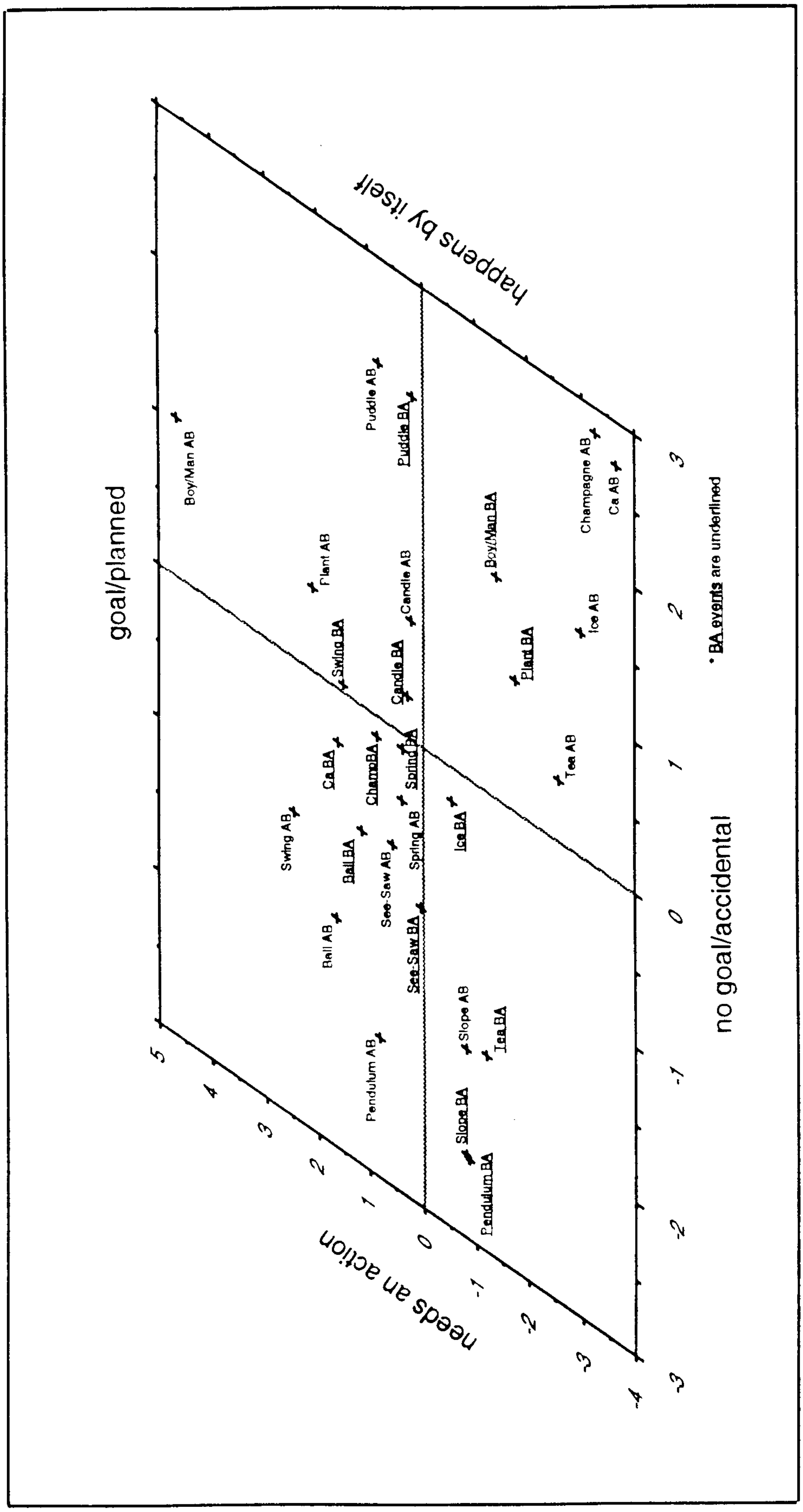


Figure G.3 - *Factor Space of 13/14 year old English Group: Dimension II vs Dimension III*

G.1.5. Interpretation of the Correlation between Factors

The negative correlation between dimension I - DOES NOT HAPPEN vs. HAPPENS - and dimension II - HAPPENS BY ITSELF vs. NEEDS AN ACTION - can be interpreted as the idea that events seen as not happening may happen when an action is taken or that the event which happens by itself, happens anyway.

The negative correlation between dimension I - DOES NOT HAPPEN vs. HAPPENS - and dimension III - GOAL vs. NO GOAL - may be related to the idea that events having a goal cannot usually be seen as not happening, because they are directed or planned to happen.

Finally, the positive correlation between dimension II - HAPPENS BY ITSELF vs. NEEDS AN ACTION - and dimension III - GOAL vs. NO GOAL - may be interpreted as events having a natural or inner goal, do not need any action to make them happen. Perhaps the goal 'replaces' the action.

G.2 The 16/17 year old English Group

Table G.2 shows the factor loadings for each phrase on the three factors, and an interpretation of them is described below.

G.2.1 Dimension I: Does Not Happen vs. Happens

This dimension is accounted by the positive loadings of

Phrase 2 - There is a law which prevents it happening
Phrase 5 - It is possible, but difficult to do in practice
Phrase 8 - It could never happen, in principle
Phrase 12 - It could happen but hardly ever will

and the negative loadings of

Phrase 4 - It happens because it ought to go to B
Phrase 7 - It happens because it was forced to go to B
Phrase 13 - There is a law which makes it happen

They all have meaningful loadings and most of them have variable complexity approximately 1. It seems clear that this dimension is related to the idea of possibility or impossibility of an event to happen. All phrases with positive loadings declare that events do not happen, and are confirmed by the phrases with negative loadings.

Thus, this dimension may again be named DOES NOT HAPPEN vs. HAPPENS. Events such as Boy/Man BA, Candle BA, Car BA are located on the 'not happen' side, whilst events such as Slope AB, Falling Ball AB, Pendulum AB are on the 'happens' side.

Table G.2 - *Oblique Solution Reference Structure-Orthotran/Varimax 16/17 year old English Group*

Phrases	Factor Loadings I	II	III	Variable Complexity
1- It is something which happens naturally	-0.441	**0.564**	-0.036	1.913
2- There is a law which prevents it happening	**0.744**	-0.001	-0.108	1.034
3- It happens accidentally	-0.184	**0.597**	**0.497**	2.096
4- It happens because it ought to go to B	**-0.485**	0.356	-0.272	2.356
5- It is possible, but difficult to do in practice	**0.703**	0.012	0.232	1.176
6- It cannot be stopped from happening	-0.200	**0.608**	0.025	1.225
7- It happens because it is forced to go to B	**-0.508**	**-0.870**	0.176	1.713
8- It could never happen, in principle	**0.861**	0.158	-0.051	1.071
9- It happens spontaneously, all by itself	-0.399	**0.597**	-0.021	1.767
10-It needs an action to make it happen	0.139	**-0.732**	0.126	1.127
11-It happens by some random process	0.079	**0.772**	0.146	1.083
12-It could happen but hardly ever will	**0.653**	-0.101	0.218	1.230
13-There is a law which makes it happen	**-0.788**	-0.043	0.098	1.031
14-It happens because getting to B is the reason for the change	-0.124	-0.040	**-0.844**	1.058

G.2.2 Dimension II: Happens by Itself vs. Needs an Action

This dimension is basically defined by the positive loadings of

Phrase 1 - It is something which happens naturally
Phrase 3 - It happens accidentally
Phrase 6 - It cannot be stopped from happening
Phrase 9 - It happens spontaneously, all by itself
Phrase 11 - It happens by some random process

and the negative loadings of

Phrase 7 - It happens because it is forced to go to A
Phrase 10 - It needs an action to make it happen

Although some of them have variable complexity bigger than 1, all have their most important loading on this factor. It seems clear that the underlying meaning of these phrases is that events having high score on them, happen naturally, accidentally, spontaneously, or randomly, with no external action being taken. The loading on phrase 6 is in accordance with this interpretation, given that an event which happens this way may be difficult to stop, even if only because it is unpredictable.

It seems that there is no clear differentiation among events happening naturally, accidentally, spontaneously, or randomly. However, if phrases with negative loadings are first considered, perhaps a general description for this dimension could be HAPPENS BY ITSELF vs. NEEDS AN ACTION/FORCED. Events such as Puddle BA, Champagne AB, Boy/Man AB are considered as happening by themselves, while Tea BA, Slope BA, Pendulum BA are considered as needing an action to happen.

G.2.3 Dimension III: No Goal/Accidental vs. Goal/Planned

This dimension is described by the positive loading of

Phrase 3 - It happens accidentally

and the negative loading of

Phrase 14 - It happens because getting to B is the reason for the change.

One extreme of this dimension can be named 'happens due to a goal or a previous plan' given that Phrase 14 has a expressive loading just on this dimension and variable complexity approximately 1. On the other hand, what does not have any goal or plan can be understood as 'happening accidentally', what is ratified by Phrase 3.

This dimension may be named HAPPENS DUE TO NO GOAL OR ACCIDENTALLY vs. HAPPENS DUE TO A GOAL OR PLAN. Event such as Ice-Cream BA, Car AB, Puddle AB are considered as happening accidentally, while Plant AB, Tea BA, Champagne AB are considered as happening due to a goal.

G.2.4 The Factor Space

The non-orthogonal three dimensional factor space is shown plotted in two dimensions in turn: Dimension I (horizontal axis) non-orthogonal to Dimension II (vertical axis) in Figure G.4, Dimension I (horizontal axis) orthogonal to Dimension III (vertical axis) in Figure G.5, and Dimension II (horizontal axis) orthogonal to Dimension III (vertical axis) in Figure G.6. In these plots, the events happening backwards - BA events - are represented by their names underlined.

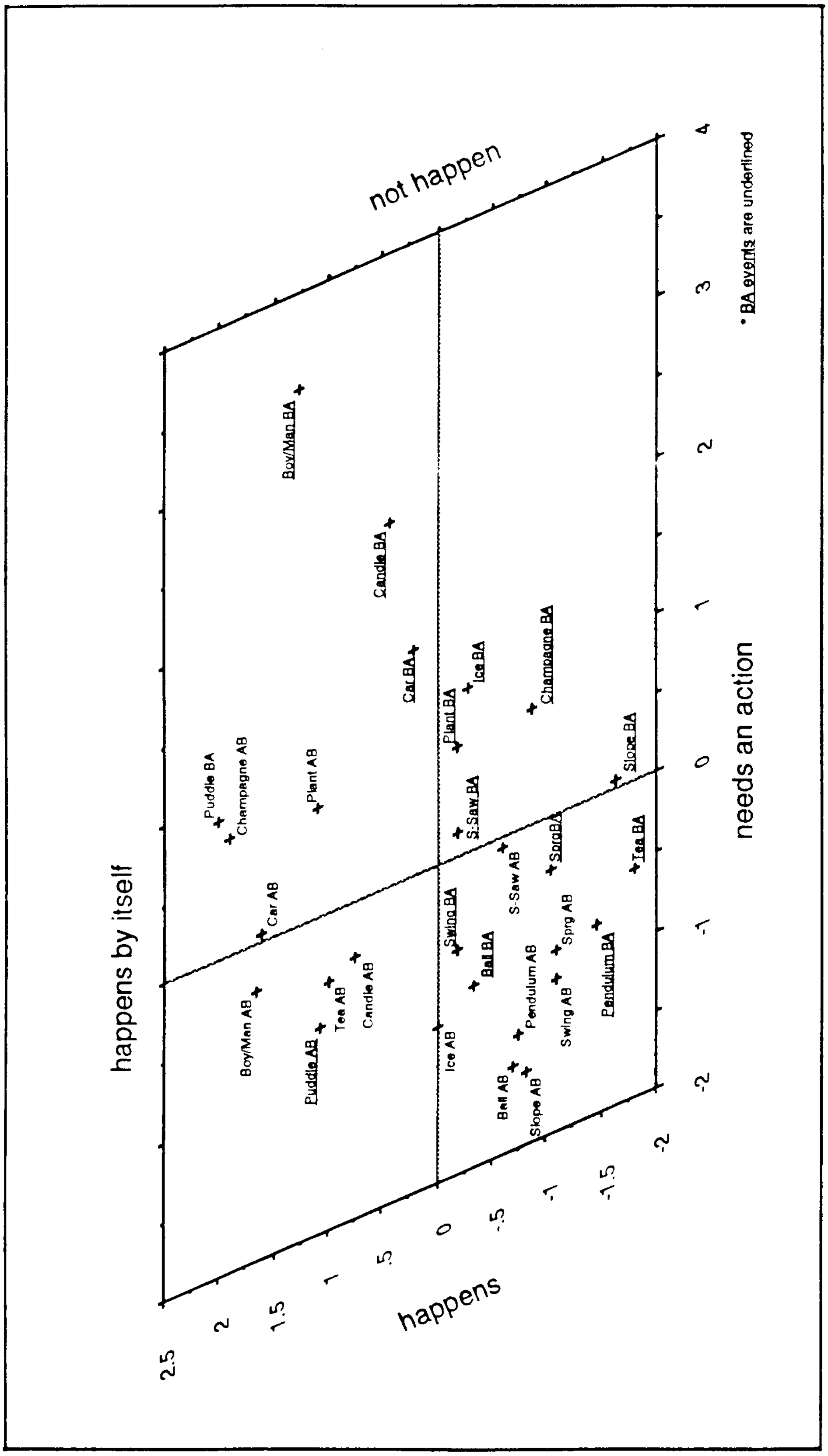


Figure G.4 - *Factor Space of 16/17 year old English Group: Dimension I vs Dimension II*

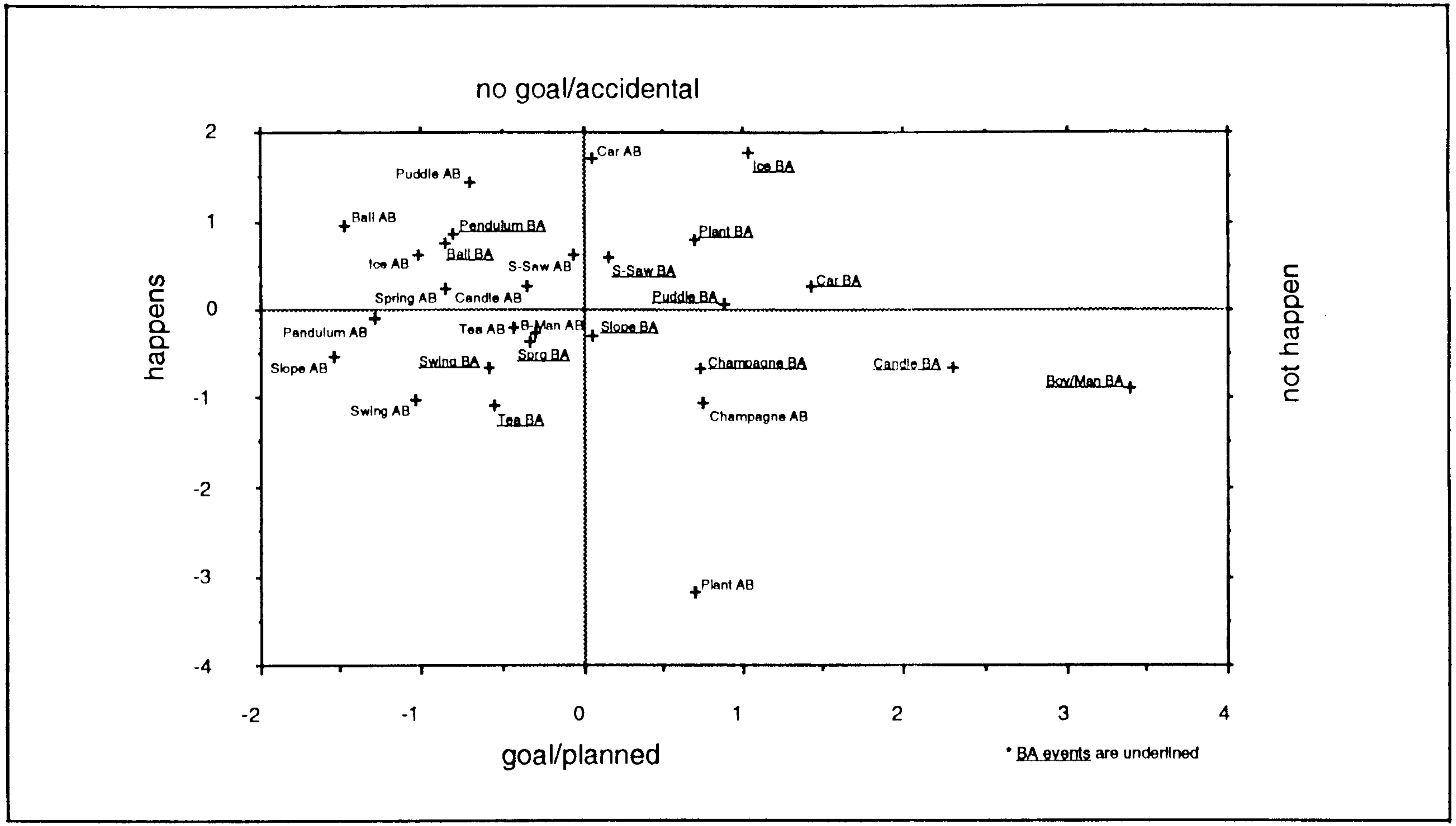


Figure G.5 - *Factor Space of 16/17 year old English Group: Dimension I vs Dimension III*

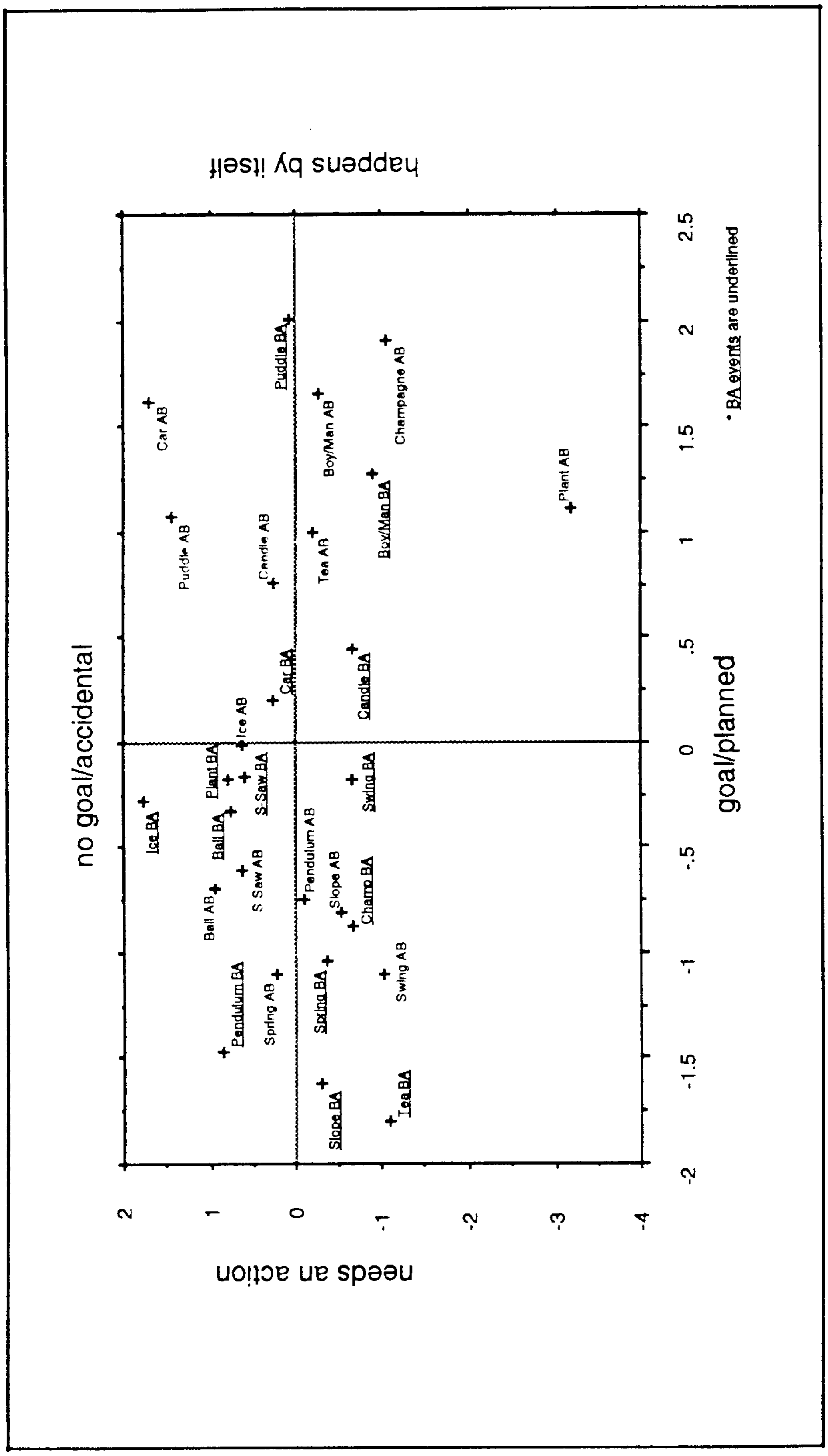


Figure G.6 - *Factor Space of 16/17 year old English Group: Dimension II vs Dimension III*

G.2.5. Interpretation of the Correlation between Factors

In this case, the negative correlation between dimension I - DOES NOT HAPPEN vs. HAPPENS - and dimension II - HAPPENS BY ITSELF vs. NEEDS AN ACTION - has a similar interpretation as for the English 13/14 group: events seen as not happening may happen when an action is taken or that the event which happens by itself, happens anyway.

G.3 The 13/14 year old Chilean Group

The interpretation of the three factors is based upon the factor loadings of each phrase shown in Table G.3.

G.3.1 Dimension I: Happens by Itself vs. Does Not Happen

The basic account of this dimension is given by the positive loadings of

Phrase 1 - It is something which happens naturally
Phrase 3 - It happens accidentally
Phrase 4 - It happens because it ought to go to B
Phrase 6 - It cannot be stopped from happening
Phrase 9 - It happens spontaneously, all by itself
Phrase 13 - There is a law which makes it happen
Phrase 14 - It happens because getting to A is the reason for the change

and the negative loadings of

Phrase 2 - There is a law which prevents it happening
Phrase 5 - It is possible, but difficult to do in practice
Phrase 8 - It could never happen, in principle
Phrase 10 - It needs an action to make it happen
Phrase 12 - It could happen but hardly ever will

It seems clear that as in the previous groups, this dimension represents the opposition between something which happens or does not happens. Furthermore, associated with the 'happens' side, there appears to exist another component related to 'naturalness', due to Phrases 1, 3, 9.

Thus, this dimension could be labelled as HAPPENS BY ITSELF OR NATURALLY vs. DOES NOT HAPPEN. Events such as Boy/Man AB, Candle AB, Tea AB are located on the 'happens by itself' side, whilst events such as Champagne BA, Candle BA, Boy/Man BA are located on the 'not happen' side.

Table G.3 - *Orthogonal Transformation Solution-Varimax 13/14 year old Chilean Group*

Phrases	Factor I	Loadings II	III	Variable Complexity
1- It is something which happens naturally	**0.946**	-0.156	0.151	1.107
2- There is a law which prevents it happening	**-0.918**	-0.193	-0.131	1.131
3- It happens accidentally	**0.546**	**0.586**	0.208	2.248
4- It happens because it ought to go to B	**0.910**	-0.076	-0.106	1.041
5- It is possible, but difficult to do in practice	**-0.821**	0.202	0.246	1.308
6- It cannot be stopped from happening	**0.900**	-0.078	0.223	1.138
7- It happens because it is forced to go to B	0.244	**0.781**	**-0.407**	1.730
8- It could never happen, in principle	**-0.944**	-0.163	0.076	1.073
9- It happens spontaneously, all by itself	**0.940**	-0.247	0.119	1.172
10-It needs an action to make it happen	**-0.720**	**0.569**	-0.096	1.940
11-It happens by some random process	0.243	0.365	**0.753**	1.683
12-It could happen but hardly ever will	**-0.933**	0.005	0.106	1.026
13-There is a law which makes it happen	**0.893**	0.149	0.001	1.055
14-It happens because getting to B is the reason for the change	**0.716**	0.049	**-0.522**	1.839

G.3.2 Dimension II: Forced + Accidental vs. Not Forced + Non Accidental

This dimension is basically defined by the positive loadings of

Phrase 3 - It happens accidentally
Phrase 7 - It happens because it is forced to go to A
Phrase 10 - It needs an action to make it happen

The interpretation seems to be related to the idea of something happening due to an action but accidentally. Thus events such as See-Saw AB, Pendulum BA, See-Saw BA happen, but they do so due to an action and by accident. On the other hand, the other extremity appears to be related either to the idea that something does not happen such as Boy/Man BA and Candle BA or happens with no intervention such as Champagne AB and Tea AB.

G.3.3 Dimension III: No Goal/Randomly vs. Goal/Planned

This dimension is described by the positive loadings of

Phrase 11 - It happens by some random process

and the negative loadings of

Phrase 7 - It happens because it is forced to go to A
Phrase 14 - It happens because getting to A is the reason for the change

It seems clear that one extreme of this dimension can be associated with events which 'happen randomly, with no goal', in opposition to events which are thought of happening due to some plan or goal. Therefore, this dimension could be named HAPPENS RANDOMLY, WITH NO GOAL vs. HAPPEN DUE TO A GOAL OR PLAN. Events such as Car AB, See-Saw AB, Puddle BA are located on the 'random' side whilst Pendulum AB, Pendulum BA, Tea BA are located on the 'goal' side.

G.3.4 The Factor Space

The orthogonal three dimension factor space is shown plotted in two dimensions in turn: Dimension I (horizontal axis) vs. Dimension II (vertical axis) in Figure G.7, Dimension I (horizontal axis) vs. Dimension III (vertical axis) in Figure G.8, and Dimension II (horizontal axis) vs. Dimension III (vertical axis) in Figure G.9. In these plots, the events happening backwards - BA events - are represented by their names underlined.

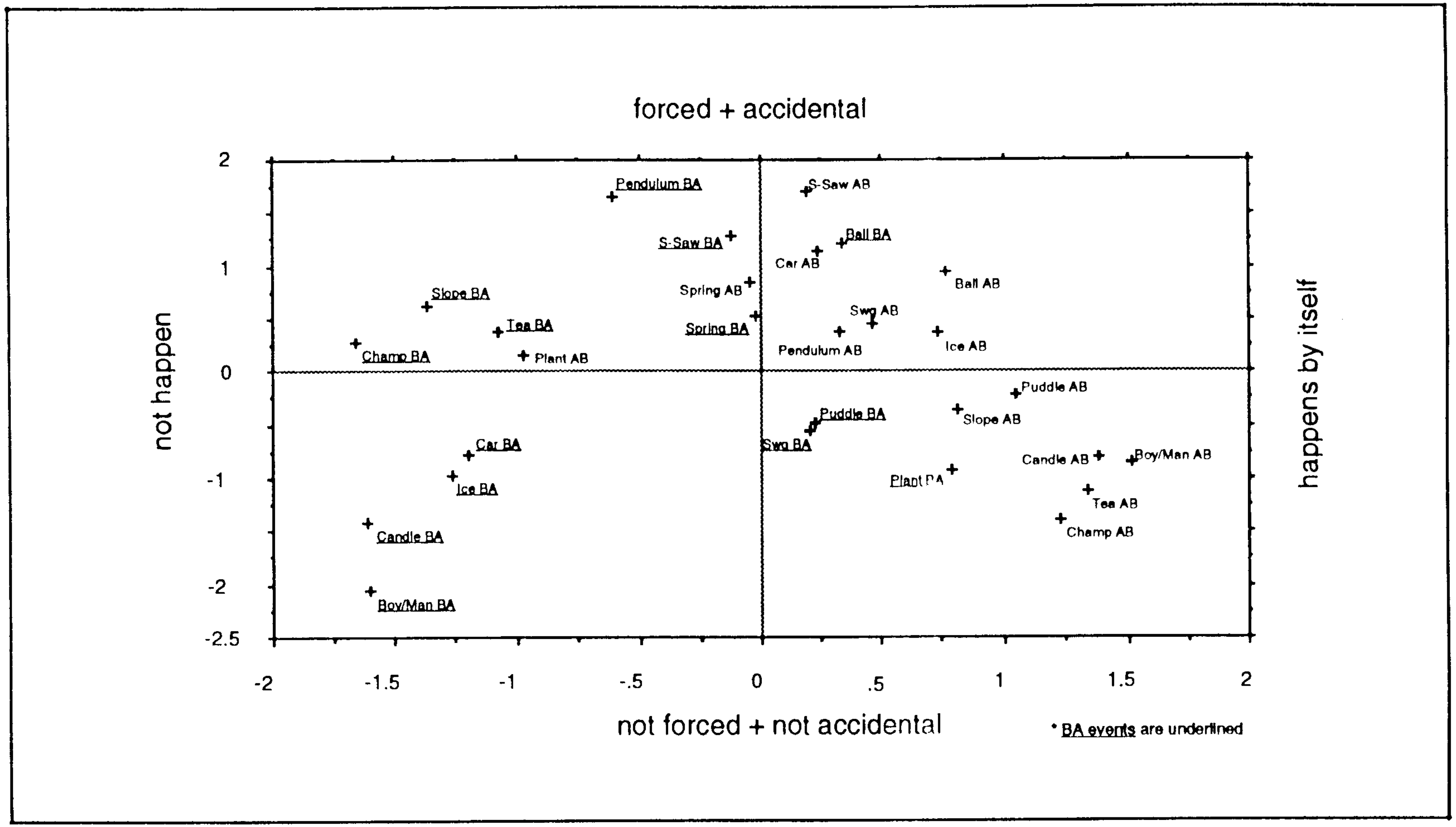


Figure G.7 - *Factor Space of 13/14 year old Chilean Group: Dimension I vs Dimension II*

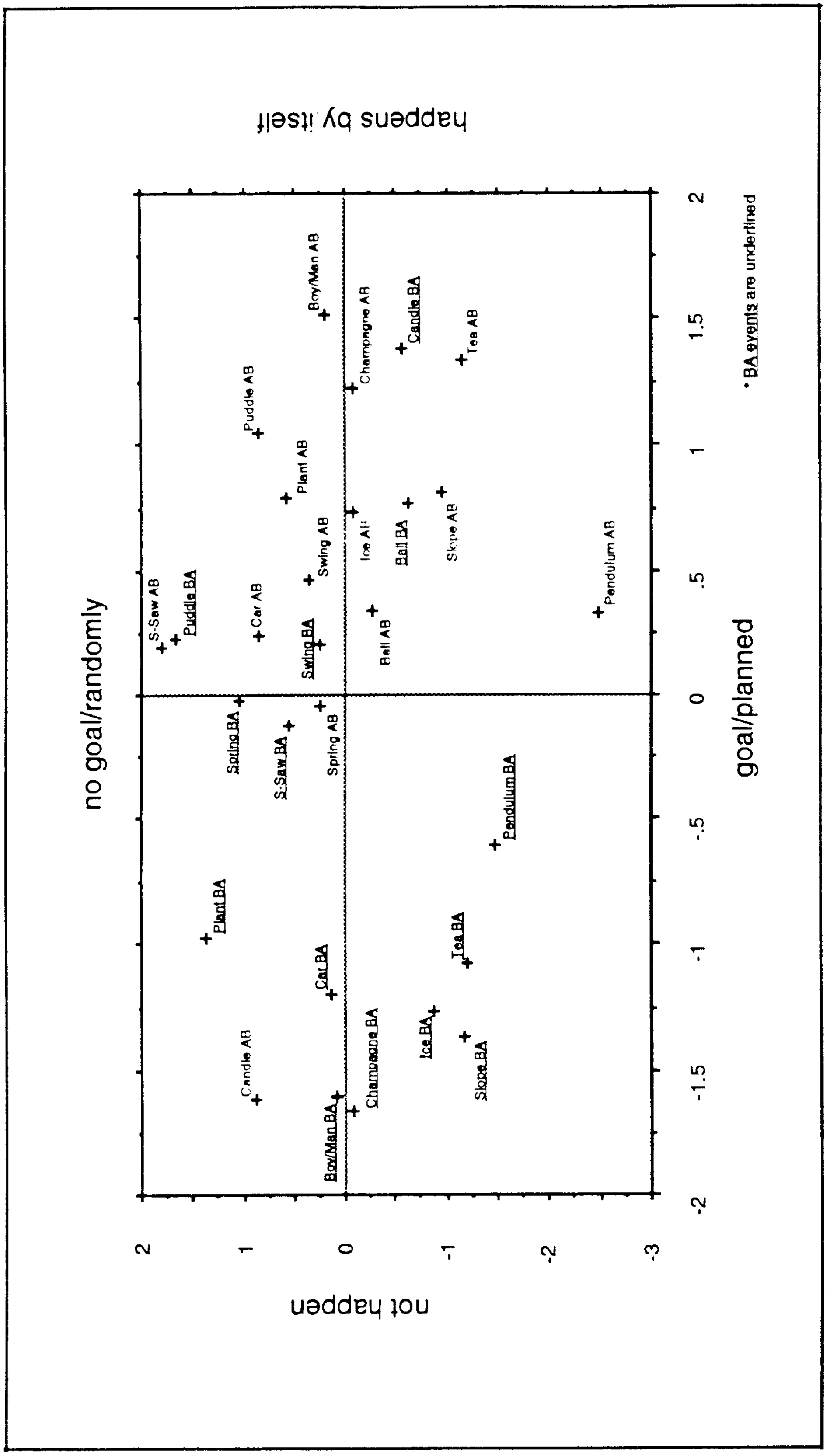


Figure G.8 - *Factor Space of 13/14 year old Chilean Group: Dimension I vs Dimension III*

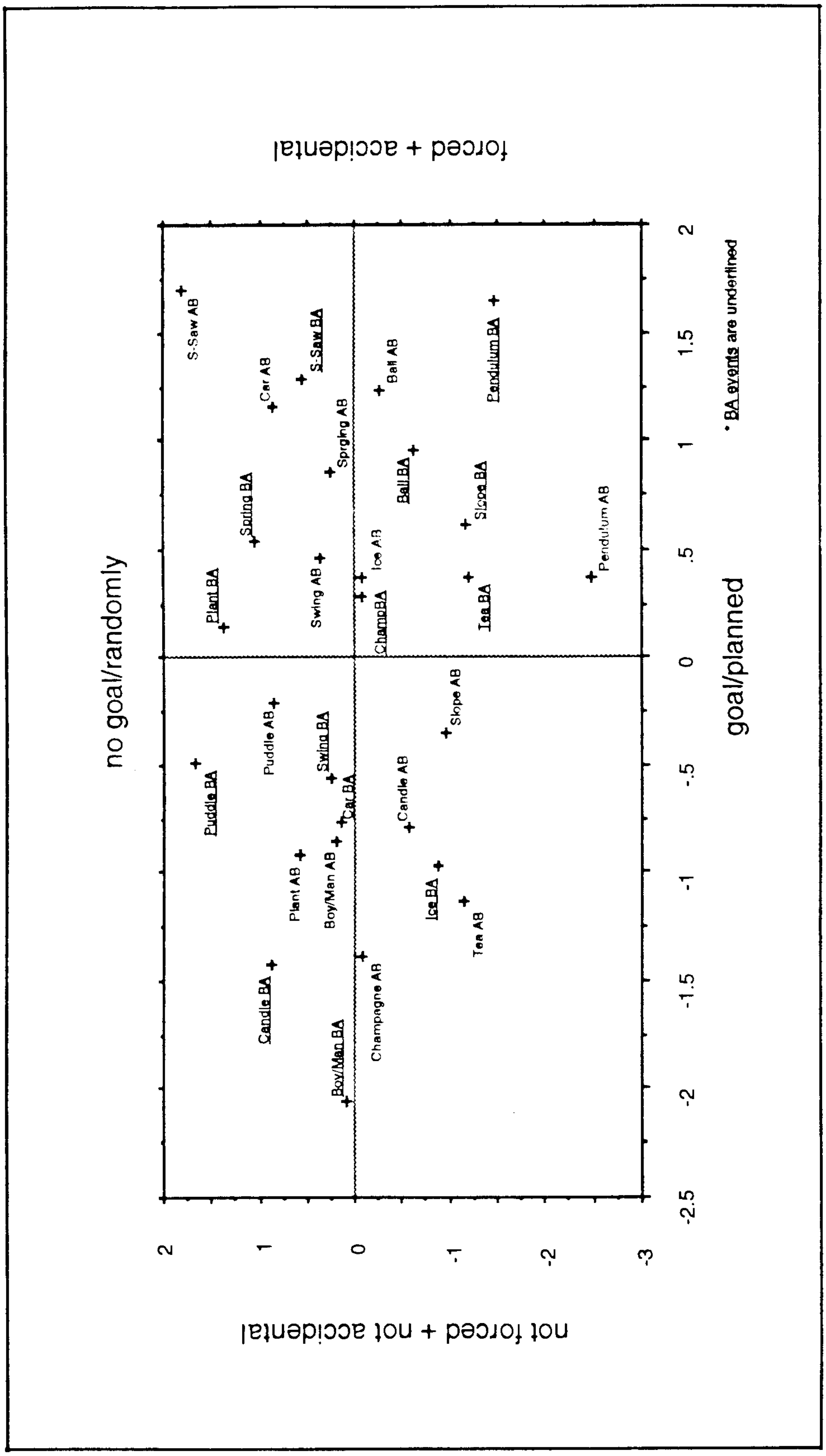


Figure G.9 - *Factor Space of 13/14 year old Chilean Group: Dimension II vs Dimension III*

G.4 The 16/17 year old Chilean Group

Initially in this case, the factor analysis permitted the extraction of 2 factors. However, it became apparent that a third factor should be considered, after running the factor analysis asking for three factors, despite the magnitude of its eigenvalue being a little lower than 1 (see Appendix E). Therefore, Table 4 shows the factor loadings for each phrases, and their interpretation is described below.

G.4.1 Dimension I: Happens by Itself vs. Does Not Happen

This dimension is accounted by the positive loadings of

Phrase 1 - It is something which happens naturally
Phrase 4 - It happens because it ought to go to A
Phrase 6 - It cannot be stopped from happening
Phrase 9 - It happens spontaneously, all by itself
Phrase 13 - There is a law which makes it happen
Phrase 14 - It happens because getting to A is the reason for the change

and the negative loadings of

Phrase 2 - There is a law which prevents it happening
Phrase 5 - It is possible, but difficult to do in practice
Phrase 8 - It could never happen, in principle
Phrase 10 - It needs an action to make it happen
Phrase 12 - It could happen but hardly ever will

Similarly to the 13/14 year old Chilean Group, this dimension can be named as HAPPENS BY ITSELF OR NATURALLY vs. DOES NOT HAPPEN. Events such as Pendulum AB, Slope AB, Tea AB are located on the 'happens by itself' side, whilst events such as Puddle BA, Plant BA, Car BA are located on the 'not happen' side.

G.4.2 Dimension II: Needs an Action vs. Does Not Need an Action

This dimension is basically defined by the positive loadings of

Phrase 7 - It happens because it is forced to go to A
Phrase 10 - It needs an action to make it happen

It seems that one side of this dimension is related to the idea of something happening due to an action - Pendulum BA, Spring BA, Slope BA, while the other extremity would be associated with the idea of something happening with no intervention such as Plant AB or Puddle AB or even not happening such as Boy/Man BA or Candle BA.

Table G.4 - *Oblique Solution Reference Structure-Orthotran/Varimax 16/17 year old Chilean Group*

Phrases	Factor Loadings			Variable
	I	II	III	Complexity
1- It is something which happens naturally	**0.550**	-0.190	0.143	1.257
2- There is a law which prevents it happening	**-0.535**	-0.325	-0.085	1.404
3- It happens accidentally	-0.052	0.130	**0.588**	1.063
4- It happens because it ought to go to B	**0.558**	-0.143	0.121	1.160
5- It is possible, but difficult to do in practice	**-0.680**	-0.066	0.146	1.102
6- It cannot be stopped from happening	**0.352**	-0.123	0.338	2.118
7- It happens because it is forced to go to B	0.056	**0.896**	0.001	1.016
8- It could never happen, in principle	**-0.502**	-0.315	-0.127	1.514
9- It happens spontaneously, all by itself	**0.646**	-0.171	0.024	1.071
10-It needs an action to make it happen	**-0.487**	**0.492**	0.003	1.794
11-It happens by some random process	-0.278	-0.044	**0.788**	1.247
12-It could happen but hardly ever will	**-0.693**	0.037	0.064	1.020
13-There is a law which makes it happen	**0.636**	0.082	0.008	1.016
14-It happens because getting to B is the reason for the change	**0.539**	0.198	0.005	1.130

G.4.3 Dimension III: Randomly/Accidental vs. Not Randomly/Not Accidental

This dimension is described by the positive loadings on

Phrase 3 - It happens accidentally

Phrase 11 - It happens by some random process

One extremity of this dimension can be labelled as 'HAPPENS RANDOMLY OR ACCIDENTALLY'. As there is no negative contribution in this case, the other extremity could be named 'DOES NOT HAPPEN RANDOMLY OR ACCIDENTALLY'. Events such as Puddle BA, Car AB, Puddle AB are located on the 'random' side whilst Pendulum AB, Slope AB, Candle BA are located on the 'not random' side.

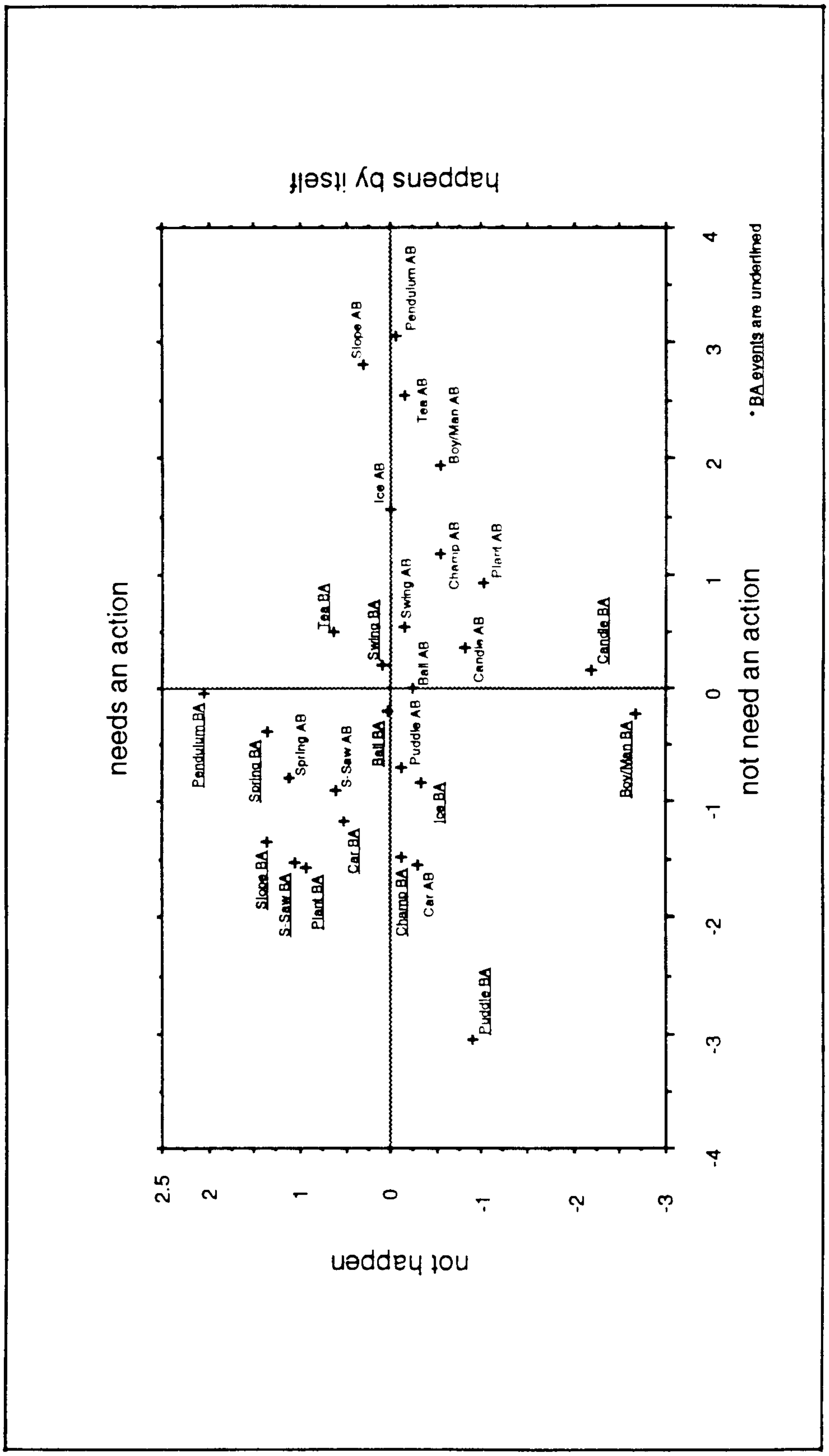


Figure G.10 - *Factor Space of 16/17 year old Chilean Group: Dimension I vs Dimension II*

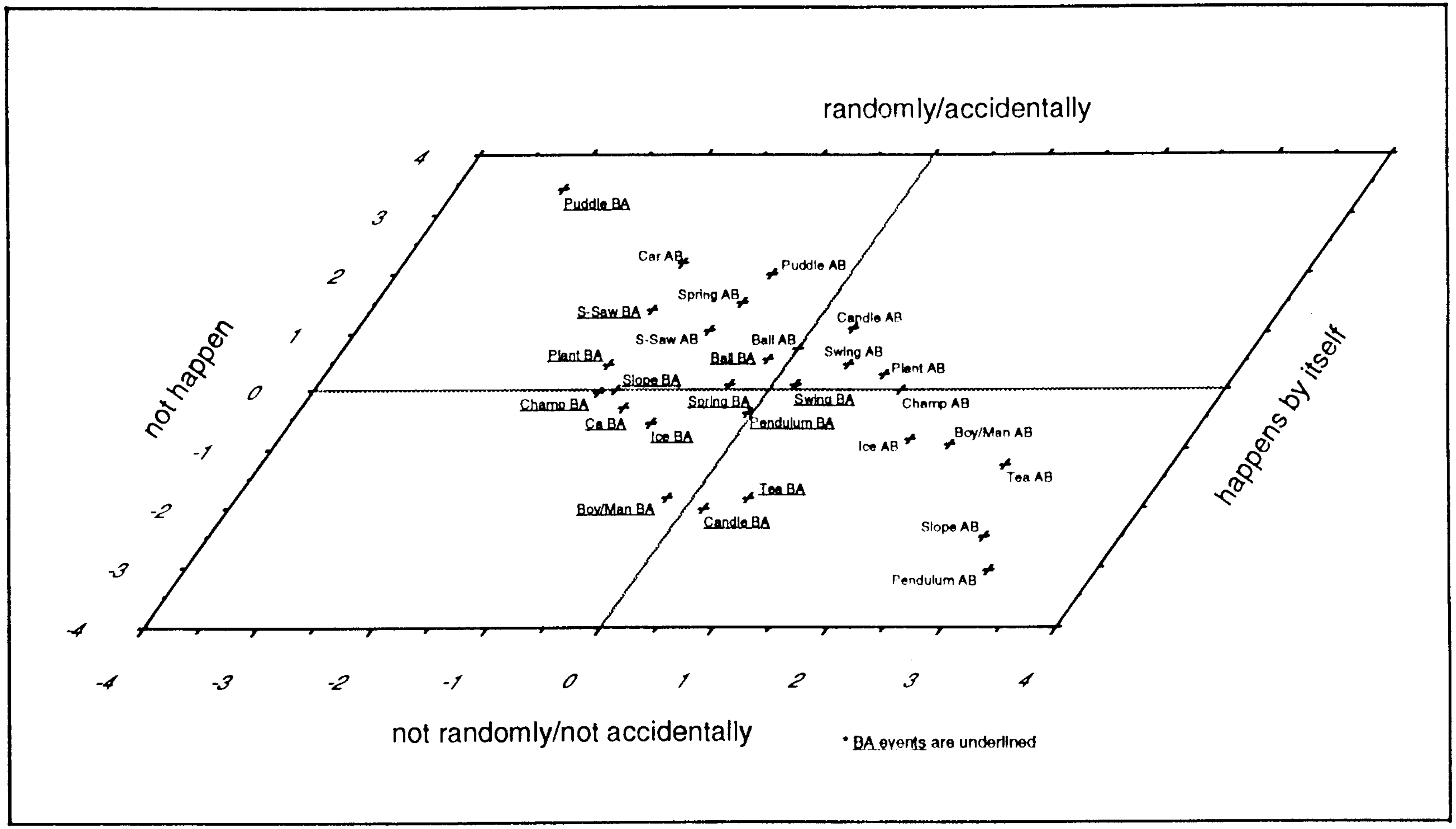


Figure G.11 - *Factor Space of 16/17 year old Chilean Group: Dimension I vs Dimension III*

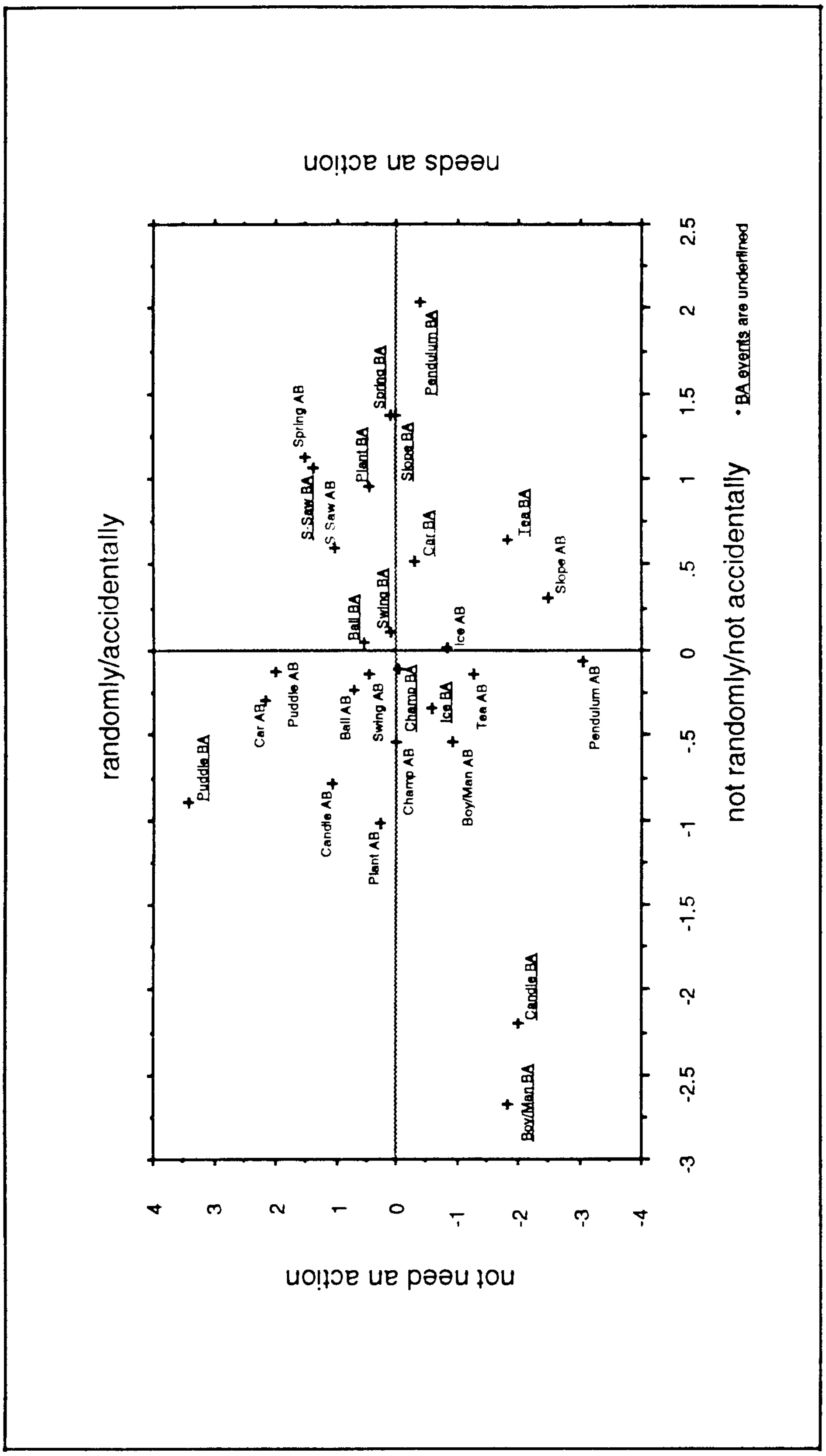


Figure G.12 - *Factor Space of 16/17 year old Chilean Group: Dimension II vs Dimension III*

G.4.4 The Factor Space

The non-orthogonal three dimensional factor space is shown plotted in two dimensions in turn: Dimension I (horizontal axis) orthogonal to Dimension II (vertical axis) in Figure G.10, Dimension I (horizontal axis) non-orthogonal to Dimension III (vertical axis) in Figure G.11, and Dimension II (horizontal axis) orthogonal to Dimension III (vertical axis) in Figure G.12. In these plots, the events happening backwards - BA events - are represented by their names underlined.

G.4.5. Interpretation of the Correlation between Factors

The negative correlation between dimension I - HAPPENS BY ITSELF vs. DOES NOT HAPPEN - and dimension III - ACCIDENTAL vs. NOT ACCIDENTAL - can be understood that in both cases the subject does not have a direct intervention on it. An event seen as happening by itself is not caused by the subject, whilst when seen as happening accidentally or randomly, the subject might cause it, but not necessarily.

G.5 The 16/17 year old Brazilian Group

The factor loadings for this case is shown in Table G.5.

G.5.1 Dimension I: Happens due to an Action vs. Does Not Happen

The meaning of this dimension is given by the positive loadings of

Phrase 7 - It happens because it is forced to go to A
Phrase 10 - It needs an action to make it happen
Phrase 13 - There is a law which makes it happen
Phrase 14 - It happens because getting to A is the reason for the change

and the negative loadings of

Phrase 2 - There is a law which prevents it happening
Phrase 5 - It is possible, but difficult to do in practice
Phrase 8 - It could never happen, in principle
Phrase 12 - It could happen but hardly ever will

It seems that this dimension is characterised by the opposition of something happening due to an action and something which does not happen at all. Events such as Pendulum BA, Pendulum AB Ice-Cream AB are seen as happening due to an intervention, while Boy/Man BA, Candle BA, Plant BA are seen as not happening.

Table G.5 - *Oblique Solution Reference Structure-Orthotran/Varimax 16/17 year old Brazilian Group*

Phrases	Factor Loadings I	II	III	Variable Complexity
1- It is something which happens naturally	0.094	**0.393**	0.147	1.195
2- There is a law which prevents it happening	**-0.354**	-0.162	**0.378**	2.099
3- It happens accidentally	-0.001	-0.086	**0.940**	1.056
4- It happens because it ought to go to B	0.088	**0.428**	0.019	1.082
5- It is possible, but difficult to do in practice	**-0.500**	0.006	-0.005	1.000
6- It cannot be stopped from happening	-0.163	**0.613**	-0.311	1.294
7- It happens because it is forced to go to B	**0.805**	**-0.450**	0.119	1.608
8- It could never happen, in principle	**-0.438**	-0.065	-0.072	1.063
9- It happens spontaneously, all by itself	-0.070	**0.559**	-0.021	1.030
10-It needs an action to make it happen	**0.718**	**-0.916**	-0.023	1.872
11-It happens by some random process	-0.218	**0.503**	**0.444**	1.833
12-It could happen but hardly ever will	**-0.422**	-0.085	0.132	1.148
13-There is a law which makes it happen	**0.842**	**-0.486**	0.060	1.627
14-It happens because getting to B is the reason for the change	**0.668**	-0.194	-0.012	1.176

G.5.2 Dimension II: Happens by Itself vs. Needs an Action

This dimension is basically defined by the positive loadings of

Phrase 1 - It is something which happens naturally
Phrase 4 - It happens because it ought to go to A
Phrase 6 - It cannot be stopped from happening
Phrase 9 - It happens spontaneously, all by itself
Phrase 11 - It happens by some random process

and the negative loadings of

Phrase 7 - It happens because it is forced to go to A
Phrase 10 - It needs an action to make it happen
Phrase 13 - There is a law which makes it happen

Similarly to the 13/14 and 16/17 year old English Group this dimension appears to be related to the idea of something happening with no intervention. Phrases with positive loadings express the idea that an event happens by itself, and those with negative loadings the idea that an action is needed. Even Phrase 13 ratifies this idea given that when an action is needed it can be understood as something which follows a law.

Therefore, this dimension might be named as HAPPENS BY ITSELF vs. ACTION/FORCED. Examples for each are Boy/Man AB, Plant AB, Tea AB and Pendulum BA, Pendulum BA, Swing AB respectively.

G.5.3 Dimension III: Random/Accidental vs. Not Random/not Accidental

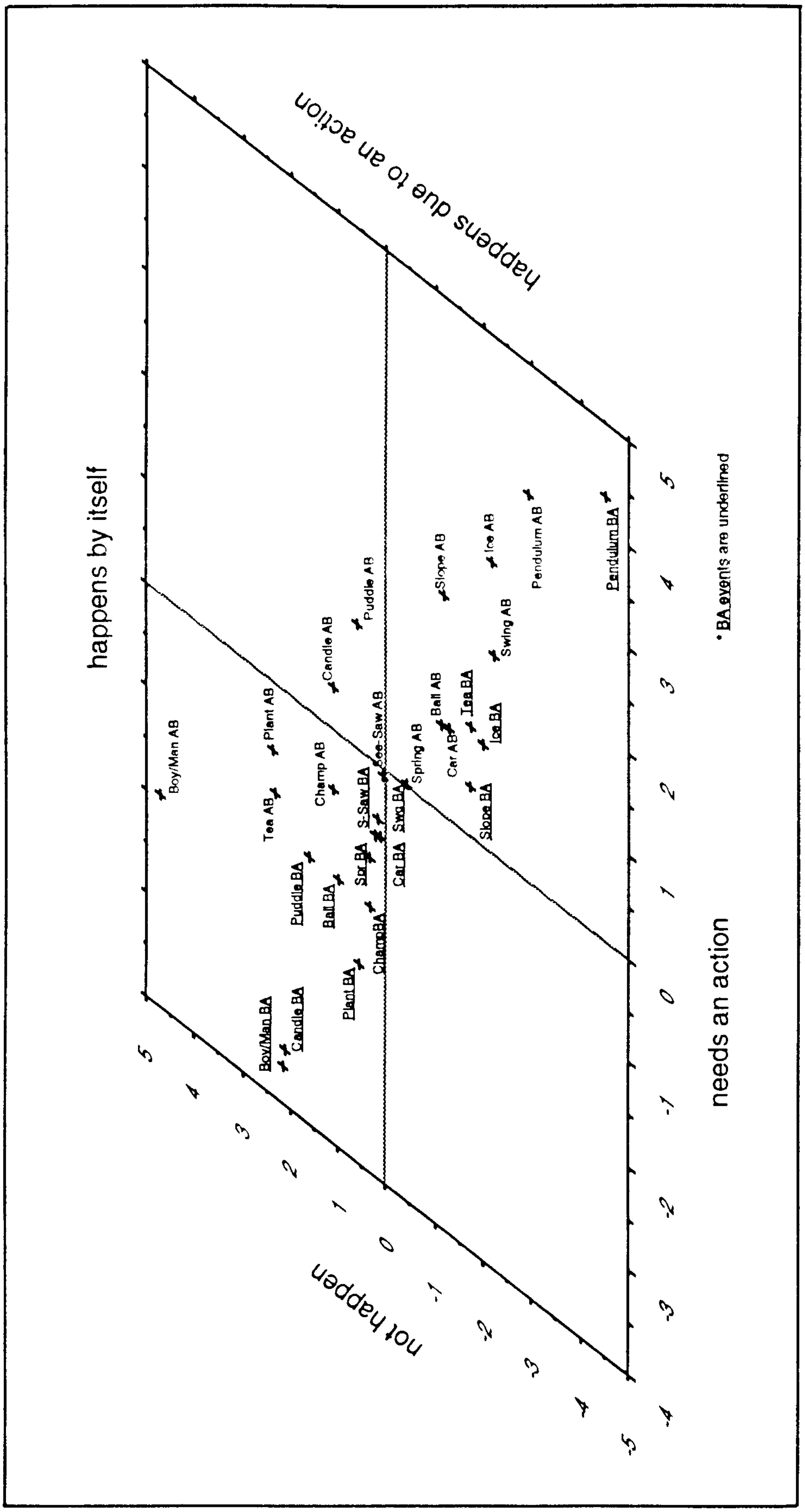
This dimension is described by the positive loadings on

Phrase 2 - There is a law which prevents it happening
Phrase 3 - It happens accidentally
Phrase 11 - It happens by some random process

It seems that this dimension is associated with the idea of something happening accidentally or randomly. As there are no negative loadings it would be named HAPPENS RANDOMLY OR ACCIDENTALLY vs. DOES NOT HAPPENS RANDOMLY OR ACCIDENTALLY. Events such as Car AB, Champagne AB, Falling Ball AB are located on the 'random' side whilst Boy/Man AB, Ice-Cream BA, Puddle AB are located on the 'not random' side.

G.5.4 The Factor Space

The non-orthogonal three dimensional factor space is shown plotted in two dimensions in turn: Dimension I (horizontal axis) non-orthogonal to Dimension II (vertical axis) in Figure G.13, Dimension I (horizontal axis) orthogonal to Dimension III (vertical axis) in Figure G.14, and Dimension II (horizontal axis) non-orthogonal to Dimension III (vertical axis) in Figure G.15. In these plots, the events happening backwards - BA events - are represented by their names underlined.



FigureG.13 - *Factor Space of 16/17 year old Brazilian Group: Dimension I vs Dimension II*

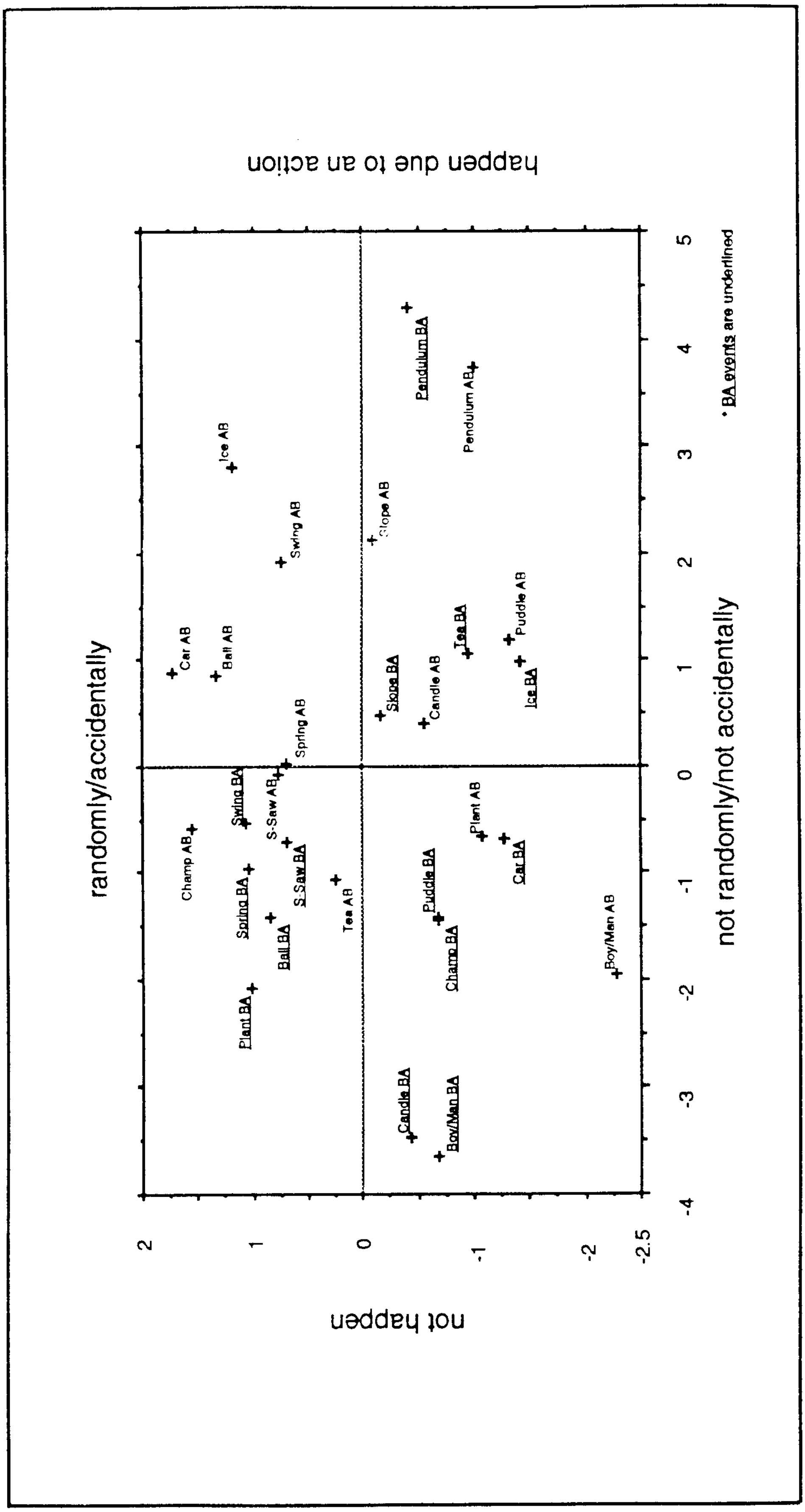


***Figure G.14** - Factor Space of 16/17 year old Brazilian Group: Dimension I vs Dimension III*

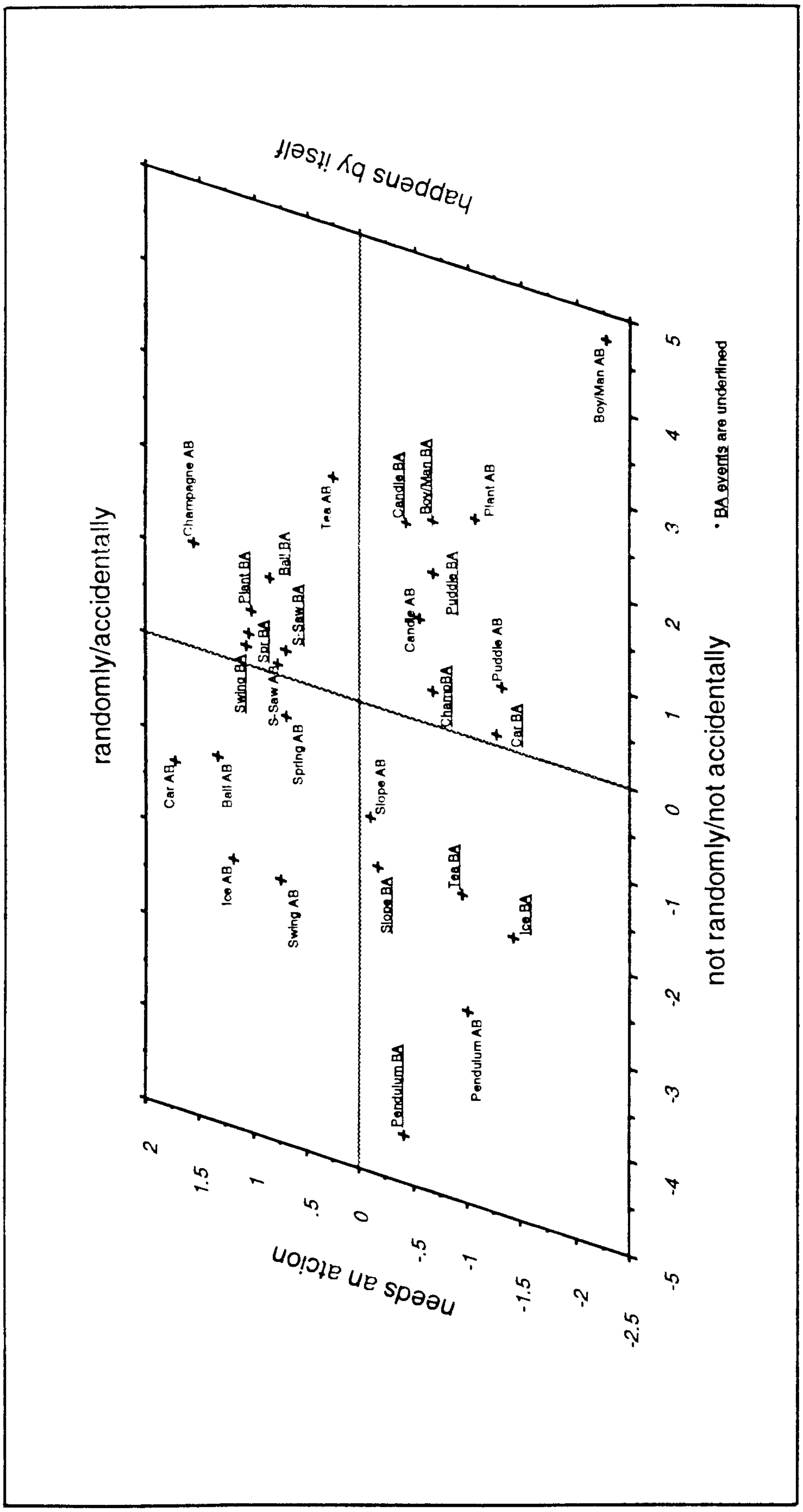


Figure G.15 - *Factor Space of 16/17 year old Brazilian Group: Dimension II vs Dimension III*

G.5.5. Interpretation of the Correlation between Factors

The positive correlation between dimension I - HAPPENS DUE TO AN ACTION vs. DOES NOT HAPPEN - and dimension II - HAPPENS BY ITSELF vs. NEEDS AN ACTION - can be explained as the idea that an event seen as not happening may happen when an action is taken, or an event happening either by itself or due to an action, happens anyway.

The negative correlation between dimension I - HAPPENS BY ITSELF vs. NEEDS AN ACTION - and dimension III - ACCIDENTAL vs. NOT ACCIDENTAL - can be interpreted as for the Chilean 16/17 group. An event seen as happening by itself and accidentally may have no subject's intervention when happening.

Appendix H

Statistical Summary of the Factor Analysis of Groups Combined

APPENDIX H: Statistical Summary for the Group Combined

- **Factor Extraction Method**: Principal Component Analysis
- **Transformation Method**: Orthotran/Varimax
- **Number of Factor**: 3
- **Factor Solution**: Oblique Solution
- **Bartlett Test of Sphericity** - DF: 104 Chi-Square: 2486.256 p: .0001

- **Eigenvalues and Proportion of Original Variance**

FACTOR	EIGENVALUE	VARIANCE PROP.	CUMULAT. PROP.
1	6.789	0.485	0.485
2	2.860	0.204	0.689
3	1.562	0.112	0.801

The three factors jointly explain 80.1% of the total variance. The remaining factors together account for only 19.9% of the variance.

- **Factor Loadings**

The factor loadings are presented in Table 8.1 - *Oblique Solution Reference Structure Orthotran/Varimax*, in Chapter 8, together with the description of the interpretation of the factor analysis.

- **Primary Intercorrelation-Orthotran/Varimax**

	FACTOR 1	FACTOR 2	FACTOR 3
FACTOR 1	1.000		
FACTOR 2	-0.305	1.000	
FACTOR 3	- 0.004	.0.151	1.000

- **Proportionate Variance Contribution**

	OBLIQUE TOTAL
FACTOR 1	0.345
FACTOR 2	0.495
FACTOR 3	0.161

• Factor Scores of Events

Sample	Event	Factor 1	Factor 2	Factor 3
England 13/14	PendulumAB	-1.574	-1.360	0.989
England 13/14	PendulumBA	-1.243	-2.235	0.646
England 13/14	Ice-Cream AB	-0.816	0.799	-0.937
England 13/14	Ice-Cream BA	0.613	-1.030	-1.136
England 13/14	Puddle AB	-0.153	1.400	-1.001
England 13/14	Puddle BA	0.115	1.175	-1.072
England 13/14	Car AB	-0.119	1.120	-1.822
England 13/14	Car BA	0.309	-0.822	-0.710
England 13/14	Boy/Man AB	-0.556	1.463	-0.082
England 13/14	Boy/Man BA	1.230	0.024	-2.425
England 13/14	Ball AB	-1.337	-0.677	0.990
England 13/14	Ball BA	-0.628	-0.473	0.158
England 13/14	See-Saw AB	-0.645	-0.598	0.265
England 13/14	See-Saw BA	-0.762	-0.992	0.131
England 13/14	Slope AB	-1.866	-0.857	0.478
England 13/14	Slope BA	-0.491	-2.291	0.292
England 13/14	Tea AB	-1.447	0.061	-1.098
England 13/14	Tea BA	-0.719	-1.871	0.028
England 13/14	Champagne AB	-0.487	1.607	-2.288
England 13/14	Champagne BA	0.649	-0.594	-0.697
England 13/14	Candle AB	-0.663	0.730	-0.605
England 13/14	Candle BA	0.781	-0.409	-1.051
England 13/14	Plant AB	-0.587	0.640	-0.246
England 13/14	Plant BA	0.410	-0.193	-1.401
England 13/14	Swing AB	-0.549	-0.491	0.691
England 13/14	Swing BA	-0.209	0.020	0.080
England 13/14	Spring AB	-0.297	-0.463	-0.159
England 13/14	Spring BA	-0.133	-0.412	-0.382
England 16/17	PendulumAB	-2.015	-1.331	0.152
England 16/17	PendulumBA	-1.481	-2.481	0.833
England 16/17	Ice-Cream AB	-1.762	-0.638	-0.677
England 16/17	Ice-Cream BA	0.291	-1.328	-0.534
England 16/17	Puddle AB	-1.059	0.523	-0.883
England 16/17	Puddle BA	-0.374	0.95	-1.869
England 16/17	Car AB	-0.615	0.773	-1.957
England 16/17	Car BA	-0.172	-1.317	-0.917
England 16/17	Boy/Man AB	-1.045	1.142	-0.948
England 16/17	Boy/Man BA	0.808	-0.802	-1.699
England 16/17	Ball AB	-1.867	-1.171	0.188
England 16/17	Ball BA	-1.461	-0.936	-0.144
England 16/17	See-Saw AB	-0.884	-1.587	0.195
England 16/17	See-Saw BA	-0.844	-1.231	-0.359
England 16/17	Slope AB	-2.219	-1.219	0.36
England 16/17	Slope BA	-1.291	-2.96	0.717
England 16/17	Tea AB	-1.532	0.283	-1.537
England 16/17	Tea BA	-1.887	-3.074	1.157
England 16/17	Champagne AB	-1.119	0.704	-2.488
England 16/17	Champagne BA	-0.597	-2.103	0.383
England 16/17	Candle AB	-1.578	-0.241	-1.286
England 16/17	Candle BA	0.379	-1.157	-0.912
England 16/17	Plant AB	-1.555	-0.201	-1.134
England 16/17	Plant BA	-0.743	-1.611	-0.81
England 16/17	Swing AB	-1.911	-1.717	0.894
England 16/17	Swing BA	-1.655	-0.938	-0.124
England 16/17	Spring AB	-1.729	-2.033	0.493
England 16/17	Spring BA	-1.589	-2.17	0.254

To be continued

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Sample	Event	Factor 1	Factor 2	Factor 3
Chile 13/14	PendulumAB	-1.2	-1.233	1.214
Chile 13/14	PendulumBA	-0.084	-1.537	0.934
Chile 13/14	Ice-Cream AB	-0.44	0.666	-0.111
Chile 13/14	Ice-Cream BA	0.205	-1.644	-0.611
Chile 13/14	Puddle AB	-0.681	1.172	-0.582
Chile 13/14	Puddle BA	0.184	0.905	-0.997
Chile 13/14	Car AB	-0.103	0.397	-0.418
Chile 13/14	Car BA	0.665	-0.878	-1.219
Chile 13/14	Boy/Man AB	-1.121	1.439	-0.265
Chile 13/14	Boy/Man BA	1.572	-0.235	-2.041
Chile 13/14	Ball AB	-1.087	-0.216	0.888
Chile 13/14	Ball BA	-0.296	-0.048	0.733
Chile 13/14	See-Saw AB	0.465	0.875	-0.215
Chile 13/14	See-Saw BA	0.545	0.372	-0.054
Chile 13/14	Slope AB	-0.997	0.122	0.331
Chile 13/14	Slope BA	1.008	-1.26	0.234
Chile 13/14	Tea AB	-1.348	0.739	-0.122
Chile 13/14	Tea BA	0.38	-1.479	0.122
Chile 13/14	Champagne AB	-1.002	1.394	-1.447
Chile 13/14	Champagne BA	1.596	-0.869	-0.559
Chile 13/14	Candle AB	-1.383	1.011	-0.482
Chile 13/14	Candle BA	1.64	-0.22	-1.654
Chile 13/14	Plant AB	-1.117	0.577	-1.12
Chile 13/14	Plant BA	0.868	-0.229	-1.267
Chile 13/14	Swing AB	-0.291	0.418	0.113
Chile 13/14	Swing BA	-0.226	0.366	-0.838
Chile 13/14	Spring AB	0.047	-0.101	0.127
Chile 13/14	Spring BA	0.211	0.52	-0.633
Chile 16/17	PendulumAB	-1.6	-0.673	0.53
Chile 16/17	PendulumBA	-1.027	-1.6	0.754
Chile 16/17	Ice-Cream AB	-1.344	0.3	-0.098
Chile 16/17	Ice-Cream BA	0.969	-0.797	-0.45
Chile 16/17	Puddle AB	-0.246	1.529	-0.235
Chile 16/17	Puddle BA	1.561	1.731	-1.563
Chile 16/17	Car AB	0.35	1.221	-1.094
Chile 16/17	Car BA	1.113	-0.91	-0.315
Chile 16/17	Boy/Man AB	-0.755	1.383	-0.073
Chile 16/17	Boy/Man BA	1.67	-0.274	-2.32
Chile 16/17	Ball AB	-0.49	0.771	-0.286
Chile 16/17	Ball BA	-0.035	0.63	-0.152
Chile 16/17	See-Saw AB	-0.483	-0.321	-0.104
Chile 16/17	See-Saw BA	-0.47	-0.877	-0.075
Chile 16/17	Slope AB	-1.895	-0.598	0.768
Chile 16/17	Slope BA	0.953	-1.377	0.745
Chile 16/17	Tea AB	-1.455	1.086	0.305
Chile 16/17	Tea BA	0.127	-1.486	0.344
Chile 16/17	Champagne AB	-1.016	1.275	-0.516
Chile 16/17	Champagne BA	1.52	-0.556	-0.782
Chile 16/17	Candle AB	-0.739	1.605	-0.585
Chile 16/17	Candle BA	1.068	-0.609	-2.016
Chile 16/17	Plant AB	-0.948	1.108	-0.289
Chile 16/17	Plant BA	0.983	-0.756	-0.079
Chile 16/17	Swing AB	-0.859	0.784	0.151
Chile 16/17	Swing BA	-0.333	0.173	0.3
Chile 16/17	Spring AB	-0.378	0.38	0.449
Chile 16/17	Spring BA	-0.325	-0.724	0.608

To be continued

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Sample	Event	Factor 1	Factor 2	Factor 3
Brazil 16/17	PendulumAB	-0.031	-0.623	2.574
Brazil 16/17	PendulumBA	0.212	-0.994	2.292
Brazil 16/17	Ice-Cream AB	0.007	0.283	2.049
Brazil 16/17	Ice-Cream BA	1.213	-0.426	0.679
Brazil 16/17	Puddle AB	-0.233	0.471	1.679
Brazil 16/17	Puddle BA	0.969	0.901	0.212
Brazil 16/17	Car AB	0.92	0.802	0.95
Brazil 16/17	Car BA	1.311	0.193	0.321
Brazil 16/17	Boy/Man AB	-0.15	1.244	1.015
Brazil 16/17	Boy/Man BA	2.077	0.731	-0.838
Brazil 16/17	Ball AB	0.894	0.669	1.217
Brazil 16/17	Ball BA	1.256	1.101	0.132
Brazil 16/17	See-Saw AB	1.132	0.975	0.953
Brazil 16/17	See-Saw BA	1.293	0.861	0.586
Brazil 16/17	Slope AB	-0.137	0.099	1.713
Brazil 16/17	Slope BA	1.42	-0.017	0.597
Brazil 16/17	Tea AB	0.159	1.135	0.68
Brazil 16/17	Tea BA	0.766	-0.483	0.872
Brazil 16/17	Champagne AB	0.489	1.351	0.543
Brazil 16/17	Champagne BA	1.553	0.369	-0.153
Brazil 16/17	Candle AB	-0.075	0.659	1.287
Brazil 16/17	Candle BA	1.836	0.63	-0.744
Brazil 16/17	Plant AB	0.051	0.969	0.949
Brazil 16/17	Plant BA	1.865	0.858	-0.213
Brazil 16/17	Swing AB	0.766	0.16	1.559
Brazil 16/17	Swing BA	1.17	0.942	0.712
Brazil 16/17	Spring AB	1.25	0.779	0.811
Brazil 16/17	Spring BA	1.533	1.074	0.471

• 'Factor Scores' for Phrases

Phrases	Factor 1	Factor 2	Factor 3
1- It is something which happens naturally	**-1.266**	**1.737**	0.042
2- There is a law which prevents it happening	**1.341**	-0.001	0.113
3- It happens accidentally	0.089	**0.806**	-0.037
4- It happens because it ought to go to B	**-0.887**	**1.131**	0.359
5- It is possible, but difficult to do in practice	**1.194**	-0.001	-0.141
6- It cannot be stopped from happening	-0.175	**1.398**	0.213
7- It happens because it is forced to go to B	-0.023	-0.176	**1.124**
8- It could never happen, in principle	**1.455**	0.111	-0.080
9- It happens spontaneously, all by itself	**-0.784**	**1.559**	-0.043
10-It needs an action to make it happen	**0.554**	**-0.990**	**0.774**
11-It happens by some random process	0.325	**0.783**	0.080
12-It could happen but hardly ever will	**1.286**	0.038	0.118
13-There is a law which makes it happen	-0.443	**0.825**	**0.997**
14-It happens because getting to B is the reason for the change	0.239	**0.673**	**1.021**