SOME DIMENSIONS OF COMMONSENSE REASONING ABOUT THE PHYSICAL WORLD: AN EMPIRICAL STUDY OF THE STRUCTURE OF STUDENTS' CONCEPTUALISATIONS

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Abstract

Research in the area of alternative conceptions in Science has been suggesting that students hold conceptualisations which are different from those learned at school. This thesis aims to investigate possible structured patterns of commonsense reasoning about the physical world present in the way students (ranging from 8-9 year old to undergraduate students of Physics) conceptualise entities in Science.

The theoretical framework was developed mainly from previous Piagetian studies (see Mariani and Ogborn 1990, 1991) about the child's construction of reality (Piaget 1937) , particularly in what concerns the fundamental role of actions in this construction, and also with a basis in some more recent studies on the representation of knowledge in the area of the cognitive sciences.

With a basis in this theoretical framework some very fundamental 'ontological' questions were addressed to the students about a selected group of entities (Can you touch it? or Can you create it? etc.). Also students were asked to compare entities and to locate them in a given number of 'ontological' dimensions (static or dynamic, cause or effect, etc.)

The empirical data was collected with the use of questionnaires and interviews. The sample consisted of five different age/instructional groups of Brazilian students. Multidimensional scaling was used to analyse the quantitative data. The qualitative data was analysed using a systemic network with which different answers given by students could be classified.

The general result of the quantitative analysis was a common four-dimensional 'ontological' space for all five groups, with the dimensions being interpreted in the same way as in a previous published pilot study (Mariani and Ogborn, 1991), and being fundamentally related to the distinctions static or dynamic, place or localized, cause or motion and immaterial fluid (continuous) or action (discrete). In these spaces entities can be located and may change their positions with different age/instructional groups. The results of the qualitative analysis give some more support to these quantitative results.

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Introduction

Commonsense reasoning has been the subject of study in a number of different areas of research and for various different reasons. For example, it has been addressed in philosophy, philosophy of science, artificial intelligence, and more recently also in the area of science education (see for example Moore 1925; Hilton 1988; Harré 1986; Hayes 1978 and 1985; Ogborn 1985).

It is sometimes understood to be a form of reasoning which makes a direct appeal to the senses (for example Moore 1925), but more generally as a form of reasoning based on people's ordinary experiences of the world (for example Hayes 1978 and 1985). The second approach proved to be particularly useful in providing the elements to try to describe people's understandings of motion (Ogborn 1985).

Commonsense reasoning can be better understood in the wider context of the studies on human reasoning in the area of the cognitive sciences (see for example Johnson-Laird 1983, Johnson-Laird and Wason 1977; Schank 1986), including studies in developmental psychology (for example Piaget 1926, 1927, 1936 and 1937; Langer 1980, 1986). The developmental studies are particularly interesting in providing a link between reasoning and the acquisition and representation of knowledge in people's minds.

In a developmental approach, commonsense reasoning will be intrinsically linked to commonsense knowledge. Such a developmental approach has already been tried in a study of pupil's commonsense thinking about causes of motion (Whitelock 1991).

The aim of the present research will be to try to relate people's knowledge of the physical world to underlying forms of commonsense reasoning about the objects and events in this world. Such reasoning will have its roots in early childhood, being fundamentally based on the manipulation of and sensory experience of objects and events by the child. This will probably have consequences, for example, for the way in which knowledge is represented in people's minds. Such an approach has already resulted in two published pieces of research (Mariani and Ogborn 1990, 1991; see Appendix A).

Two areas of study were chosen to provide the fundamental theoretical background for this research: genetic psychology and representational studies in cognitive science. The first because it links the knowledge acquired by a child through the manipulation and sensory experience of concrete objects to more abstract forms of knowledge in adulthood by means of the presence of a common underlying reasoning about objects and actions. The second because it describes the possible different forms in which knowledge can be represented, particularly with the use of imagery.

Studies in genetic psychology have been carried out since the first half of this century by Jean Piaget , and some of them will be used in the present research, particularly the studies of the construction of the physical world (Piaget 1936, 1937, 1946a and b; with Inhelder 1948) and of a logic of meaning (Piaget and Garcia 1987). Studies of representational issues of interest in the way commonsense knowledge is understood in the present research have been carried out by a number of researchers in the area of cognitive science (Johnson-Laird 1983, Schank and Abelson 1977).

This theoretical background will provide the elements to develop a theoretical framework in which to describe and understand commonsense reasoning in its relationship with commonsense knowledge of the physical world. This theoretical framework will also generate the questions to be addressed in the empirical work and provide a framework for the interpretation of the data obtained. The questions to be addressed will try to obtain information about the way in which pupils (8-10 year-olds to undergraduates in Physics) imagine entities of the physical world.

The methodology selected for the empirical work will also reflect the way in which commonsense reasoning and commonsense knowledge of the physical world will be understood and related to each other in the theoretical framework. Some difficulties in carrying out such empirical work are suggested by the fact that asking people about the way in which they sense and experience the world can appear to be at once rather trivial and rather deep . Trivial because it is the sort of knowledge of the world which is taken for granted by the individual, being considered to be related to the way things 'really' are; and deep because the sort of reasoning leading to such a knowledge of things in the world is not necessarily, and often is not, the object of reflection in daily life.

In order to deal with the problem as effectively as possible a methodology was adopted in which first subjects were asked to give yes/no answers to direct questions about the way they sense some physical entities in the world: Can you see it ? Can you touch it? etc. By doing this the questioning was reduced to its most elementary level so that the answers would be those which appear to be rather obvious to the subject. At a different moment the subject was also asked to think a bit more deeply about the same entities.

The reasoning which leads to what is known about the physical world is difficult to access, both to the individual and the researcher. Given answers to many such simple questions as mentioned above, a possible way to access it would be to try to find some regularities in the answers obtained. In this sense the methodology was also convenient in providing data which could be analysed in terms of underlying 'dimensions' and 'factors' (Everitt and Dunn 1983; O'Muircheartaigh and Payne 1977). These regularities will then be characterised and understood in terms of 'fundamental dimensions of commonsense reasoning about the physical world'.

Thus commonsense knowledge of the physical world, which is here being characterised as fundamentally the way one experiences and senses this world, is supported by forms of reasoning about this world which could be described in terms of some fundamental 'dimensions' of commonsense reasoning.

These 'dimensions' are the ones which will be used to describe the regularities present in the way people answer simple questions about their knowledge of entities present in the physical world. They can simply be seen as the result of the analysis of data in terms of a n-dimensional space (the result of a multidimensional scaling; see O'Muircheartaigh and Payne 1977) or as factors underlying the responses obtained. This is the only reason why they will be called 'dimensions' of commonsense reasoning. But it is also intended to relate these dimensions with possible fundamental categories of thought about reality, like the ones described by Piaget (Piaget 1936).

The first Chapter will describe in more detail the context in which the present research has originated: a context in which studies in the area of alternative conceptions in Science develop links with studies in the cognitive sciences and developmental psychology. The aim of this Chapter is to build a suitable theoretical framework for the research.

For more than two decades researches in the area of alternative conceptions have been trying to describe and understand the particular way in which students, science teachers and the public in general make sense of scientific ideas (for a review see for example Driver and Erickson 1983). These particular ways have been variously called misconceptions, spontaneous ways of reasoning in Science, alternative frameworks, naive theories, and so on (see for example Gilbert and Watts 1983). More recently these alternative conceptions have been thought of as related to 'commonsense' ways of reasoning (Ogborn 1985).

In trying to make sense of these ideas in Science in terms of common underlying forms of reasoning some researchers (for example Ogborn 1985; Andersson 1986) turned to studies in the cognitive sciences (for example Johnson-Laird 1983, Lakoff and Johnson 1980) and some (for example Whitelock 1991) to developmental psychology (Piaget 1926 and 1937). A similar approach will be tried in the present research, with some preliminary results already published (Mariani and Ogborn 1990, 1991; see Appendix A).

In the second Chapter the details of the empirical design of the research will be presented. Some questionnaires were designed to be easily answered and able to be analysed with a search for underlying factors or dimensions to which the data could be reduced. The results of a pilot study proved quite promising and further elaboration led to the conception of the main study which will be presented in Chapter 3.

The target population were Brazilian students of Science or Physics divided in five different age/instructional groups: from 8-10 year-olds to graduating physicists. The result of multidimensional scaling applied to the data obtained via questionnaires for all groups and the results for each group will be presented . Also the results of different profiles of answers for individuals rather than groups, and the results of interviews, will be presented in this Chapter.

In the last Chapter the results presented in Chapter 3 will be discussed with reference to the theoretical framework developed in Chapter 1 and the empirical design developed in Chapter 2. Some conclusions will then be drawn in view of the general results and discussion presented in Chapter 4.

Chapter 1: Development of a theoretical framework

1.1. Introduction

In this Chapter the general context in which the present research had its origin and development will be described.

Starting with an overview of research on alternative conceptions and cognitive sciences an attempt will be made to establish possible links between these two areas of investigation in order to develop a theoretical framework for the present research. With a basis in this theoretical framework it will be possible to clearly define the research questions and also to design a suitable empirical study and analysis of the data to be collected.

An overview of past and recent research in the area of alternative conceptions will be of particular interest in trying to clarify the general aims of the research in this area and the results which have been obtained so far.

Concerning the cognitive sciences it is necessary first to decide which are the studies on human cognition of particular interest for the development of a theoretical framework for the present research, and which are seen to be in more direct relation with the studies on alternative conceptions. Taking the broad definition of cognitive sciences as "any research discipline with an interest in human cognition" (Aitkenhead and Slack 1985) which would include disciplines like philosophy, psychology, artificial intelligence, linguistic, anthropology and neuroscience (Gardner 1987) the following areas of research will be addressed:

1. An overview of some relevant developmental studies of reasoning in the area of cognitive psychology;

2. An overview of some relevant studies of representation of knowledge in cognitive psychology and artificial intelligence;

3. An overview of some relevant studies in Philosophy and History of Science particularly concerned with scientists' reasoning and the construction of knowledge.

By relating these theoretical studies of human cognition and the variety of data collected in the area of alternative conceptions it is intended to develop a theoretical framework in the last section of this Chapter.

1.2. Overview of research in the area of alternative conceptions

The main objective of this section will be to discuss some of the more relevant findings in this area of investigation which would be of interest for the development of the theoretical framework.

In the last two decades a large number of researches have described pupils' alternative conceptions in Science (for reviews see Driver and Erickson 1983, Gilbert and Watts 1983, Tiberghien 1984; McDermott 1984), but only more recently have a number of researches been trying to explain the regularities which seem to be present in pupils' answers in terms of underlying forms of reasoning (Guidoni 1985, Ogborn 1985, Andersson 1986, diSessa 1988).

One of the first difficulties to be found in this area of research is to decide the sort of status to be attributed to pupils' ideas in Science: researchers sometimes refer to them as being pupils' 'misconceptions, alternative conceptions or frameworks, children's science, spontaneous reasoning, commonsense reasoning, natural thinking' and so on .

In the first case the term 'misconceptions' indicates that these ideas are seen to be the result of mistakes made by pupils' in their process of learning Science, and by being so, are things which should be corrected by teaching (for example in Doran 1972; Rowell, Dawson and Lyndon 1990). By calling them 'alternative conceptions or frameworks' these ideas are considered as constituting an alternative body of knowledge about the world which should not be thought of as right or wrong (see Driver and Easley 1978) but which can be changed (Gilbert, Osborne and Fensham 1982) . The remaining terms suggest the presence of forms of reasoning or thinking about events which is causing the appearance of certain patterns in pupils' responses (see Ogborn 1985, Guidoni 1985) which differ from those 'desirable' in Science. To what extent a natural way of reasoning can be substituted by formal reasoning is still unclear.

The majority of studies in the area of alternative conceptions have tried to describe the way in which different scientific concepts are understood by pupils at different ages and/or instructional level. Most of the work which has been done is about fundamental concepts in Physics like force and motion (Viennot 1979; Caramazza, McCloskey and Green 1980; Saltiel and Malgrange 1980), energy (Duit 1984; Solomon 1985; Watts and Gilbert 1983; Bliss and Ogborn 1985), heat and temperature (Erickson 1979 and 1980; Stavy and Berkovitz 1980; Carey and Wiser 1983), electricity (Solomon, Black, Oldham and Stuart 1985 and 1987),light (Guesne 1984) and gravity (Watts 1982).

Concerning force and motion one interesting result is the fact that pupils attribute a force to any moving object and believe that an object will always require a force to be maintained in motion. Energy is also often considered to be like a force. The concepts of heat and temperature seem to be undifferentiated. Electricity can be thought of as a sort of substance, as can energy and heat. Light is something one can see rather than something which makes seeing possible.

It is possible to look at this sort of data from the different points of views described above, thinking of these ideas as misconceptions, alternative conceptions or spontaneous reasoning.

In the first case they will merely be the result of misunderstanding whatever is taught about these concepts at school. This explanation does not account for the fact that pupils do not make mistakes at random, but instead that there seems to be a tendency to make mistakes in a certain way.

From a different point of view these ideas can be seen to constitute an organised alternative theoretical framework from which the individual is able to construct explanations of physical events. It is still not clear why children have these ideas and not others, or to what extent students give answers which are coherent with one or with various theoretical frameworks, and what sort of theoretical framework that would be, which some researchers have tried to describe as being theories comparable to the ones developed in Science in the past (Carey and Wiser 1983).

It is also possible to look at these ideas in terms of underlying forms of reasoning about entities and events in Science. This view would account for the similarities in the sort of answers obtained from one or more individuals in the various studies, but at the same time would account for the various possible ways in which these individuals could give an answer in function of, for example, the general context in which the research is conducted. But the way in which this reasoning would relate to the actual ideas developed by the individuals is still not clear.

Generally most researches look at these ideas by appealing to a mixture of the points of view described above, sometimes favouring their interpretation as misunderstandings (Rowell, Dawson and Lyndon 1990), alternative conceptions (Clough and Driver 1986) or spontaneous reasoning (Viennot 1985). An interesting approach is that in which pupils' theoretical frameworks are seen to be related to forms of commonsense reasoning (Bliss, Ogborn and Whitelock 1989; Whitelock 1991).

In methodological terms the research in this area has been developed with data obtained via questionnaires given to groups of pupils from primary and/or secondary school. Some techniques for interviewing were also developed by some researchers (for example Gilbert, Watts and Osborne 1982). The analysis is often qualitative, describing the responses obtained, with some attempts to categorise them. With questionnaires in the form of tests the analysis is often in terms of the percentages of 'right' or 'wrong' answers. Usually the statistics applied are of the descriptive type.

Only more recently have multivariate exploratory methods in statistics been used with the purpose of finding possible underlying structures in the numerical data obtained (see for example Whitelock 1991; Mariani and Ogborn 1991).

Most researches in the area refer to other kinds of investigation in order to construct a theoretical framework. Such a framework can be used to try to understand pupils' ideas, to devise a pedagogical approach to the concepts under investigation, or also to provide some methodology. Often a reference is made to researches in developmental psychology and cognitive science, but also to the History and Philosophy of Science.

Often some reference is made to the work of Jean Piaget on conceptual development to provide with a rationale for techniques of pedagogical intervention (Driver and Easley 1978; Rowell 1984; Posner and Gertzog 1982). Some also refer to the work of Ausubel, proposing methodological and pedagogical techniques (Novak 1978; Finley 1985). It has being suggested that Piaget's theory of reasoning and concept development can be useful in developing a theoretical framework within which to understand the origin and structure of pupils' ideas in Science (Ogborn 1985, Whitelock 1991, Mariani and Ogborn 1990 and 1991).

Some recent work in the area of cognitive science has also been used in order to devise techniques for pedagogical intervention (diSessa 1982) and to suggest a theoretical framework in which to study pupils' ideas (Andersson 1986; Ogborn 1985; diSessa 1988).

Often references have been made to the History and Philosophy of Science with multi-level purposes: simply characterising pupils' ideas in relation to past ideas in Science, calling these ideas 'Aristotelian' for example (diSessa 1982); to reflect upon possibilities for pedagogical intervention (Posner, Strike, Hewson and Gertzog 1982) or looking for common patterns of reasoning in Science (Carey 1985; Mariani and Ogborn 1990 and 1991).

In the next Sections these areas of research and their relationships with research on alternative conceptions will be addressed .

1.3. Overview of research in the area of cognitive sciences

1.3.1. Introduction

Although the term 'cognitive science' began to appear in the early seventies this 'new' science reaches back to the Greeks in their search to "unravel the nature of human knowledge" (Gardner 1987). It can be defined as "a contemporary, empirically based effort to answer long-standing epistemological questions - particularly those concerned with the nature of knowledge" (Gardner 1987). Cognitive scientists draw from disciplines like philosophy, psychology, artificial intelligence, linguistics, anthropology and neuroscience - in fact any research discipline with an interest in human cognition (Aitkenhead and Slack 1985). It is possible to consider for example Noam Chomsky and Jean Piaget as being part of a 'first generation' of workers in cognitive science (Gardner 1987).

It is within this perspective of the cognitive sciences that the present Section will be developed. Starting with some relevant work in the area of developmental psychology it is intended to build up an overview of research in the genesis of thinking about the physical world which would be relevant to the understanding of pupils' ideas in Science.

For example in a Piagetian approach to reasoning the sensorimotor activity of a child is to be seen as the basis for the building up of logical relationships and representation of knowledge. Sensorimotor activity involves not only motor actions upon objects, such as moving objects around, but also the sensory experience which is necessarily linked to it, like seeing the object in a particular way. Piagetian schemas of action will always involve sensory and motor activity.

Touching, seeing, moving, stopping and so on can be considered, in this view, as essential activities with which to construct logical relationships between, and representation of, the experienced objects and events (see Piaget 1936).

Other important studies in this area of investigation are those performed by Vygotsky (Vygotsky 1986), and recently by Langer (Langer 1980 and 1986). Vygotsky believed that the 'interpsychological' relations become the 'intrapsychological' mental functions, and so associated the origins of thought to the acquisition of language. Langer however adopted a Piagetian framework and found that part-whole and means-ends transformations developed in action by young infants could be seen as basic to the construction of cognition even before the acquisition of language.

Following the discussion of some developmental studies of reasoning, a brief overview of studies of the representation of knowledge will be presented. Recently many different approaches to the issue of representation of knowledge have been tried , mainly in the areas of artificial intelligence and cognitive psychology. Much of the research in cognitive science nowadays is concerned with suitable forms of representing peoples' knowledge of the world (Rumelhart and Norman 1985; Johnson-Laird 1983; Schank and Abelson 1977).

Finally in this Section some relevant work in the area of Philosophy and History of Science will be briefly discussed. The studies of interest here are those concerning scientists' reasoning and the construction of knowledge in Science. These studies bring some interesting elements to the discussion of pupils' reasoning and construction of knowledge about the physical world. This possibility has already been investigated within a Piagetian framework for the construction of knowledge (Piaget and Garcia 1983). Other studies also suggest the use of the History of Science as a source of information about human reasoning (for example Gruber 1974 and 1981; Miller 1987).

These different areas of investigation will be related to each other and will provide the elements for developing a theoretical framework for the present research on commonsense reasoning about entities in Science.

1.3.2. Developmental studies on reasoning

For Piaget intelligence is adaptation (Piaget 1936). There is a continuity between biological processes and intelligence in the adaptation of the organism to the environment. In mental development, making an analogy with the adaptation of the species to the environment, there are invariant functions and variable adaptable structures. These invariant functions are related by Piaget to fundamental categories of thought inspired by Kantian categories, as can be seen in Figure 1.1.

Biological Functions		**Intellectual Functions**	**Categories of Thought**
	Organisation	Regulating Function	a. Totality X Relation (reciprocity) b. Ideal (end) X Value (means)
Adaptation	Assimilation	Implicating Function	a. Quality X Class b. Quantitative relation X Number
	Accommodation	Explicating Function	a. Object X Space b. Causality X Time

a. Static Categories b. Dynamic Categories

Figure 1.1. Piaget's account of Fundamental Categories of Thought.

The categories related to the organisation function regulate the other categories in the sense of maintaining their coherence, and attributing values to actions and logical operations.

Concerning the categories of thought related to the functions of assimilation (or adaptation of the environment to the subject) and accommodation (or adaptation of the subject to the environment), Piaget refers to the ones related to accommodation as the 'real' ones, in the sense of their being seen as the content (or reality) to be constructed with sensorimotor experience: they are causality, object, space and time. In Piaget's view these categories are related to the explicating function of intellect, conferring permanence to reality (static categories) and providing the reasons for the transformations (dynamic categories) in the physical world.

These 'real' categories are intrinsically related to the ones obtained with the function of assimilation or implication: there is always an interaction between an implication and the spatio-temporal data. So for example from one side classes and numbers could not be constructed without a connection with objects and their causal relationships, and no spatio-temporal structure would be possible without a logico-mathematical deduction.

In a subsequent work Piaget (Piaget 1937) tried to show how from actions the child progressively constructs the permanence of objects, together with the construction of causality, space and time. Piaget described how it is that at first just at the level of actions the child progressively constructs an understanding of the world. The acquisition of what can be called 'knowledge-in-action', or practical knowledge culminates in the first internal representation of an object which disappears, attributing permanence to it.

At the same time that the permanence of objects is acquired by the child, a notion of causality is acquired in the sense of being able to use actions or sequences of actions to obtain a desirable effect, or being able to understand what other people's actions can do to objects. Time and space are also being constructed with the progressive organisation of sequences of actions.

Piaget also suggests the presence of a 'protologic' in action , first described in detail in a recent work by Piaget and Garcia (Piaget and Garcia 1987). In the search for an object which disappeared the child may be right or wrong. If an action is not in itself right or wrong (or true or false) an 'implication' between actions can be true or false (Piaget and Garcia 1987). This makes it possible to look for psychogenetic roots of the construction of a 'natural' logic at a sensorimotor level.

Piaget and Garcia describe a logic which is called the logic of 'meaning'. An implication between actions is an implication between the meaning of these actions. The meaning is the result of an assimilation of the object by a schema, or of an interpretation of data and not pure observables. A schema in Piagetian terminology is that which can be generalised and repeatable in an action.

In Piaget's view the meanings of objects are subordinated to the meanings of the actions performed upon them : an object is *what you can do to it* (move it, stop it and so on) and *what it is made of,* in the second case referring to actions which build up or break up these objects, which Piaget relates to what he calls 'sub-logic' (Piaget and Inhelder 1948) of part and whole transformations. Such a logic deals with part-whole inclusions for single objects and "since they constitute objects sub-logic operations are accompanied by symbolic images (mental images or pictorial representations)" (Piaget and Inhelder 1948). Part-whole relationships would also include shared properties between objects (of being 'round' or having a 'mass' for example) (Johansson 1989).

Concerning actions, they have their own meaning in *what they make happen,* or by the effects they cause.

In this view the roots for the elaboration of meaning should be sought in early infancy. Action not language is at the heart of concept formation. With the beginnings of language, implications between actions will be followed by enunciates and there will be implication between these enunciates (Piaget and Garcia 1987).

For example the act of pushing may be later followed by the word 'push' or 'pushing' which will be understood in the child's mind in terms of the sequence of actions performed to push something (or in terms of a repeatable schema of 'pushing'). If a ball rolls as a consequence the child may say 'rolling' which can be understood in terms of the 'push' given . 'Pushing' and 'rolling' as actions and consequently enunciates can have their meanings associated by one implicating the other.

Objects like the 'ball' in the example above would also have their meaning associated with the actions (and later enunciates) of 'pushing' and 'rolling' meaning that a ball is something one can push and roll. Also for example actions like 'fitting' different objects or parts of objects (sub-logic of part-whole relationships) will be of extreme importance in the elaboration of the meaning of objects.

Another important study of the construction of meaning, but this time not appealing to actions but to the acquisition of language, is Vygotsky's work on the development of thought (Vygotsky 1986). In his study of the development of concepts he pays special attention to the use of words by children and adults. For him "words and other signs are those means that direct our mental operations, control their course, and channel them toward the solution of the problem confronting us" (Vygotsky 1986).

In the development of concepts Vygotsky distinguishes three basic phases in the child's and adult's construction of word meaning, which he studied empirically by proposing the categorisation of concrete objects to groups of people. In the first, word meaning denotes nothing more to the child than a "vague syncretic conglomeration of individual objects". The second phase on the way to concept formation comprises a type of thinking called 'thinking in complexes' leading to the formation of what he calls 'pseudoconcepts'. The third is related to a different possible root in the construction of concepts from that of complexes, basically by abstraction and generalisation, leading to the construction of what he calls 'potential concepts' (Vygotsky 1986). Vygotsky considers the second phase as a major phase in the construction of concepts and it will be described here in more detail.

In a 'complex' the bonds between the components of a set are concrete and factual. They can be of associative type, the bond between the objects of a set being of similarity, contrast or proximity for example. A complex can be like a 'collection', objects being together on the basis of some one trait in which they differ and consequently complementing one another, including some forms of functional grouping (for example cup, saucer and spoon). A collection can be seen as a grouping of objects "on the basis of their participation in the same practical operation " (Vygotsky 1986).

After 'collections' there is the 'chain complex', a dynamic, consecutive joining of individual links into a single chain, with meaning carried over from one link to the next (for example: first a set of triangular blocks until there is a blue triangular block and then blue blocks of any shape are added to the set and so on). The chain complex may be considered the purest form of thinking in complexes in the terms of Vygotsky.

There is also the so called 'diffuse complex', where even a remote similarity is enough to create a bond (for example: triangles and trapezoids and then squares; or yellow objects and then orange objects and so on). Complexes resulting from this kind of thinking are so indefinite as to be in fact limitless.

Finally there is the complex called a 'pseudoconcept'. In the experimental setting "the child produces a pseudoconcept every time he surrounds a sample with objects that could just as well have been assembled on the basis of an abstract concept" (for example only triangles or squares) (Vygotsky 1986). The pseudoconcept serves as a connecting link between thinking in complexes and thinking in concepts.

The notion of pseudoconcept is fundamental in Vygotsky's account of reasoning. A pseudoconcept is a unique, ambivalent, and contradictory form of the child's thinking. At the same time only the functional equivalence of concepts and pseudoconcepts ensures a successful dialogue between the child and the adult. For example the child and the adult can now talk about a certain shape, a triangle or a square, and understand each other.

From his experiments he concludes that "at the complex stage, word meaning as perceived by the child refers to the same objects that the adult has in mind, which ensures understanding between child and adult, except that the child thinks the same thing in a different way, by means of different mental operations" (Vygotsky 1986).

Complex formation also results in the fact that one word may in different situations have different or even opposite meanings, as long as there is some associative link between them. Complex formation also plays a role in explaining some facts in the history of languages and also in the thought of primitive societies (Vygotsky 1986).

Concerning the thought of adolescents and adults Vygotsky makes an important remark concerning the fact that thinking in 'complexes' is not exclusive to children: "Even after the adolescent has learned to produce concepts, he does not abandon the more elementary forms; they continue for a long time to operate, indeed to dominate, in many areas of his thinking...even adults often resort to thinking in complexes. Moreover, even conceptual thinking in adolescents and adults, insofar as it is involved in solving daily problems, does not advance beyond the level of pseudoconcepts" (Vygotsky 1986).

Most recent studies on categorisation and concept formation have faced a difficult task in trying to understand the way in which people decide whether an object belongs to a category or not. A criterion of similarity does not seem to be enough (Keil 1981; Murphy and Medin 1985; Medin, Wattenmaker and Hampson 1987; for a review in the area see Smith and Medin 1981).

Studies on the nature and formation of concepts have been the subject of different areas: Philosophy, Psychology, Linguistics and Artificial Intelligence (for example Wittgenstein 1953; Rosch 1978; Chomsky 1986; Lakoff 1987 and Jackendoff 1987). What concepts are for, the way children and adults categorise objects in the world, the learning of language and language structures, and the construction of meaning, are important issues in this respect.

Some developmental studies have tried to obtain more information about the way in which conceptual thought evolves by looking into the categorisations of young children before the acquisition of language (Langer 1980 and 1986; for other studies with a similar approach see Forman 1982). The subjects in Langer's studies are simply presented with small objects and their manipulations of these objects are recorded, all the procedures being nonverbal.

Langer has identified in object play certain schemes that he calls 'proto-operations', meaning that these actions have a logical form. For him the elements of cognition are constructed by infants during their first year: what he calls part-whole transformations are basic to constructing logico-mathematical cognition, and what he calls means-ends transformations are basic to constructing physical cognition.

The principal part-whole transformations he refers to are the uniting of objects into compositions of objects, the reuniting of compositions into derivative variants, the separating of compositions into sub-collections and the separating of compositions into related objects (Langer 1980 and 1986) .

Unlike part-whole transformations, means-ends transformations are generated by children when they are solving some goal, object or problem (for example when the subject propels one object with another, or one object is used to block and stop another object). Means-ends transformations vary depending upon whether infants construct causal (for example pushing something) or spatial dependencies (contact between things). For Langer the development of spatial functions parallels those of causality functions.

In Langer's view the development of logico-mathematical constructions becomes progressively necessary. A complementary assumption is that developing physical constructions become progressively contingent such that possible and impossible physical phenomena are progressively differentiated and co-ordinated. It follows that the roots of cognizing logical necessity and physical possibility and impossibility may be traced to the infant's elementary part-whole and means-ends transformations. In fact several genetic epistemological assumptions underpin these theoretical distinctions made by Langer between logico-mathematical and physical cognition (Piaget 1981 and 1983).

Also in his view symbolisation is not the hallmark of representation nor is language essential to the origins of representational cognition. Representation is formed by infants combining their elementary cognitions. In Langer's view linguistic development is not even necessary for conceptual development up to at least the age of 24 months.

Determining the initial and developing relations between language and thought is still a problem for all major cognitive developmental theories of thought (see Beilin 1975 and Mandler 1983 for reviews).

1.3.3. Recent studies on the representation of knowledge

For most cognitive Scientists it is almost impossible to imagine a cognitive system in which a system of representation would not play a central role. But among those for whom representation plays a central role in cognition there are still a number of controversies concerning the most adequate format to represent knowledge. Three major controversies are: the propositional-analogical controversy, the continuous-discrete controversy and the declarative-procedural controversy (Rumelhart and Norman 1985).

The propositional-analogical controversy is related to the possibility of having a representational system which corresponds as directly as possible to the real world, and to whether this form of representation (analogical) would be more desirable. It could reasonably be solved by assuming different levels at which the representational system operates (from the more abstract propositional forms to the more 'concrete' analogical forms). In this case the analogical representation can be generated by an underlying propositional format, making possible the generation of images.

The intermediary step between the propositional form and the generation of images could also be understood in terms of a mental model, as described by Johnson -Laird "... propositional representations are interpreted with respect to mental models " and images correspond to " views of the models: they represent the perceptible features of the corresponding real-world objects (...) .Models, like images, are highly specific" but " although a model must be specific, it does not follow that it cannot be used to represent a general class of entities. The interpretation of a specific model depends upon a variety of interpretative processes, and they may treat the model as no more than a representative sample from a larger set (...) "(Johnson-Laird 1983).

So Johnson -Laird proposes the existence of "at least three types of mental representation: propositional representations which are strings of symbols that correspond to natural language, mental models which are structural analogues of the world, and images, which are the perceptual correlates of models from a particular point of view (...). Mental models provide a basis for representing premises, and their manipulation makes it possible to reason without logic. The search for alternative interpretations, however, demands an independent representation of the premises, a representation that is propositional in form (...) I have assumed that descriptions are initially represented propositionally, i. e., by expressions in a mental language, and that the semantics of the mental language maps these propositional representations into mental models" (Johnson-Laird 1983).

The continuous-discrete controversy (of representing variables as continuous or discrete) parallels very closely the first one, as often the discrete format is associated with the propositional format and the continuous with the analogical format. But this is more likely to be a concern of research in Artificial Intelligence and not of particular relevance to the present study.

The declarative-procedural controversy is a controversy concerning the accessibility of the information stored in the mind. Declarative knowledge is knowledge about something while procedural knowledge is a knowledge about how to do something. We seem to have conscious access to declarative knowledge but not to procedural knowledge. Or one might say that in so far as procedural knowledge is not represented, it is available for use but not for thought.

Here a distinction between representation of procedures and procedural representation is necessary (Rumelhart and Norman 1985). The first is representable in the declarative format, which means that the same information can be viewed as data (declarative) or programme (procedural). In the second case it would be impossible to have access to knowledge structures, except to the output of the operations themselves. This form of representation operates at an inherent unconscious level concerning motor skills, overlearned procedures and unconscious presuppositions present in daily thinking (Rumelhart and Norman 1985). This controversy is far from being solved.

Most of the work in the area has been dedicated to the development of propositional forms of representation, a important step being taken with the development of semantic networks (Quillian 1968). In a semantic network knowledge is represented in a graph structure in which the nodes represent concepts interrelated by relations to other nodes or concepts. The meaning of a concept in this case is given by the pattern of relationships in which it participates. One important application of the semantic network has been the work of Schank in the area of Artificial Intelligence (Schank 1975; Schank and Abelson 1977).

In Schank's early work there is a set of conceptual primitives which are supposed to represent the kind of knowledge underlying language use. Language is regarded as a 'multi-leveled system' and understanding is "the process of mapping linear strings of words into well formed conceptual structures" defined as "a network of concepts" and "the conceptual level is considered to underlie language" and " it is also considered to be apart from language" (Schank 1975).

Schank introduces categories called PP (a conceptual nominal restricted to physical objects); PA (a state which together with a value describes PP); ACT (conceptualisations of mental ACTs); LOC (coordinates); T (time); AA (modification of an ACT) and VAL (value of a state).

Conceptualisations will consist for example of an actor (an animate PP), an ACT, an object (a PP for example) and an instrument (conceptualisation). Eleven possible different ACTs are proposed: ATRANS (transfers an abstract relationship); PTRANS (transfer of a physical location), PROPEL (application of a physical force to an object), MOVE (movement of a body part), GRASP, INGEST, EXPEL, MTRANS (transfer of mental information), MBUILD (construction of new information), SPEAK and ATTEND.

Schank's studies led him to the description of what are called scripts, considered to be large units with which the representational system operates (Schank and Abelson 1977). Other studies in the area have proposed schemas (Rumelhart and Ortony 1977) and frames (Minsky 1975) as being these large units.

Concerning schemas, despite the origin of the term in early Piagetian studies (Piaget 1936) there are no strong similarities with the use made of it in recent research by Rumelhart and Ortony (1977).

These large units can be seen as models of the outside world, suggesting a possible comparison between schemas and mental models (Brewer 1987). The difference is that schemas are multi-leveled representational structures and can be said to represent whatever is known, from objects to events and sequence of events, while mental models have a more restricted definition of being a necessary interface between propositional representations and images generated for particular objects, events or sequences of events.

These studies will be related to the ones described in the preceding Sections after a brief discussion of research on scientific reasoning and the construction of concepts in Science as opposed to the study of people's ordinary daily thinking.

1.3.4. Scientific reasoning in the Philosophy and History of Science

The idea that a fruitful way to come to an understanding of concept formation in Science is by starting from an analysis of the available data provided by the reflection of scientists themselves upon their own field of knowledge - with an analysis of the papers, lectures, notebooks, etc. of scientists - and a subsequent analysis of the cognitive processes involved in concept formation with the help of cognitive psychology- is shared by many researchers in the area of history and Philosophy of science (for example Miller 1987; Holton 1973, 1978; Nersessian 1984; Kuhn 1962; Gruber 1974 and 1981).

Miller (Miller 1987), for example, analysing the thinking of great scientists like Poincaré and Einstein, considers imagery as being a fundamental tool in the construction of new concepts. The use of physical analogies is seen as fundamental by Nersessian (Nersessiann 1984). Gruber refers to insights and the use of metaphors in Darwin's construction of the Theory of Evolution (Gruber 1974), but he also considers fruitful the use of the notion of schemas and repetition - as they appear in the Piagetian studies - to understand scientists' thoughts (Gruber 1983).

One of the aspects that has given interest to the study of scientific discoveries is the recognition that human reasoning involves additional modes of reasoning other than deductive logic and induction (Bechtel 1988), like the use of imagery in thinking (Miller 1987) . Because scientific reasoning is simply an extension of human reasoning, strategies which violate the norms of formal logic should figure also in Science.

One example of the power of imagery in scientific thought is Hertz's rejection of the use of the concept of 'force' as a fundamental entity in his "Principles of Mechanics" (Hertz 1899). His rejection of the concept had its justification in the fact that Hertz felt that the concept of force generated conflicting images when explaining an event, and as such could not be attributed any reality. Also for Boltzmann (McGuiness 1974) "all our ideas and concepts are only internal mental pictures".

From a different perspective another important contribution to an analysis of scientific reasoning is Harré's defence of Realism (Harré 1986). In his defence of Realism Harré develops an interesting analysis of concept and theory construction in Science, showing the important role played by analogical thinking. Harré also considers scientific explanations to be essentially causal in nature and with a basis in 'causal powers' attributed to substances in the physical world (Harré and Madden 1975).

From a constructivist perspective the genesis of ideas in the History of science has also been the subject of studies by Piaget and Garcia (Piaget and Garcia 1983), being termed in their work the 'sociogenesis' of knowledge as opposed to the psychogenesis of knowledge in early childhood.

The term sociogenesis refers to "a certain conception of the world...which has a direct influence on the content of Science, i.e. the way in which concepts are developed and theories are shaped" (Garcia 1987).

Scientists developing scientific theories in different times and places in history have as a background the sort of beliefs existent in their societies concerning the nature of things under investigation. Garcia for example describes the way in which different philosophical positions in France, Germany and Britain in the last Century led to the evolution of different complementary ideas in thermodynamics (Garcia 1987) .

These studies in the area of Philosophy and History of Science throw some light on the way in which the forms of reasoning which are common to all human individuals led to the construction of scientific concepts and theories, which are often seen as being beyond the reach of comprehension of the non-expert.

1.4. Possible links between the research on alternative conceptions and the research on the cognitive sciences

The ways in which the different areas of research presented in this Chapter can be interrelated, from the Philosophy of Science to studies in the area of pupil's alternative conceptions in Science, will be discussed in this Section.

The possible links are various. In fact most studies in the area of alternative conceptions are interdisciplinary. Very often the use of resources from other areas of research aim at the devising of pedagogical strategies, and only more recently have these resources been used more systematically, aiming at the construction of a theoretical framework in which pupil's ideas could be explained and predicted (see for example Ogborn 1985; Andersson 1986).

The use of developmental psychology is more or less restricted to the use of some Piagetian studies related to the operational stages of development (see Driver and Easley 1978) and recently Piaget's theory of equilibration (see Rowell and Dawson 1985). Piagetian studies of the construction of reality were recently used in order to construct a theoretical framework in which to explore pupil's ideas in Science (Whitelock 1991; Mariani and Ogborn 1990 and 1991).

Philosophy and history of Science have played quite a fundamental role in the discussion of alternative conceptions, but the relationships are still very unclear. It is quite frequent for researchers to refer to alternative conceptions as being Aristotelian, or to assert that pupil's have conceptions which look like concepts which were used in the history of science like the concepts of 'caloric' for heat and of 'impetus' for force (see for example Carey and Wiser 1983).

Recent studies in cognitive psychology have been very rarely used in the area of spontaneous conceptions. For example some reference has been made to the notion of 'mental models' current in use in the area of research on representation of knowledge (Ogborn 1985) or to 'prototypes' current in use in the area of research on categorisation (Guidoni 1985).

In the same way that the research in the area of alternative conceptions has been related to these other areas of investigation, there are also interesting relationships between these other areas of research.

Studies in the area of the cognitive sciences and also developmental psychology have been used by researches in the area of Philosophy and History of science (for example Miller 1987). This relationship is made possible by approaching scientific reasoning as a form of reasoning which would use the same resources available to everyday ordinary reasoning. Developmental studies have also been related to studies in artificial intelligence (Schank 1975). This is done with the assumption that actions for example are the source of later representations. Recent researches in cognitive psychology and artificial intelligence are very close to one another making possible a rich interchange of ideas (for example Johnson-Laird and Byrne 1991 on "Deduction"). This is due to the fact that simulations in the computer are considered to be a very powerful tool in the modelling of cognition.

1.5. Relationship with the present research

It will be assumed as a point of departure that pupils use their own commonsense knowledge of the physical world in trying to understand scientific concepts. This commonsense knowledge is supported by commonsense forms of reasoning about objects and events.

These forms of commonsense reasoning will be assumed to have their origin in early infancy, thus developmental studies will be used to provide information about the way in which such forms of reasoning could have developed. The fundamental hypothesis will be that actions provide the elements with which to develop these forms of reasoning about objects and events.

Concept development will be taken to have its roots in the sensorimotor experience of the world following a Piagetian position (Piaget 1937). This hypothesis will not exclude a possible relation of concept formation and language (Vygotsky 1986). In fact there are various points of agreement between both these views. Piaget himself pointed out possible areas of agreement (Piaget 1962). Vygotsky's disagreement with the Piagetian view on the relationship between thought and language refers basically to the Piagetian notion of 'egocentrism', which Piaget himself accepted as a pertinent critique of his study of thought and language (Piaget 1923).

In fact many of Vygotsky's findings on concept formation are not in contradiction with the idea that actions, in the Piagetian sense, play a fundamental role in the construction of concepts even before the acquisition of language. One could imagine that the existence of 'complexes' for example rather than 'concepts' in people's mind could have some relationship with the beginnings of the construction of meaning relying upon actions even before the acquisition of language.

For example if a child puts in the same group a fork, a plate and a glass it could be explained by the fact that all these objects have a common meaning given by the action of 'eating'.

Considering that commonsense reasoning is fundamentally based upon actions performed on objects, so that the tools for the construction of concepts are elaborated even before the acquisition of language, it follows that the representation of commonsense knowledge can constitute basically the images of these objects and events in the mind. As discussed in Section 1.3.3. this fact does not exclude the possibility of the existence of a multi-leveled system of representation operating for the construction of these images.

If images are such fundamental tools for reasoning, part-whole relationships could be seen as constituting a fundamental logic with which to manipulate these images in the mind. Langer's studies are particularly relevant in showing that part-whole relationships play a fundamental role in the development of reasoning (Langer 1980 and 1986).

Studies in the History and Philosophy of Science will make it possible to relate commonsense reasoning about entities in Science to the ways in which the scientists themselves reflect upon entities, constructing new ones for example from a substratum of commonsense ideas about objects and events.

1.6. The theoretical framework

It is on the basis of Piagetian studies which show how from action and movement the child constructs fundamental categories of thought about reality that the following diagram was constructed (Mariani and Ogborn 1990):

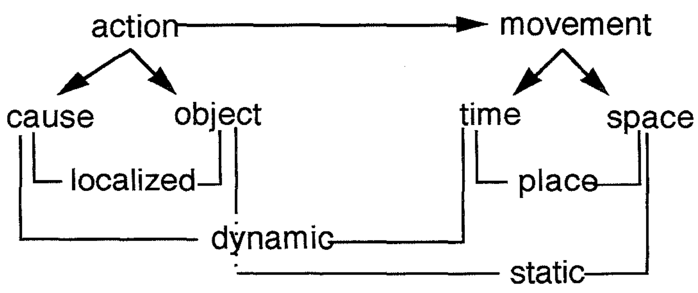


Figure 1.2. Diagram showing the relationships between action and movement and the fundamental categories of thought about reality.

This diagram shows the psychogenesis of fundamental ontological categories of thought. These categories of cause, object, time and space are built out of action and movement. It shows that these categories are not dissociated: that a cause expects an object to act upon, that an object can be acted on and move, that time divides causes from effects and that space contains objects (Mariani and Ogborn 1990).

Assuming that these ontological categories are constructed by means of actions much follows. Objects being constructed by actions, their meaning will be subordinated to the meaning of the actions themselves (Piaget and Garcia 1987). Objects will be *what you can do to them* and *what they are made of*, the meaning being that which can be said or thought of objects.

The first meaning is constructed by the manipulation of objects (for example moving it) and the second is related to constructive actions (for example putting pieces together), later internalised as operations. With a basis in Langer's work (Langer 1980) it is also possible to call these manipulations means-ends (for example pushing an object) and part-whole transformations (the uniting and separating of objects; objects can also be made from pieces or separated into pieces).

the same despite actions (Mariani and Ogborn 1990). This permanence is first constructed in early infancy and it is considered to mark the beginnings of the representation of objects in the mind (Piaget 1937). Objects can be considered to be that which exists independently of our own will. They can also be seen as constituting the fundamental substratum with which to construct representations in the mind.

Actions have their meaning in *what they make happen*, the effects (or movements) they cause to objects. Movements can be seen as constituting the 'prototypes' for change in the mind.

It is the progressive consciousness of the self by children in early infancy, with their desires and motivations, which results in the first construction of causes in the sensorimotor period (Piaget 1937). If there is an event it is because of a previous desire for it to happen: first the child's desire, and progressively other people's (or even things') desires. The construction of causes is intrinsically linked to the appearance of conscious activity.

Time and space are also categories of thought to be constructed by means of actions. The construction of space follows in general lines the construction of objects, both being considered static categories (Piaget 1936), but with space being continuous and objects being discrete. The substratum for the construction of a representation of space can be sought in part-whole transformations with objects. The construction of time follows that of causes, both being dynamic categories. The roots for its representation can be found in the analysis of means-ends transformations.

It is then to be expected that the representation of objects and space and of causes and time will probably be closely interrelated, the representation of space and time requiring further abstractions (presence in the absence of objects and desires).

But while objects can be seen to constitute that which is external or real, time will be seen as that which is acting in the mind (by being abstracted from actions); while causes constitute the desire to change things in the world, space will be that which is absolutely passive (by being abstracted from objects).

The fundamental hypothesis assumed is that commonsense reasoning draws from the diagram (Figure 1) the essential relationships between action and fundamental ontological categories.

Actions will provide the elements with which to conceptualise the physical world, by providing the meanings to be attached to objects and events. Concept formation will be the result of the intersection of possible actions performed on the objects. These possible actions are determined by the way in which a new object, and later a new concept, are related to the fundamental categories.

For example space can be conceptualised by means of different actions: in fact there is not a lot you can do to space, but you can for example fill it with objects. This means that space is where objects can be put inside. Suppose now that a new scientific entity is introduced to a child, a field for example, and that this entity is of that kind in which objects can be put inside. The meaning generated by this action is then shared between space and field. But a field will be also related to other actions, like being able to change things in the world, and this will result in it sharing some other meanings with causes. Its conceptualisation will be spatial and also causal. In fact each new entity can have an unique conceptualisation in this process.

At this level of analysis the studies conducted by Vygotsky on concept formation will be of fundamental importance (Vygotsky 1986). Concept formation in Science seems to be a complicated matter in view of the studies in the area of alternative conceptions (see Section 1.2). Vygotsky's identification of 'complexes' in people's minds, and consequently the notion of 'pseudo-concepts' replacing 'concepts', is of particular interest.

The conceptualisation of an entity would require the use of the subject's ability to imagine it and manipulate it mentally in order to generate meanings, but at the same time being able to relate it to other entities or events with which to share some meanings.

In this framework the problem of investigating commonsense reasoning about entities in Science can then be reduced to that of investigating if it is possible to describe pupils' conceptualisations in terms of the meanings generated by actions performed upon objects and also to investigate how these actions relate to the fundamental categories of object, cause, space and time.

In summary the fundamental research questions to be answered are:

1. Would it be possible to find a description of people's conceptualisations of entities in Science in terms of the 'meanings' attributed to entities with a basis in actions?

2. How would these actions relate to the fundamental categories of thought presented in figure 1.2?

3. If such a description is possible what would be the implications for the understanding of commonsense reasoning in Science ?

The empirical work designed for this purpose will be described in the next Chapter.

1.7. Conclusion

In this Chapter a theoretical framework was developed in which to investigate pupil's commonsense reasoning about entities in Science.

This framework was basically constructed with a basis in some studies in Developmental Psychology concerning the construction of reality (Piaget 1937) and with some reference to concept and word formation (Vygotsky 1986). Some auxiliary hypotheses were also extracted from works in the area of cognitive science (Johnson-Laird 1983).

This framework reduces the problem of studying pupil's commonsense reasoning about entities in Science to looking into the way in which actions are used in the construction of concepts, and also the way in which these conceptualisations refer to fundamental ontological categories.

Chapter 2 : The design of the empirical research

2.1. Introduction

In this Chapter it is intended to give an account of the way in which the theoretical framework was used to develop the empirical design of the research.

Developmental studies of reasoning, as discussed in the previous Chapter, were used as a starting point, particularly in what concerns the role of actions in the construction of scientific concepts. In a Piagetian framework the actions performed upon objects in early childhood provide the elements for future conceptualisations, by attributing meanings to objects and actions (Piaget 1937, Piaget and Garcia 1987). The way in which meanings are later attributed to words is the object of study of quite a lot of empirical research in the area of developmental psychology (see for example Smith and Medin 1981; Clark 1983; Hoffmann 1982; Rosch 1978). Of particular importance are Vygotsky's studies of the relationship of thought and language (Vygotsky 1986).

The empirical work will focus on trying to describe people's commonsense reasoning about entities in Science in terms of actions and to relate these actions to some fundamental categories of thought as described by Piaget (Piaget 1937). At the same time it is necessary to investigate the way in which actions are used to provide meanings, first for objects and actions and later for the conceptualisations of scientific entities.

The choice of the methodology to be used to investigate these issues starts from a view similar to that of some previous work on commonsense reasoning in Science (Whitelock 1991). The methodology basically assumes that people's ordinary daily 'commonsense' reasoning is not the object of reflection by the individual and as such is not easily directly accessible by questioning. At the same time it is assumed that these ordinary forms of reasoning present a number of regularities shared by groups of individuals.

These two assumptions lead to the use of a methodology in which very simple and immediate questions are asked to individuals, and in which there is a search for regularities in the data obtained from groups of individuals. In this search for regularities the data obtained is reduced to a certain number of fundamental factors or dimensions.

In the next Section this empirical approach will be developed for the purpose of presenting some of the initial data obtained for this research. The initial findings will be described in Section 2.3. These initial findings then contribute to the design of the main study presented in Section 2.4 followed by some conclusions.

2.2. The general conception

The general conception of the empirical study has its roots in a previous work on conservation (Mariani and Ogborn 1990; see also Appendix D.1). In this work some of the theoretical ideas which support the present research were developed and an empirical study was conducted in a way which inspired the present study.

In the paper cited above the objective was to describe pupils' ideas of conservation. Six different questions about conservation (Does it last forever? Can it be created or destroyed? and so on) were asked about 32 different concrete and abstract objects (wood, energy, car, and so on). The subjects were Italian 14-17 year-old students.

It was expected that some pattern of responses would appear for a group of pupils which would identify ways of thinking about conservation. A way to look for a pattern in the answers obtained is the use of multivariate techniques in order to find underlying factors or dimensions with which to reduce the amount of information obtained. In this case factor analysis was used (see for example Everitt and Dunn 1983).

Since there were two factors it was possible to use a bidimensional space in which to describe the information obtained. The two underlying factors were: one interpreted as being related to permanence or conservation and the other to sources of creative power. Entities with a high score on the factor related to conservation were for example time, atomic particles, space, energy and movement. All of them could be related to some rules of conservation found in a qualitative analysis of the way the students explained their answers: objects out of the reach of actions or objects which can be kept out of the reach of actions; objects which can still be identified in the course of actions. The entities with a high score on the other factor were the Sun, energy and plant for example. These are entities considered to be producing something out of nothing.

Daily concrete objects like a clock, a car or a radio do not score positively on these factors, basically by being easily accessible to actions and using external power given to them. Energy appeared to be an entity which had both creationist power and also was conserved.

These results led to the construction of a systemic network (see Bliss, Monk and Ogborn 1983) first presented in the cited paper (Mariani and Ogborn 1990). This network can be seen in figure 2.1.

In this network an attempt is made to relate the way in which one thinks about entities in Science to actions performed upon them. It was from this network that a set of direct questions were initially extracted to elicit the way in which people reason about entities in Science. These questions were such as for example: Can you touch it? Can you destroy it?

The empirical problem was which and how many questions to ask and how to reduce the amount of information obtained in this way. Three different ways of thinking about an entity were then extracted from Piagetian studies on reasoning (Piaget and Garcia 1987): an entity is "what you can do to it, what it can do to you and what it is made of " (Mariani and Ogborn 1990 and 1991).

It would be desirable to have a set of questions for each of these three aspects of thinking and a first set of 66 questions was used in a

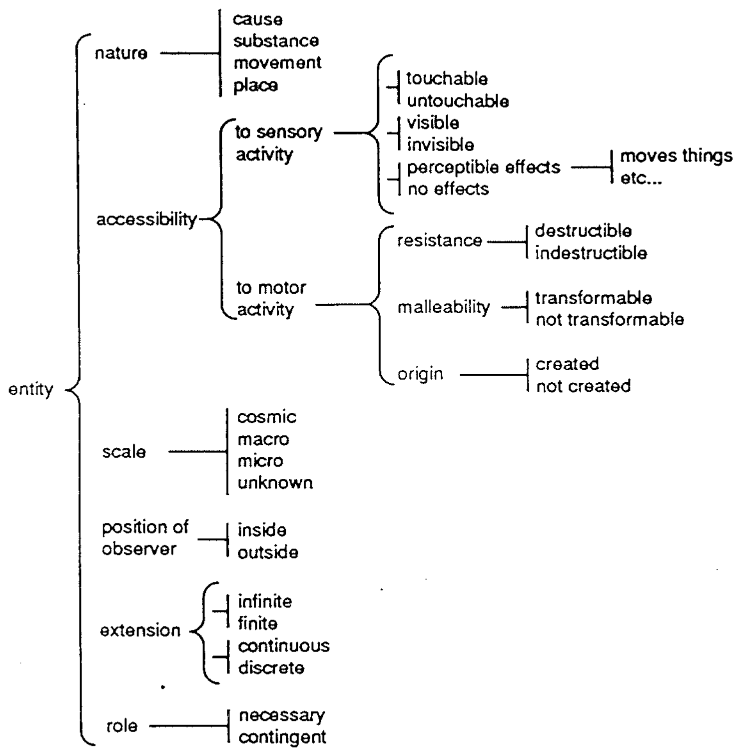


Figure 2.1. Network constructed for basic ontology.

published pilot study (Mariani and Ogborn 1991; see also Appendix D.2). They can be seen in table 2.1. These questions can be interpreted as being possible 'features' attributed to entities in Science.

The questions all require a yes/no form of answer for each entity asked about. A questionnaire was thought to be a convenient way in which to ask such questions to a group of pupils (See the form of the questionnaire in Appendix A). Being a test it could be quickly answered for a large number of questions asked.

The results of this pilot study will be discussed in the next Section.

2.3. First results

A questionnaire designed in the way shown in Appendix A was given to a group of 38 Brazilian 16-18 year-old students. The frequency of 'yes' responses obtained can be seen in Appendix B.

Again some method of data reduction was necessary. A possible way of looking for regularities in the data obtained would be to display all the information obtained in relation to a small number of factors or dimensions. Obviously in this kind of analysis the aim is to reduce as much as possible the amount of information obtained to just a minimum number of factors or dimensions (see Everitt and Dunn 1983; O'Muircheartaigh and Payne 1977).

The ideal number of factors or dimensions are determined firstly by the amount of variation in the data explained by the use of a reduced number of factors. Different criteria are suggested to decide this number. For example in factor analysis there are various possibilities: retain only the factors with eigenvalues greater than unity or the number of factors corresponding to the point at which the eigenvalues begin to form an horizontal line in a graph and so on (Everitt and Dunn 1983).

When there is no clear cut-off as suggested above (for example, factors with eigenvalues very close to one or no straight lines in the plot of eigenvalues) criteria provided by the researcher have to be used to

Main features

What it is like:

1. like a kind of gas
2. like particles
3. like a kind of a fluid
4. like a kind of a solid
5. microscopic
6. macroscopic
7. of unknown dimension
8. immaterial
9. has real existence
10. only exists in our mind
11. like a kind of force
12. like a kind of place
13. like a kind of wave
14. it is everywhere
15. it is nowhere
16. can be localized in a certain place
17. it is only movement

What it can do:

18. acts by contact
19. acts at distance
20. acts by itself
21. destroys things
22. transforms things
23. creates things
24. transfers things from one place to another
25. causes movement
26. it is the reason for everything that happens
27. acts under the control of something else
28. distributes by itself
29. concentrates by itself
30. multiplies by itself
31. exists without acting
32. appears and disappears

What can be done to it:

33. see it
34. see through it
35. touch it
36. touch through it
37. hear it
38. hear through it
39. feel it
40. create it
41. destroy it
42. transform it
43. transfer it
44. concentrate it
45. disperse it
46. stop it
47. conserve it
48. move things inside it
49. see its effects

Added features

you can treat it as:

1. a gas
2. a fluid
3. a solid
4. particles
5. microscopic
6. macroscopic
7. a force
8. a place
9. real
10. imaginary
11. movement
12. waves

you can use it to:

13. transform things
14. conserve things
15. move things
16. create things
17. destroy things

Table 2.1. *Ontological features used in the questionnaires.*

include or remove one extra factor. In this case the interpretability of these factors will also play a role.

Various techniques were applied to the data obtained in the present study : factor analysis, principal component analysis, cluster analysis and multidimensional scaling (for a description of these techniques see Everitt and Dunn 1983; Everitt 1974; Child 1970; O'Muircheartaigh and Payne 1977). It is in fact suggested that all these techniques should be used together as a way to explore possible structures present in the data, it being generally the case that some of the techniques will shown to be more suitable in relation to the kind of data collected and the purpose of the researcher. Also, if different techniques give similar results, confidence in the results is increased.

In the case of having 66 features for which correlations will be extracted in order to uncover some structure present in the data collected it was the case that factors could be particularly difficult to interpret. For example bipolar factors, with some variables having positive loadings and others negative loadings, could be of difficult interpretation (see for example Everitt and Dunn 1983).

Multidimensional scaling seemed very suitable for the sort of data collected in this study. It not only allows the rotation, reflection and inversion of the dimensions obtained, in order to facilitate the interpretation of the space, but it also allows the direct comparison between spaces obtained for different groups of people. Also in the present work, the space was generated only using distances ordinally and so making fewer assumptions about the distribution of the data.

Thus in the multidimensional scaling, the correlations between features were transformed into ordinal distances between these features in an hypothetical space to be tentatively generated. For example it is possible to try to fit all these features, with their respective distances between each other, into a bidimensional space. But there is a way to measure to what extent this space is able to represent all the information given.

For example suppose the distances introduced are the distances between the points of a spherical surface. In a bidimensional space this surface will be in a sense 'squashed'. In a three-dimensional space these distances would be perfectly represented. That will be so for any other high-order space one might try. So there a sort of measure of the minimum dimensionality necessary for the data not to be 'squashed'. This measure is called 'stress' (a good fit would require a stress between 0.05 and 0.10). Formally, the stress is a normalised sum of squares of differences between fitted and empirical distances.

Taking the correlations between pairs of the 66 features across nine fundamental concepts in Science (I.e. force, energy, space, time, sound, light, movement, heat and matter), if the frequencies of 'yes' responses to a pair of features are highly correlated, these features can be regarded as being 'close' to one another in a hypothetical space. To investigate the space, the matrix of correlations was converted into distances (1-correlation) and subjected to multidimensional scaling, using ALSCAL.

The multidimensional scaling procedure attempts to locate the features in an n-dimensional space, so that the distances between them in this space reproduce ordinally the distances between the features derived from their inter-correlation. The dimensionality of the space is controlled by the user.

It turned out that a scree plot of the stresses for different numbers of dimensions suggested four dimensions (stresses were 0.25 for two dimensions; 0.15 for three dimensions; 0.07 for four dimensions and 0.05 for five dimensions). The coordinates of the 66 features in this four dimensional space can be seen in Appendix C.

The next step is to try to give an interpretation to the space obtained. In figure 2.2 it is possible to take a first look into the way in which the features were distributed in this space. It is important to remember that there is no need to keep the dimensions in the way they are generated, and to make interpretation easier it is always possible to rotate, for example, these dimensions to a more convenient position.

Highly positively scored on dimension 1 are for example the features: exist without acting, like a solid, can touch it, can see it. Highly negative are for example: immaterial, act at distance, see effects, like a force.

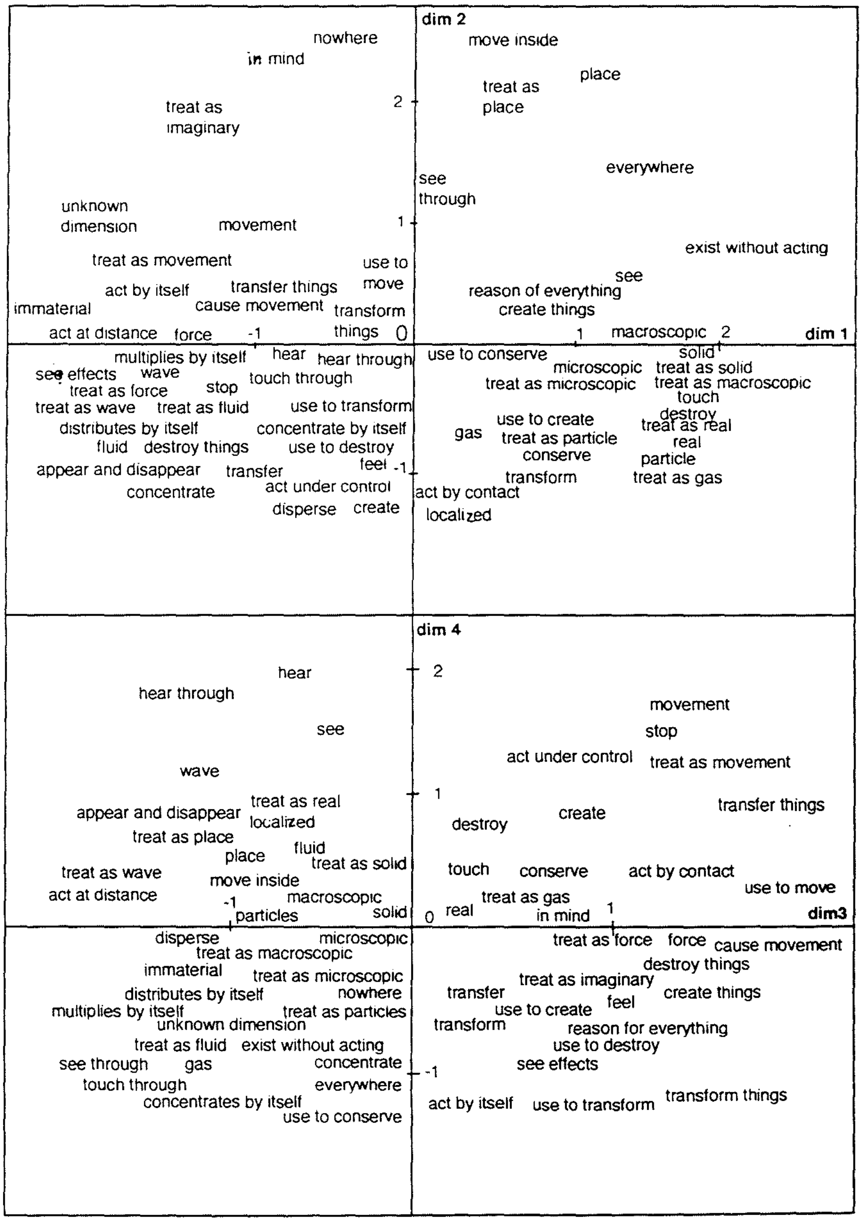


Figure 2.2. *Four-dimensional space obtained with 66 features.*

Highly positively scored on dimension 2 are for example: can move inside, like a place, it is nowhere, it is in the mind. Highly negative are for example: localized, can create it, act by contact, can disperse it.

Highly positive on dimension 3 are for example: can use to move, can transfer things, can cause movement, act by contact. Highly negative are for example: treat as wave, act at distance, can disperse it, immaterial.

Highly positive on dimension 4 are for example: can hear, can see, like movement, can stop it. Highly negative are for example: use to conserve, act by itself, use to transform, concentrates by itself.

It is possible at this level to try to give an interpretation, but it is desirable to try some more techniques before deciding the best interpretation. One possibility is to try to locate the entities in the space. It is reasonable to imagine these entities as represented by vectors in this space pointing to the region in which the features there located are the ones which better characterise these entities with a high proportion of yes answers (for example the vector 'space' pointing towards the region where the feature 'place' is located).

The location of these vectors was found by averaging the coordinates of all features, weighting each with the fraction of 'yes' responses on the concept, for that feature. Figure 2.3 summarises the results showing all the nine vectors together.

A first look at this result suggests that dimensions 1 and 2 split quite clearly time, space, matter and not the other entities which are very much constrained to a certain area; and that these other entities are split in dimensions 3 and 4, time, space and matter being very unclearly related to these dimensions 3 and 4 (determined by the sizes of the vectors).

An attempt at interpretation of the space with the use of the vectors representing the entities and the location of the features can be seen in figure 2.4. The interpretation was made in a way in which the entities, features of these entities and dimensions will have consistent descriptions with one another.

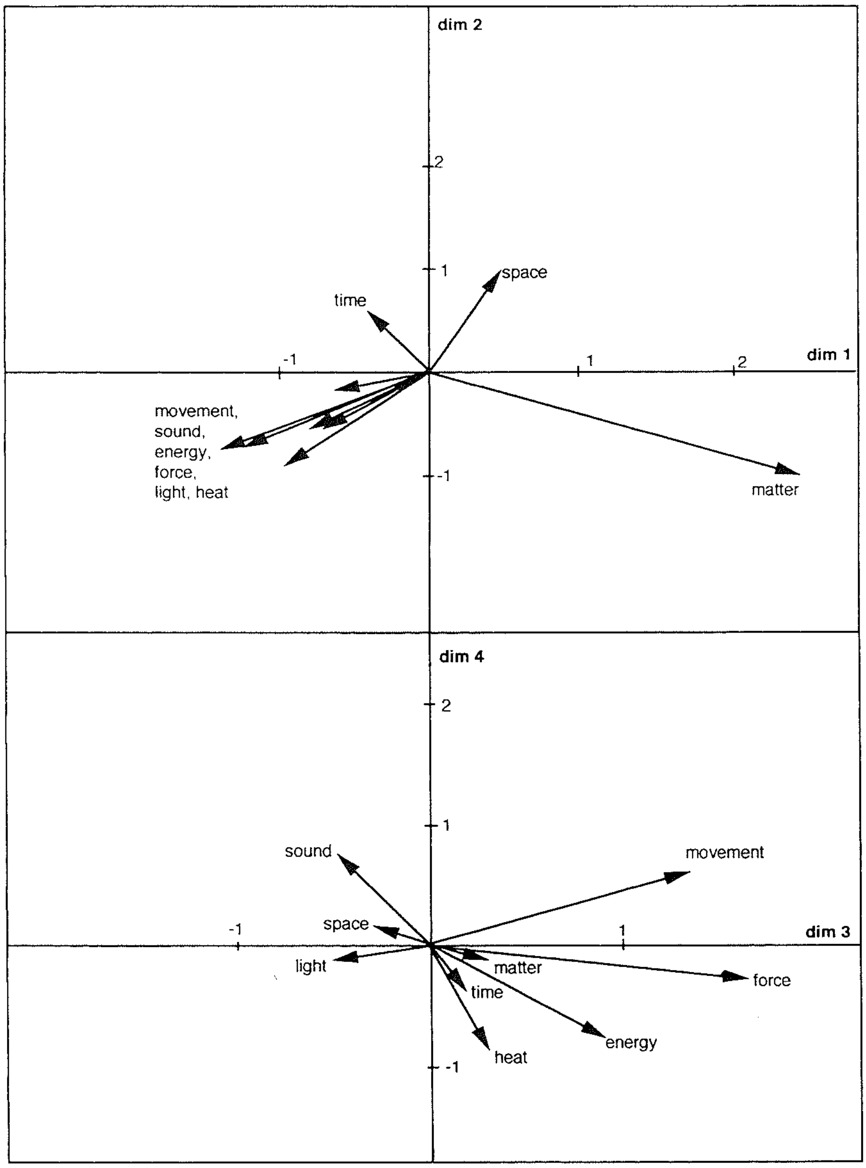


Figure 2.3. *Entities in the four-dimensional space obtained with 66 features.*

The first dimension is related to the distinction static-dynamic. Features characteristic of something static are for example: it exists without acting, like solid, can touch it, can see it. Entities considered to be rather static are space and matter. Features characteristic of something dynamic are for example: immaterial, act at distance, can see effects, act by itself. Entities considered to be rather dynamic are all the other seven entities: time, movement, force, energy, heat, light and sound.

The second dimension is related to the distinction place-localized. Features characteristic of something like a place are for example: it is nowhere, can move inside it, like a place, exists only in the mind. Entities considered to be rather like place are time and space. Features of something localized are for example : can create it, it is localized, act by contact, can disperse it. Entities considered to be rather located are: matter, movement, force, sound, light, heat and energy.

The third dimension is related to the distinction action-immaterial substance, or more abstractly 'discrete'-'continuous' activity. Features characteristic of something like an action are for example: can use to move, can transfer things, can cause movement, act by contact. Entities considered to be rather like an action are: movement, force, energy and heat. Features characteristic of something like an immaterial substance are for example: treat as wave, act at distance, can disperse it, immaterial. Entities considered to be rather like an immaterial substance are sound, light and maybe space.

The fourth dimension is related to the distinction motion-cause. Features characteristic of something like motion are for example: can hear, can see, like movement, can stop it. Entities considered to be rather like motion are movement and sound. Features of something like a cause are for example: use to conserve, act by itself, use to transform, concentrates by itself. Entities considered to be rather like a cause are heat, energy and maybe force and light.

The interpretation of the space can be further enriched by the use of cluster analysis, clustering the points in the space. Some of the features seemed to form groups of features which are interrelated. A complete

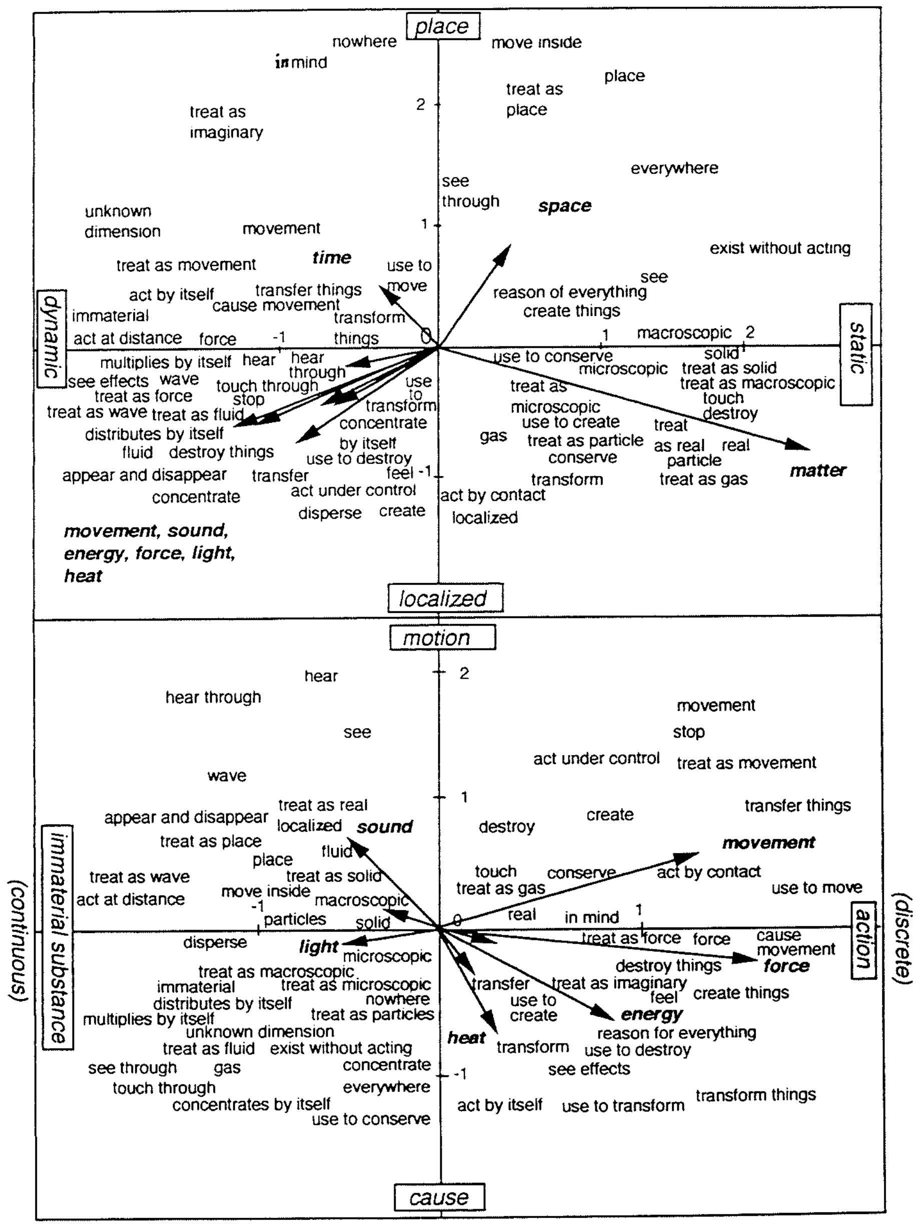


Figure 2.4. *Tentative interpretation of the four-dimensional space.*

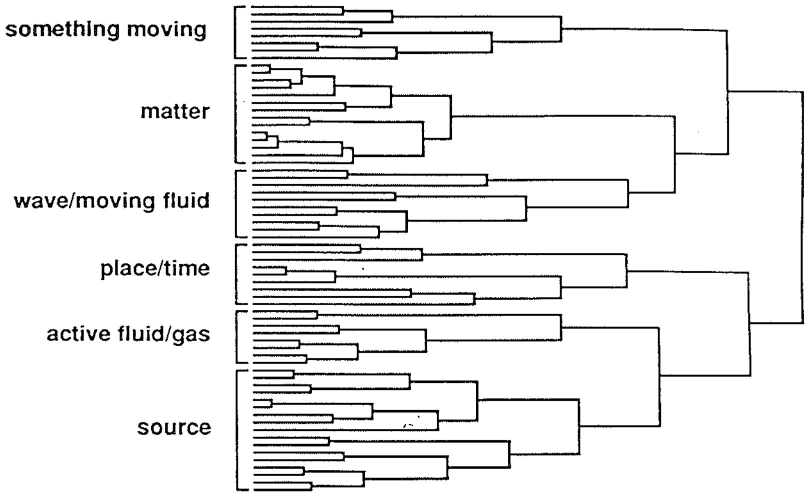
linkage method was used (see Everitt 1977 on cluster analysis techniques), clustering the coordinates of the features in the space. The clusters obtained can be seen in figure 2.5. Their help in the interpretation of the space obtained can be seen in figure 2.6.

These clusters of features can most easily be used to characterise the entities which are located mainly in the diagonals of the space. The cluster of features related to 'something moving' apply very well to movement; the cluster of features related to 'matter' clearly define it; the 'moving fluid/wave' cluster characterise sound; the 'place/time' cluster characterise both space and time; the 'active fluid/gas' characterises light; the 'source' cluster characterises energy, heat and force.

In figure 2.6 it is possible to see the distribution of these clusters in the space obtained. Only the clusters of features related to place/time and matter are separated in the first two dimensions, place/time being associated with positive values in dimension 1 and matter with negative values in both dimension 1 and 2, contributing to the interpretation of the diagonals in the space of the first two dimensions. The other four clusters will be separated in dimensions 3 and 4, each one in a different quadrant also contributing to the interpretation of the diagonals.

It is important to notice that in this space, which one could call 'ontological space', entities can be attributed features which fall in opposite locations, leading to the view of an entity as rather one thing or rather another, giving a complex conceptualisation of an entity. In figure 2.7 it is possible to see to what extent these entities are to be considered as complex in their characterisation. It shows the distribution in ontological space of those features with 'yes' answers in the upper quartile).

In figure 2.7 it is possible to see how the features which better characterise each entity are spread in the space. Movement is mostly seen as dynamic, but has a few of the so called 'static' features (you can see it, for example). Heat is mostly seen as a source but it has a few 'active fluid or gas' features. Time is more like a place, but it has quite a few 'localized' features and it can be seen as 'continuous' or 'discrete', 'motion' or 'cause'. Sound has a few 'static' features and can be seen as



something moving:
treat as movement
it's only movement
you can stop it
use to move
can transfer it
can create it
act by contact

matter:
treat as solid
kind of solid
can touch it
real
macroscopic
treat as real
can destroy it
can treat as gas
can conserve it
treat as macroscopic
microscopic
treat as microscopic
like particles
treat as particles

wave/moving fluid:
hear it
hear through it
see it
can disperse
localized
treat as wave
act at distance
appear/disappear
fluid
wave

place/time:
it's nowhere
it's in your mind
treat as imaginary
treat as place
like a place
can move inside it
exists without acting
it's everywhere
can see through it

active fluid/gas:
immaterial
unknown dimension
concentrates
kind of gas
treat as fluid
distributes by itself
touch through it
multiplies

source:
reason for everything
creates things
use to transform
transform things
use to destroy
feel it
use to create
can transform it
use to conserve
can concentrate it
transfer it
see effects
acts by itself
causes movement
like a force
treat as force
destroys things

Figure 2.5. Clusters of features.

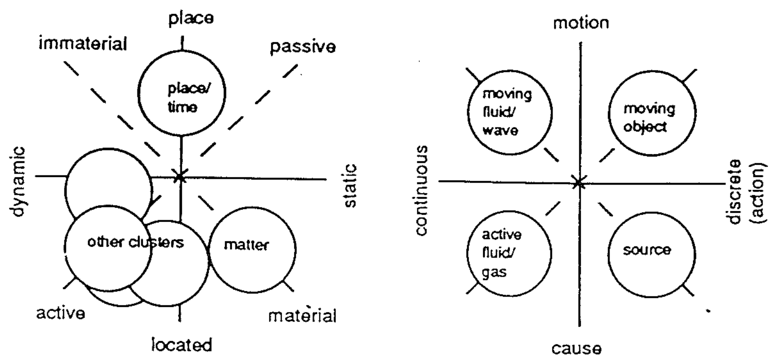


Figure 2.6. Interpretation of the ontological space.

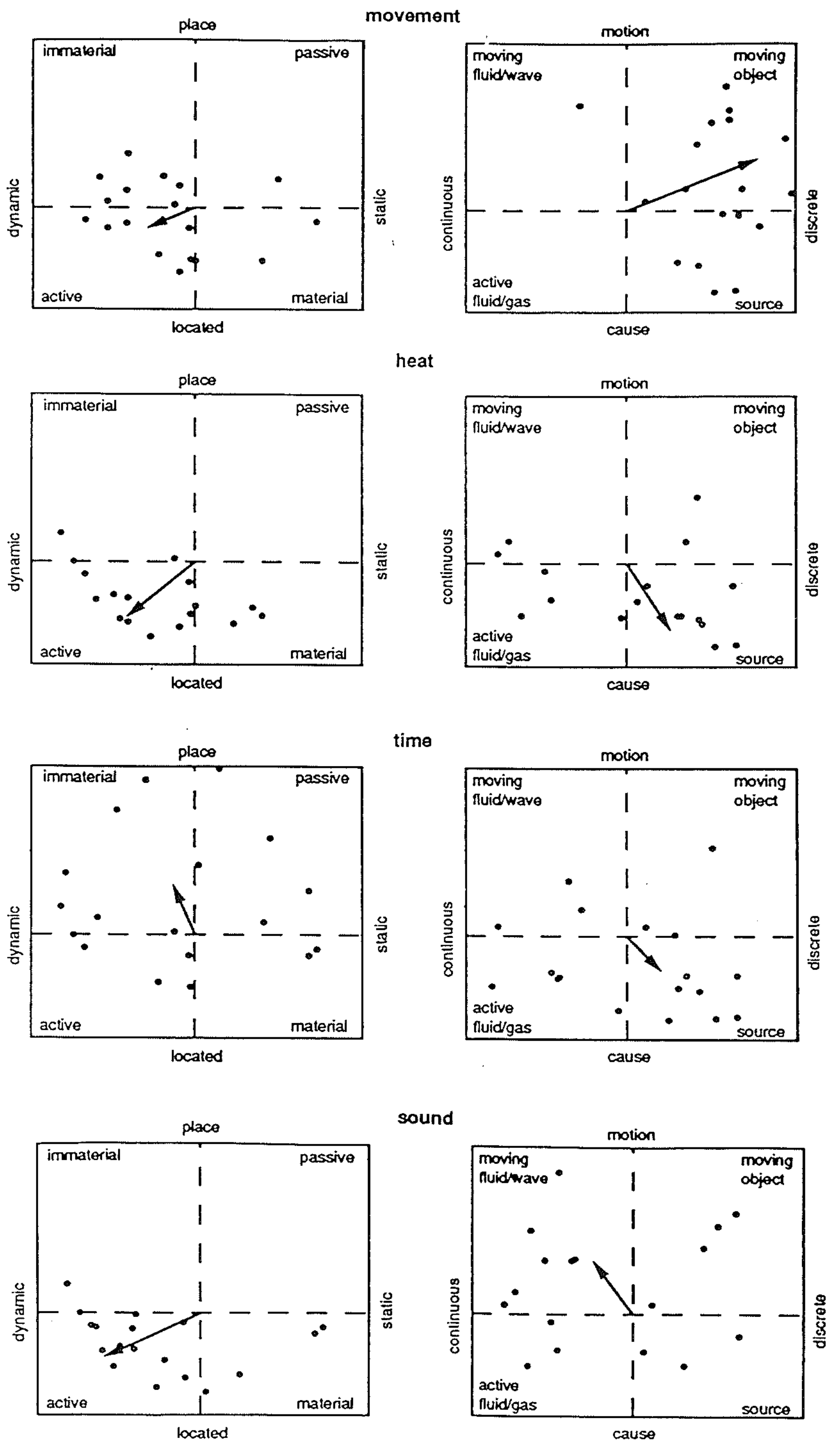


Figure 2.7. Location of concepts in ontological space.

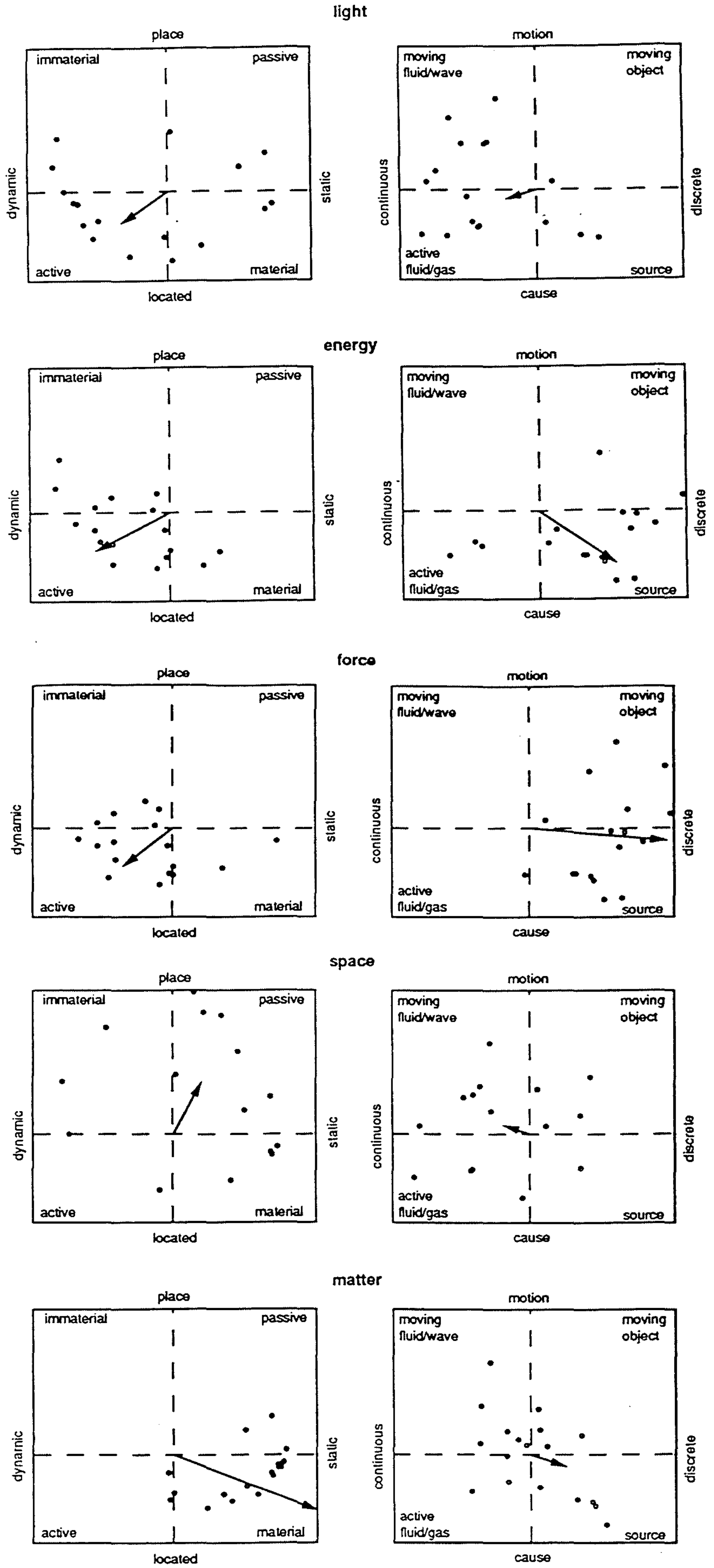


Figure 2.7. *Location of concepts in ontological space (continued).*

'discrete' or 'continuous'. Light has 'static' and 'dynamic' features, and can be seen as 'place' like. Energy has a few 'active fluid or gas' characteristics. Force can be 'motion' or 'cause'. Space has a few 'localized' features and features spread all over dimensions 3 and 4. Matter also has features spread all over dimensions 3 and 4.

Some further interesting results were obtained by asking the students to write about each of the nine fundamental entities and these results can be seen in the paper in Appendix D.2.

From these initial results it was possible to design the main study to be presented in the next Section.

2.4. Design of the main study

For the design of the main study further reflection upon the results obtained was necessary. Many questions were raised by these first results: Would it be possible that the same four dimensional space could be generated with the use of a wide range of age groups and also with modifications in the number of entities and features being asked? Could there be other ways of generating the same space with the use of other forms of questionnaire and interviews? How would individuals differ in their characterisations of entities in this space? In other words: to what extent would this space be 'stable' across different age groups, different features and entities asked about, and across different individuals and with the use of alternative methodologies. An important change was to adapt the questionnaires to a wide range of ages and experience.

There is of course no reason to expect the space to be stable for any kind of change in amount of data or method of elicitation. But there was a chance that for some changes this would be the case.

Firstly a certain minimum core of features should be maintained. This core must be related to features corresponding to the clusters obtained. In other words, highly correlated features suggest that only some of them are really necessary: they can be understood as being 'synonymous' with one another. Secondly it would be important to guarantee that features and entities will be spread all over the space.

It seemed evidently necessary to simplify the questionnaires and to reduce the number of features for younger children. But it would also be desirable to introduce more abstract features and entities for older groups.

From the 66 features originally used, 17 were simply another way of asking the same question, and all proved to be strongly correlated, so they were eliminated. Some others which strongly correlated were also eliminated.

The basic core to be maintained consisted of 30 features presented in table 2.2.

what you can do	**what it can do**	**what it is made of/looks like**	
sensory experience			
1. Can see it	9. Can act by contact	16. Kind of solid	24. You are inside it
2. Can touch it	10. Can act at distance	17. Kind of gas	25. It is nowhere
3. Can hear it	11. Can act by itself	18. Kind of fluid	26. It is localized
4. Can feel it	12. Can appear and	19. Kind of force	somewhere
motor experience	disappear	20. Kind of action	27. It is imaginary
5. Can create it	13. Can transform	21. Like a place	28. It is real
6. Can destroy it	things	22. Like movement	29. It is concrete
7. Can spread it	14. Can create things	23. At rest	30. It is immaterial
8. Can stop it	15. Can destroy things		

Table 2.2. Core of ontological features to be used.

This core of features was maintained across all age groups. A common core of concepts will also be maintained, the nine fundamental entities already investigated: force, space, time, energy, heat, sound, light , but with mass in the place of matter, as being more familiar to young children. Different groups then had added to these features and entities some further entities and features.

Concerning the groups selected it was considered desirable to have a group of children not yet familiar with the teaching of these fundamental concepts, but also to have the opposite, a group of adults with an extensive amount of scientific information. Primary and secondary school pupils and a group of young working adults with only basic information in Science were taken as useful intermediate groups to test the stability of the ontological space. All these groups were selected taking account of the Educational System in Brazil.

Five different target groups were then selected for the main study:

1. 8-10 year-old Brazilian pupils with very little scientific information;

2. 11-13 year-old Brazilian pupils with some introductory scientific notions of these concepts;

3. 16-18 year-old Brazilian pupils with a basic course of Physics;

4. Young adults (on average 20 year-old Brazilians) with some basic notion in Physics;

5. Undergraduate Brazilian physicists, just about to leave their studies at University.

The empirical study was conducted in two states in the developed South of Brazil: São Paulo and Paraná. All the schools selected, except for the group of young adult workers, are located in big cities in these states (Curitiba and São Paulo) and are attended by middle class pupils, being private or state schools. The schools selected for the group of young adults are attended mainly by working class pupils in the evenings. The undergraduate physicists were studying in the Institute of Physics of the University of São Paulo, widely considered to be the best University in Brazil.

The form of the questionnaires was adapted to each group. It was desirable to have samples of average size of at least around N:30-40 for each group (significance levels for Pearson Product-Moment correlations of about 0.30/0.34 at 5% level; see Child 1970). For the young children of the first group the questionnaire was given by individual interview, the sample being reduced in this case (N:23; see table 2.3). This methodology was considered to be more suitable to 8-10 year-olds. They were presented with cards, each card with an entity represented on it in writing and drawing. They were asked to think about each of the entities presented and give a yes/no answer to a series of questions, each question written on a separate card.

The form of the questionnaire given to the 16-18 year old pupils in the pilot study was maintained for the same age group and for the undergraduate physicists. Because the number of entities investigated was increased, more than one questionnaire had to be designed with a division of the number of entities presented in each (N: 50 for each of four questionnaires given to 16-18 year-olds, see table 2.5; N:32 for each of two questionnaires given to undergraduate physicists, see table 2.7). These different questionnaires were given to similar samples.

A simplified questionnaire was given to 13-14 year-olds (N:33; see table 2.4) and working adults (N:31 for each of two questionnaires given, see table 2.6) presenting each entity in a separate page. The form of these questionnaires and the form of cards presented to 8-10 year-olds can be seen in Appendix E.

The group of 8-10 year olds had two more features added to the core: you can't do anything to it and it can move things, which were not asked for some of the other groups. Features added to the group of 13-14 year-olds and working young adults can be seen in table 2.8.

Size of the sample:	23
Males:	15
Females:	8
Year of study:	
2nd year Primary school:	2
3rd year Primary school:	15
4th year Primary school:	6
School:	
"Anjo da Guarda":	13
"Mariaté":	10
Age:	
8 years old:	5
9 years old:	10
10 years old:	8

Table 2.3. Description of sample: 8-10 year-olds.

Size of the sample:	33
Males:	19
Females:	14
Year of study:	
8th year Primary school:	33
School:	
"Jardim Bonfiglioli":	33
Age:	
13 years old:	6
14 years old:	27

Table 2.4. Description of sample: 13-14 year-olds.

Questionnaire 1	Questionnaire 2	Questionnaire 3	Questionnaire 4
Size of the sample: 50	Size of the sample: 50	Size of the sample: 50	Size of the sample: 50
Males:21	Males:15	Males:20	Males:14
Females:29	Females:35	Females:30	Females:36
Year of study(secondary school):			
2nd year:21	2nd year:27	2nd year:13	2nd year:18
3rd year:29	3rd year:23	3rd year:37	3rd year:32
School:			
"Alexandre GUSMÃO":16	"Alexandre GUSMÃO":36	"Alexandre GUSMÃO":25	"Alexandre GUSMÃO":22
"Victor MEIRELLES": -	"Victor MEIRELLES":14	"Victor MEIRELLES":25	"Victor MEIRELLES": -
"Paulo NOVAES":34	"Paulo NOVAES": -	"Paulo NOVAES": -	"Paulo NOVAES":28
Age:			
16 years old:23	16 years old:23	16 years old:19	16 years old:24
17 years old:13	17 years old:17	17 years old:17	17 years old:15
18 years old:14	18 years old:10	18 years old:14	18 years old:11

Table 2.5. Description of sample: 16-18 year-olds.

Questionnaire 1	Questionnaire 2
Size of the sample: 31	Size of the sample: 31
Males: 16	Males: 17
Females: 15	Females. 14
Year of study(secondary school - evenings):	
2nd year:31	2nd year:31
School:	
"José LEITE": 21	"José LEITE": 10
"GUALTEI da Silva": 10	"GUALTEI da Silva": 21
Age:	
17-20 years old:20	17-20 years old:21
21-30 years old:11	21-30 years old:10
Occupation:	
Office Assistant:14	Office Assistant:10
Bank Cashier:5	Bank Cashier:2
Receptionist	Receptionist·
Secretary:3	Secretary:1
Sales Assistant:3	Sales Assistant:3
Mechanic:2	Mechanic:1
working in Industry:2	working in Industry:2
working with computers:1	working with computers:1
working in a Post Office: -	working in a Post Office:2
student:1	student:8
Other: -	Other:1(Portier)

Table 2.6. *Description of sample: young working adults.*

Questionnaire 1	Questionnaire 2
Size of the sample: 32	Size of the sample: 32
Males:24	Males:23
Females:8	Females:9
Age:	
20-25 years old:20	20-25 years old:25
26-31 years old:12	26-31 years old:7
Occupation:	
Teaching:6	Teaching:4
Research:2	Research:3
Student: 18	Student:23
Other: 6	Other:2

Obs.: All undergratuate students of Physics(last year) from the University of São Paulo

Table 2.7. *Description of sample: undergraduate physicists.*

what you can do	what it can do	what it is made of/looks like
31. Can touch through	38. Causes movement	43. Like particles
31. Can see effects	39. Exists without acting	44. Like wave
33. Can transform it	40. Distributes by itself	45. Cause
34. Can concentrate it	41. Concentrates by itself	46. Effect
35. Can transfer it	42. Multiplies by itself	47. Substance
36. Can conserve it		48. Microscopic
37. Can't do anything to it		49. Macroscopic

Table 2.8. Added features for 13-14 year-olds and adult workers.

As can be seen a certain number of features were added to each of the three aspects, these usually being more abstract features, and re-introducing some of those features already used in the pilot study. For the 16-18 year-olds the following more abstract five features were also added: it is like a field, like a vacuum, like energy, it is material and also it can transfer things.

Physicists had a large number of more abstract features added: of being a property, a relation, a quantity, discrete, a continuum, a state, an invariant, immutable, a transformation and passive. Also some features were re-introduced: it is everywhere and it can act under control. A total of 65 features were used.

One more fundamental entity was introduced for the 8-10 and 13-14 year olds: impulse. Impulse is only not present in the undergraduate physicists' questionnaire. To the working adults six other fundamental entities together with impulse were introduced: gravity, matter, electron, weight, temperature and atom. To the 16-18 year-olds twelve other entities were added: the ones cited above, substituting electron by electricity, and atmosphere, vacuum, microwave, radioactivity, solar radiation and magnetism.

The physicists were asked about quite a different group of more abstract concepts added to the nine fundamental entities: photon, spin, charge, field, quark, neutrino, gamma rays, wave and also action. Other entities introduced were also matter, gravity, electricity, magnetism and microwave.

A complete list of the features and entities used for each group can be seen in tables in the Appendix E.

Some additional information about the way the subjects think about these entities is obtained by asking individuals to write one or two lines about the things they can think about each entity. These answers will be discussed in the next Chapter.

Multidimensional scaling using ALSCAL was used for the analysis of the data obtained for each group, allowing the construction of an ontological space for each individual group. These spaces can then be interpreted and compared.

It was also possible to obtain a direct comparison of the data of each group with the use of INDSCAL (Individual Differences Scaling). In this second case a common space is generated with the use of all the common features between the groups, and a weight is attributed for each group in relation to the common dimensions obtained. A group's weight can be interpreted as the importance of a dimension to that group. The weights rescale, 'stretching' or 'shrinking', each dimension for a group. By comparing the weights obtained for each group it is possible to see how 'distorted' the individual space of a group would be relation to the common space obtained for all groups. The only limitation of INDSCAL in relation to ALSCAL is that no rotations are allowed with the use of INDSCAL.

The data obtained for the main study will be presented and discussed in the next Chapter. A brief description of the techniques used in the analysis of data can be seen in Appendix K.

It was also desirable to investigate the stability of such a space by the use of different questionnaire and interview techniques and to generate this space in a way in which individuals of a group could be represented in their different views of entities in the space. The dimensions discussed so far are purely the outcome of statistical procedures, and it would therefore be helpful to ask people directly about these dimensions.

For these reasons two groups, the 16-18 year-olds and undergraduate physicists, were selected for the purpose of a second study (N:30 and N:18; for a description of the samples see tables 2.9 and 2.10.).

The subjects were asked to locate some fundamental entities in a proposed ten-dimensional space. The dimensions proposed were the four obtained in the pilot study, with the use of a dual interpretation for dimension 3 (action/immaterial fluid). They were presented in a slightly different form, if considered necessary, for methodological reasons. Some other five dimensions were added.

The first four dimensions are the ones already described: place/localized, static/dynamic ('dynamic' presented as 'in motion' to 16-18 year-olds), cause/motion ('motion' presented as 'effect' for both groups), action/immaterial fluid (the last presented as 'substance' for both groups). The alternative interpretation of dimension 3, discrete/ continuous, was also added (it was presented as object/vacuum for 16-18 year-olds). Additional dimensions were the interpretations of the diagonals of the space previously obtained (see paper in the Appendix D.2.): material/immaterial and passive/active. Some other relevant dimensions presented were: concrete/abstract, conserved/not conserved and real/imaginary.

The entities suggested were the nine fundamental entities of the pilot study plus electricity for the 16-18 year-old group and plus photon, charge, gravity and mass for the undergraduate physicists.

The form of the questionnaires for this second study can be seen in Appendix F. The dimensions were presented in the form of semantic differentials. Both groups had to choose a position for each entity in each dimension given as a differential. The undergraduate physicists had each dimension represented by an axis with positive and negative values.

students(initials) 16-18 year-old	(sex;age:years;months)	year (secondary school)	School
1.Luc	(f;16;11)	3rd	Alexandre de GUSMÃO
2.Luc	(f;17;06)	3rd	Alexandre de GUSMÃO
3.Lui	(m;17;02)	3rd	Alexandre de GUSMÃO
4.Mar	(f;17;10)	3rd	Alexandre de GUSMÃO
5.Mar	(m;17;04)	3rd	Alexandre de GUSMÃO
6.Lil	(f;16;11)	3rd	Alexandre de GUSMÃO
7.Mar	(m;18;11)	3rd	Alexandre de GUSMÃO
8.Luc	(f;16;09)	3rd	Alexandre de GUSMÃO
9.Luc	(f;17;04)	3rd	Alexandre de GUSMÃO
10.Pri	(f;17;01)	3rd	Alexandre de GUSMÃO
11.Mar	(m;16;07)	3rd	Alexandre de GUSMÃO
12.Rei	(m;18;10)	3rd	Alexandre de GUSMÃO
13.Luc	(f;16;08)	3rd	Alexandre de GUSMÃO
14.Reg	(m;16;00)	3rd	Alexandre de GUSMÃO
15.Lin	(f;17;01)	3rd	Alexandre de GUSMÃO
16.Reg	(f;16;10)	3rd	Alexandre de GUSMÃO
17.Ren	(f;16;08)	3rd	Alexandre de GUSMÃO
18.Luc	(f;18;08)	3rd	Alexandre de GUSMÃO
19.Pat	(f;18;04)	3rd	Alexandre de GUSMÃO
20.Pat	(f;17;02)	3rd	Alexandre de GUSMÃO
21.Pri	(f;18;10)	3rd	Alexandre de GUSMÃO
22.Mar	(m;16;09)	3rd	Alexandre de GUSMÃO
23.Jul	(f;18;04)	3rd	Alexandre de GUSMÃO
24.Ale	(m;18;02)	3rd	Alexandre de GUSMÃO
25.Ale	(m;17;08)	3rd	Alexandre de GUSMÃO
26.Aff	(m;18;03)	3rd	Alexandre de GUSMÃO
27.Ale	(f;17;05)	3rd	Alexandre de GUSMÃO
28.Car	(f;16;09)	3rd	Alexandre de GUSMÃO
29.Aud	(f;18;03)	3rd	Alexandre de GUSMÃO
30.Chr	(f;17;09)	3rd	Alexandre de GUSMÃO

Table 2.9. Sample of 16-18 year-old students for the study of individuals.

physicists (initials)	(sex;age:years; months)	occupation	course to be finished	period	course completed
1.Cel	(m;23;05)	student	licentiate*	full time	bachelor
2.Iza	(f;21;11)	teacher	bachelor*	full time	
3.Gui	(m;22;11)	student	bachelor	full time	
4.Mar	(m;22;03)	student	licenciate	full time	
5.Lui	(m;23;08)	student	bachelor/licentiate	full time	
6.Car	(m;25;05)	teacher	licentiate	part time	
7.Fra	(m;23;05)	student	licentiate	part time	
8.Cri	(m;28;01)	system analyst	licentiate	part time	
9.Fab	(m;22;05)	teacher	bachelor/licentiate	full time	
10.Sil	(f;23;10)	researcher	licentiate	full time	bachelor
11.Ale	(m;25;06)	technician	bachelor/licentiate	part time	
12.Vic	(m;31;11)	student	licentiate	part time	
13.Zos	(f;24;00)	student	licentiate	part time	bachelor
14.Edu	(m;30;02)	technician	licentiate	part time	
15.Tan	(f;24;00)	teacher	licentiate	part time	
16.Ric	(m;30;03)	teacher	bachelor/licentiate	part time	
17.Cla	(f;21;08)	student	licentiate	part time	bachelor
18.Ami	(m;24;09)	system analyst	licentiate	part time	

Table 2.10. Sample of undergraduate physicists for the study of individuals.

* *bachelor*: enables to the practice of research and the teaching of Physics in the University ;

licentiate: enables to the practice of teaching Science(General Science,Physics and Chemistry) and Mathematics in Primary and Secondary schools only.

For example if the dimension was imaginary/real they would have to choose between a entity being:

For the 16-18 year-olds:

1. It is real;

2. It appears more to be real than imaginary;

3. Neither one nor the other;

4. It appears more to be imaginary than real;

5. It is imaginary;

6. I don't know.

For undergraduate physicists:

-5: imaginary *with absolute certainty*;
-4: *certainly* imaginary;
-3: *quite probably* imaginary;
-2: *probably* imaginary;
-1: *maybe* imaginary;
0: none;
1: *maybe* real;
2: *probably* real;
3: *quite probably* real;
4: *certainly* real;
5: real *with absolute certainty*;

These data were analysed using Principal Component Analysis with which the number of dimensions can be reduced. The correlations were obtained using the mean scores on each dimension of the ten entities suggested for a group of individuals. The factor loadings show how these ten dimensions correlate with a reduced number of factors or dimensions. The factor scores for each entity can be found in this space so that entities can be represented by points in the space.

This technique also allows the position of the entities to vary in accordance with the score attributed to it by different individuals. This can be calculated by the mean of the product of the score given by one individual to one entity on each of the ten dimensions, with the loadings of these dimensions on the factors obtained.

Results of these questionnaires were used to investigate whether it was possible to obtain a similar space to that obtained with the multidimensional scaling (in fact Principal Component Analysis is very similar to multidimensional scaling; see Everitt and Dunn 1978) and also to have more information about the different ways in which entities can be located in the space by different individuals.

A qualitative analysis was performed on additional data obtained in the questionnaires. The individuals were asked to write about how they understand or define the dimensions suggested in the questionnaires. Their answers were categorised with the use of a systemic network (see Bliss, Monk and Ogborn 1983; see also Appendix D.1 for a description of a network presented there).

Child's name initials	date of birth	(sex;age:years; months)	year (primary school)	School
1.Car	07 08 80	(m;09;09)	3rd	Mariaté
2.Rod	01 06 79	(m;10;11)	3rd	Mariaté
3.Jos	03 01 80	(m;10;04)	3rd	Mariaté
4.Raf	24 01 81	(m;09;04)	3rd	Mariaté
5.Gab	05 06 81	(f;08;11)	3rd	Mariaté
6.Fer	13 12 81	(f;08;05)	3rd	Anjo da Guarda
7.Mic	27 09 81	(f;08;08)	3rd	Anjo da Guarda
8.Fab	30 05 80	(m;10;00)	3rd	Anjo da Guarda
9.Die	14 08 79	(m;10;09)	3rd	Anjo da Guarda
10.Car	22 06 81	(f;08;11)	3rd	Anjo da Guarda
11.Raf	31 05 80	(f;10;00)	4th	Anjo da Guarda
12.Tia	21 05 80	(m;10;00)	4th	Anjo da Guarda
13.Fer	21 08 80	(f;09;09)	4th	Anjo da Guarda
14.Ott	19 09 80	(m;09;08)	4th	Anjo da Guarda
15.Gus	04 01 81	(m;09;04)	4th	Anjo da Guarda
16.Vin	20 01 81	(m;09;04)	4th	Anjo da Guarda
17.Eli	30 09 80	(m;09;08)	3rd	Mariaté
18.Let	11 08 79	(f;10;09)	3rd	Mariaté
19.Kat	10 02 81	(f;09;03)	3rd	Mariaté
20.Jos	29 11 79	(m;10;06)	3rd	Mariaté
21.Dan	07 09 80	(m;09;08)	2nd	Mariaté

Table 2.11. Sample of 8-10 year-old children interviewed.

student(initials) 16-18 year-old	date of birth	(sex;age:years; months)	year(secondary school)	School
1.Wen	01/02/72	(m;18;03)	3rd	Alexandre de GUSMÃO
2.Ren	10/12/73	(f;16;05)	3rd	Alexandre de GUSMÃO
3.Ric	21/06/72	(m;17;11)	3rd	Alexandre de GUSMÃO
4.Hij	17 02 73	(f;17;03)	3rd	Alexandre de GUSMÃO
5.Reg	31 07 73	(m;16;10)	3rd	Alexandre de GUSMÃO
6.She	22 12 73	(f;16;05)	3rd	Alexandre de GUSMÃO
7.San	28/03/73	(f;17;02)	3rd	Alexandre de GUSMÃO
8.Ric	05/09/72	(m;17;08)	3rd	Alexandre de GUSMÃO
9.Gla	06/03/72	(m;18;02)	3rd	Alexandre de GUSMÃO
10.Edi	19/03/72	(m;18;02)	3rd	Alexandre de GUSMÃO
11.Val	23/05/74	(m;16;00)	2nd	Alexandre de GUSMÃO
12.Mar	18 08 73	(f;16;09)	3rd	Alexandre de GUSMÃO
13.Ang	31/08/72	(f;17;09)	3rd	Alexandre de GUSMÃO
14.Eri	16 03 72	(f;18;02)	3rd	Alexandre de GUSMÃO
15.Adr	21 07 72	(f;17;10)	3rd	Alexandre de GUSMÃO
16.Ros	02 11 72	(f;17;06)	2nd	Alexandre de GUSMÃO
17.Wil	21/02/73	(m;17;03)	2nd	Alexandre de GUSMÃO
18.Mar	21/04/74	(m;16;01)	2nd	Alexandre de GUSMÃO

Table 2.12. Sample of 16-18 year-old students interviewed.

Additional information was also obtained by interviewing a group of 16-18 year old pupils (N:18; see description in table 2.12) and most individuals of the same group of 8-10 year-olds interviewed before for the first study (N:21; see description in table 2.11). The structure and form of analysis of these interviews can be seen in Appendix G.

The objective of these interviews was to see the way in which individuals would spontaneously relate entities and also relate features to entities, by simply grouping them and explaining the groups formed. The design of the interviews was quite straightforward.

A number of cards, with the entities used in the questionnaires for 16-18 year-olds represented each by a card (N:22 entities; for example: force, energy and so on), were presented to a sample of this same age group. They were asked to form groups of entities which seemed like each other. After that they were asked to briefly explain the reasons why they made the groups. The group of 8-10 year-olds performed the same task using only the ten entities previously used for this group.

After their explanation the 16-18 year-olds were also presented with cards with the features used in the questionnaires (N:54; for example: you can see it, you can touch it, and so on), one feature written on each card, and asked to group together similar entities and things one can think about them. This task makes it possible to compare these groupings directly with the spaces generated by multidimensional scaling.

The analysis was mainly a qualitative description of the explanations obtained, with the construction of systemic networks in which categories of answers were structured (see Bliss, Monk and Ogborn 1983). Also the groupings obtained were compared with the results obtained via questionnaires.

2.5. Conclusion

In this Chapter the general conception of the empirical study was discussed with the objective of introducing the data collected for the main study in the next Chapter. It was also intended to be able to link the theoretical framework to the design of this empirical study.

The general idea for the main study was developed from two previously published papers, including a pilot study for the present research (Mariani and Ogborn 1990 and 1991).

These previous works indicated the ways in which it would be desirable to extend the description of 'ontological spaces' for different groups of individuals and with the use of different methodologies and techniques of analysis.

The results of the main study described here will be presented in the next Chapter.

Chapter 3: Data obtained and analysis

3.1. Introduction

In this Chapter the data obtained and the analysis will be described in the following way:

1. Firstly the general results obtained in the first study for the five different age/instructional samples described in the previous Chapter, including raw data and the dimensionality chosen for the spaces obtained with the use of multidimensional scaling, will be presented;

2. In the same Section these spaces will be briefly described for each sample and also the common space obtained for all samples will be described. The interpretation of the dimensions of these spaces will be aided by the use of a Cluster Analysis performed in these spaces;

3. A more detailed description of the space obtained for each group in the first study will then follow in individual Sections, looking for the similarities and dissimilarities between these spaces;

4. The raw data and the analysis of the responses obtained in the second study for individuals about their understanding of the dimensions, with the use of Principal Components analysis, will be presented as a whole and for each of the two groups used;

5. The data obtained and analysis of interviews will be presented in the form of a network of categories of responses obtained and commented on as a whole and for each of the two groups used;

6. Some concluding remarks on the analysis and results will be presented in the last Section.

3.2. Results obtained in the first study

3.2.1. General results

The tables with the raw data obtained in the first study for the five groups described in the previous Chapter can be seen in Appendix H. In these tables the frequency of 'yes' answers obtained from each group for each entity for each feature is given.

Merely by looking at these tables it is possible to have an idea of the features which are most often used to describe each entity: for example mass and matter can be touched and seen for the majority of individuals in all samples, sound is something you can hear, and so on.

Because of the large number of entities and features it is difficult to describe the data just by looking at these tables. One way of helping this analysis is the use of some exploratory techniques.

A way of doing that is transforming the data obtained into a matrix of similarities. Correlations obtained between pairs of features were used for this purpose (Pearson Product-Moment Correlations).

If frequencies of 'yes' answers to a pair of features correlate across a number of concepts, these two features can be regarded as being 'close' to one another in a hypothetical space. The matrix of correlation obtained for each group was converted into distances (1-correlation coefficient) and subjected to multidimensional scaling, using ALSCAL.

A brief description of the techniques used in the analysis of data can be seen in Appendix K.

Multidimensional scaling finds the best arrangement of points in a space of a given number of dimensions, so that the distances between the points in this space reproduce the ordering of the empirical distances. In the present analysis, the distances were treated only as ordinal quantities, to avoid making assumptions about their distribution.

Goodness-of-fit of the space to the data is indicated by the value of the stress (the normalised sum of squares of differences between actual and fitted distances). A scree plot of the stresses for different numbers of dimensions and the value of these stresses suggest four dimensions to be an acceptable result for all five groups. The presence of an 'elbow' is clearest for the group of 13-14 year-olds. This result can be seen in figure 3.1.

The following advice is given about the ideal value for the stress of a chosen dimensionality (Everitt and Dunn 1983):

Kruskal goodness-of-fit

0.2	poor
0.1	fair
0.05	good
0.025	excellent
0	perfect

The stresses of the four dimensional solutions obtained for each group are close to a good fit, as can be seen in table 3.1. RSq (squared correlation in distances), the value indicating the proportion of the variance of the scaled data (disparities) which is accounted for by the four dimensional model, is also shown.

With the use of INDSCAL it was possible to find a common four-dimensional space in which to represent the results of all the five groups together. This was done with the use of:

1. Correlation between pairs of features for each group considering *all the entities* used in each group (N: 10, 10, 16, 22, and 23 entities);

2. Correlations between pairs of features for each group considering only *the common entities* between groups (N: 9 fundamental entities).

The values of stresses and RSq in each case can be seen in table 3.2. The averaged (RMS) stress and RSq over matrices is also shown. These stresses are probably higher in relation to the study using ALSCAL because of the necessity of finding a space in which the results from all groups can be represented. The averaged stress is closer to a fair stress

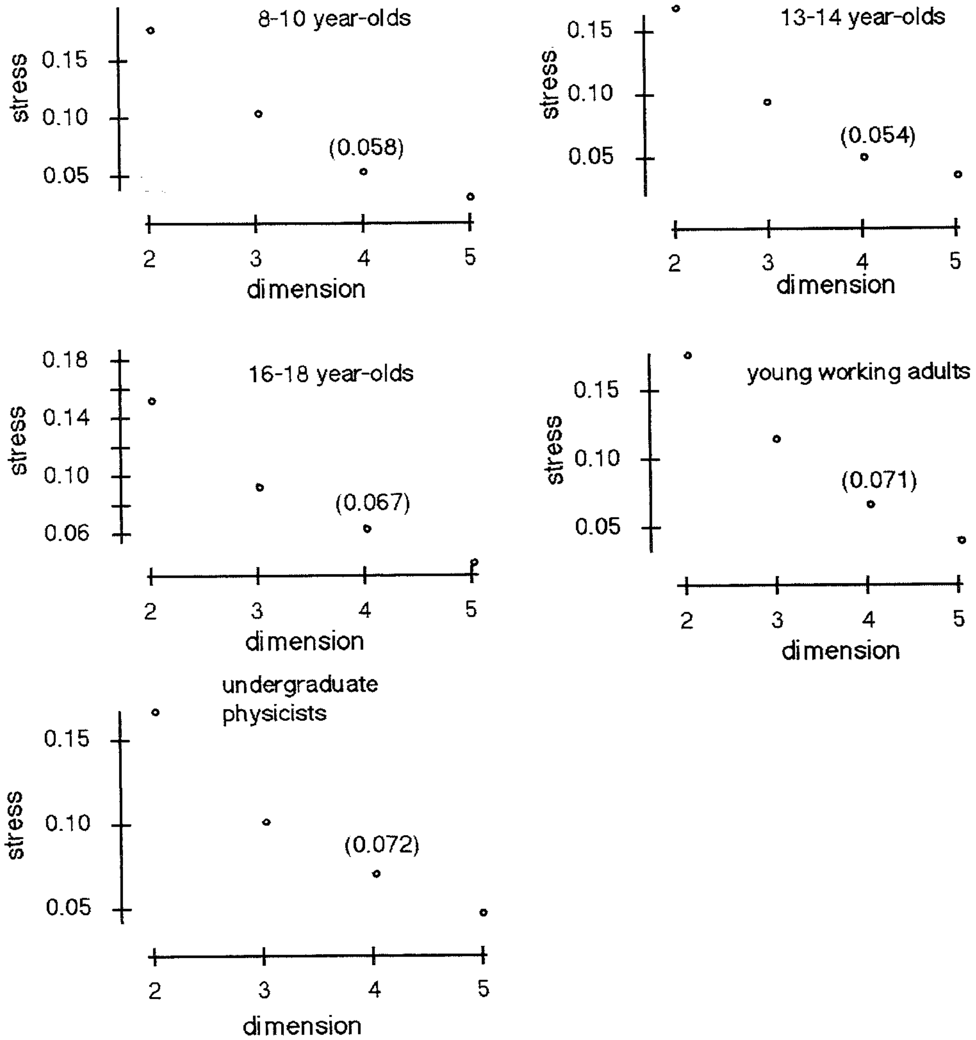


Figure 3.1. *Kruskal stresses obtained for the 2, 3, 4 and 5 dimensional solutions. The value for the 4-dimensional solution is indicated.*

Groups	Stress	RSq
8-10 year-old	0.058	0.962
13-14 year-old	0.054	0.971
16-18 year-old	0.067	0.958
workers	0.071	0.946
physicists	0.072	0.951

Table 3.1. *The stresses of the 4-dimensional solutions. RSq values are the proportion of variance of the scaled data explained by the fitted values.*

	common entities		all entities	
Groups	stress	RSq	stress	RSq
8-10 year-old	0.163	0.683	0.153	0.720
13-14 year-old	0.112	0.848	0.113	0.844
16-18 year-old	0.143	0.754	0.131	0.796
workers	0.129	0.801	0.118	0.837
physicists	0.179	0.618	0.186	0.629
averaged(RMS)	*0.147*	*0.741*	*0.143*	*0.765*

Table 3.2. *The stresses for the solutions with the use of INDSCAL. RSq values are the proportion of variance of the scaled data explained by the fitted values.*

in the Kruskal table. Other measurements related to the relationship between groups in this space will be presented later.

Considering the results obtained with ALSCAL, the four dimensional spaces obtained could have their dimensions interpreted in the same way as in the pilot study (Mariani and Ogborn 1991; see Appendix D.2.) described in the previous Chapter. No rotations were necessary to allow the interpretation except for the group of 16-18 year-olds, with a 45 degree rotation of all dimensions. Inversions were necessary in order to compare these groups. The order in which the dimensions are presented (first, second and so on) does not necessarily coincide with the order in which they appear as a result of the multidimensional scaling performed.

The tables with the coordinates of each feature in these spaces can be seen in Appendix H. The coordinates are presented in a descending order to facilitate interpretation. In the pilot study the dimensions were interpreted as:

Dimension 1. Place like -localized within a place
Dimension 2. Static-dynamic
Dimension 3. Motion (effect) -cause
Dimension 4. Action (or discrete)-immaterial fluid (or continuous)

In these tables the dimensions are presented with this interpretation. For the last dimension an interpretation as action-immaterial fluid was substituted by discrete-continuous, but only for the group of undergraduate physicists.

Features with moderate or high positive or negative values in each dimension guided this interpretation. Features in italic in these tables (Appendix H) are shared with most of the other groups (including the result obtained considering all groups together), the ones underlined being shared between all groups. Being 'shared' means that the same feature will be found in the same positive or negative side of the same dimension for different groups (by being 'shared' sometimes they will have a high or moderate value for one group and not a high or moderate value for another).

The features 'shared' by groups for a given dimension are listed below (underlined are the ones shared with all groups) helping in the interpretation of these dimensions:

1. Place: imaginary, you are inside it, like a place, exist without acting, can't do anything to it , like a field, like a vacuum - localized: it appears and disappears, act by contact, localized somewhere, you can destroy it, you can spread it;

2. Static: it is at rest, like a solid, concrete, macroscopic, microscopic, substance, like particles, exist without acting, localized somewhere, material, you can touch it, you can see it, it is real, it is like a place - dynamic: like a force, destroy things, like a movement, like an action, it causes movement, it is a cause, you can see the effects, it is an effect, like a wave;

3. Motion (effect): you can see it, you can hear it, you can stop it, like a movement, like a wave, it is an effect, like a place, you are inside it - cause: you can feel it, it is a cause, microscopic, like an energy, it transforms things, it acts by itself, it destroys things, act by contact;

4. Action (or discrete): can create things, you can create it, you can touch it, you can stop it, it move things, can cause movement, you can destroy it, like an action, concrete, like a solid, like a movement, macroscopic, act by contact, like a force - immaterial fluid (or continuous): immaterial, like a gas, act by itself, you can be inside it, act at a distance, like a place, imaginary, multiply by itself, spreads by itself, you can touch through it, like a fluid, it is at rest.

The results of a Cluster Analysis (Complete linkage method; see Everitt 1974; see also Appendix K), clustering features on their coordinates in the four dimensional spaces can be seen in Appendix I.

It is interesting to observe the way in which the clusters combine with one another in their projections on these dimensions. An example is the way in which the clusters associated with being dynamic in dimension 2 are distributed in dimensions 3 and 4 (motion-cause and action-immaterial fluid) as would be expected from the fact that dimensions 3 and 4 are saying something more about dynamic entities.

Unfortunately no additional interpretation of the space was provided by the clusters obtained. One reason is the presence of dissimilar clusters between groups, but also a more complex grouping of features than those obtained in the pilot study. The clusters will be used in the description of the distribution of entities in the spaces.

Together with features it is possible to display the entities in the spaces obtained. For each entity the coordinates of all features were averaged weighting each feature with the fraction of 'yes' responses on the entity for that feature. The entities can then be represented by vectors pointing to the region of the space where one would expect to find a greater number of features which were associated with that entity by the subjects. The coordinates obtained for entities can be seen in Appendix H.

In figures 3.2a to 3.6b the spaces obtained for each of the five groups are shown. All the groups present a similar distribution in the first two dimensions with only small variations of the nine fundamental entities which are shared between these groups: time, space, mass, force, movement, sound, heat, light and energy.

In relation to the first two dimensions time and space are like a place (not very much for 8-10 and 13-14 year-olds), time being dynamic and space being static. Mass is localized and static. The other entities, except light, movement and impulse for 8-10 year-olds and light for 13-14 year-olds, are localized and dynamic. Light is localized and static for 8-10 year-olds and 13-14 year-olds. Movement and impulse are a bit like a place for 8-10 year-olds.

In relation to the third and fourth dimensions, more differences appear between groups. Light, space and time are seen as immaterial fluids by the 8-10 and 13-14 year-olds, the other entities (except heat for the 13-14 year-olds) being more like an action for them. Light, space and sound are an immaterial fluid for the young working adults, but time is like an action, as is the case for the other entities. For the 16-18 year-olds light, energy, heat and sound are like immaterial fluids, and movement and force are

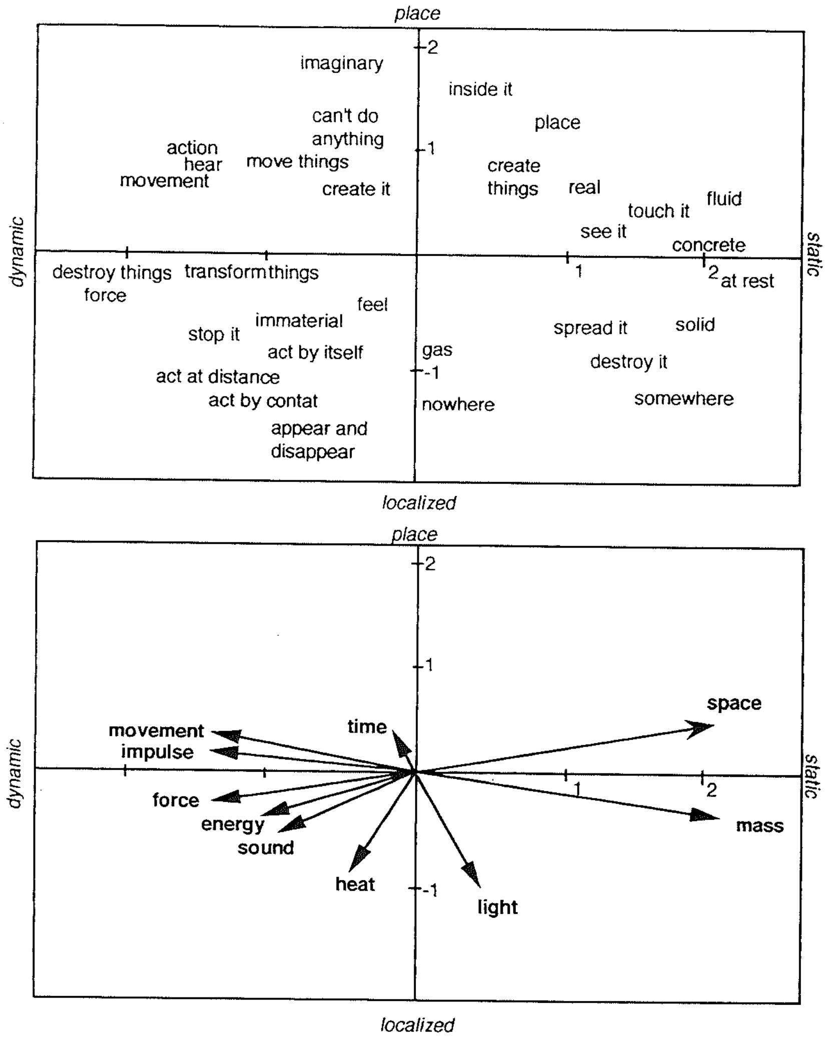


Figure 3.2 a. *The 4-dimensional space obtained for 8-10 year-old students showing the 32 features and 10 entities in the first two dimensions.*

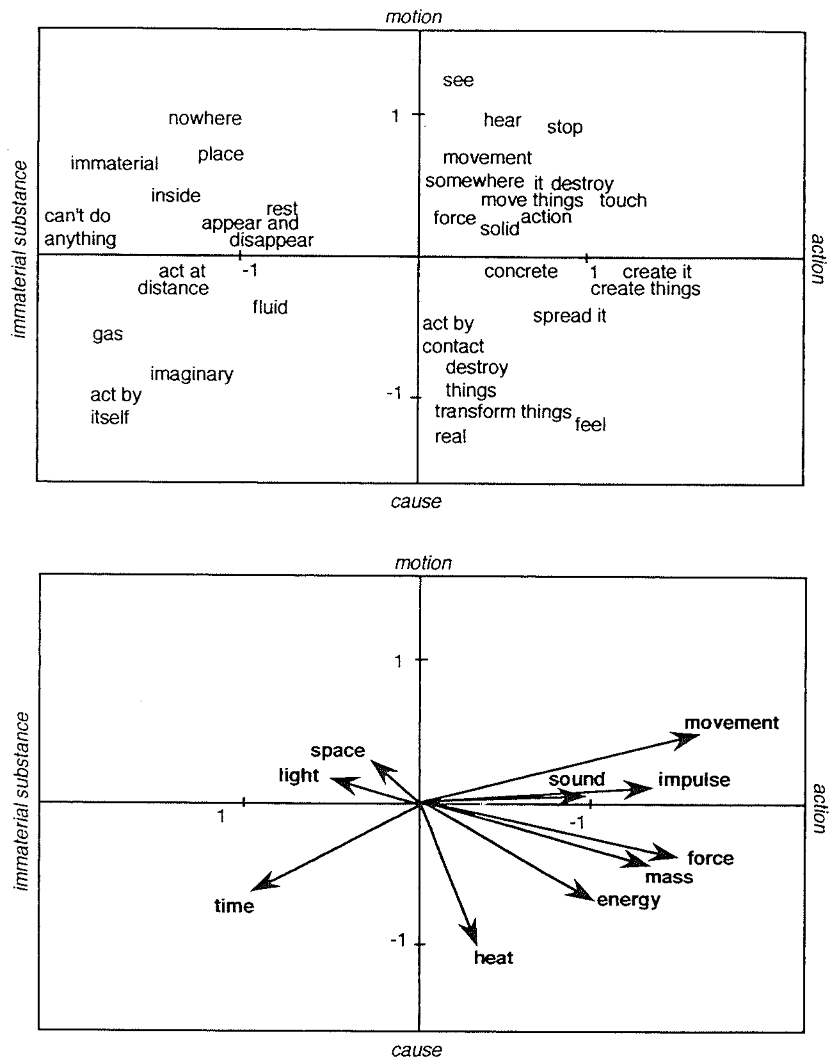
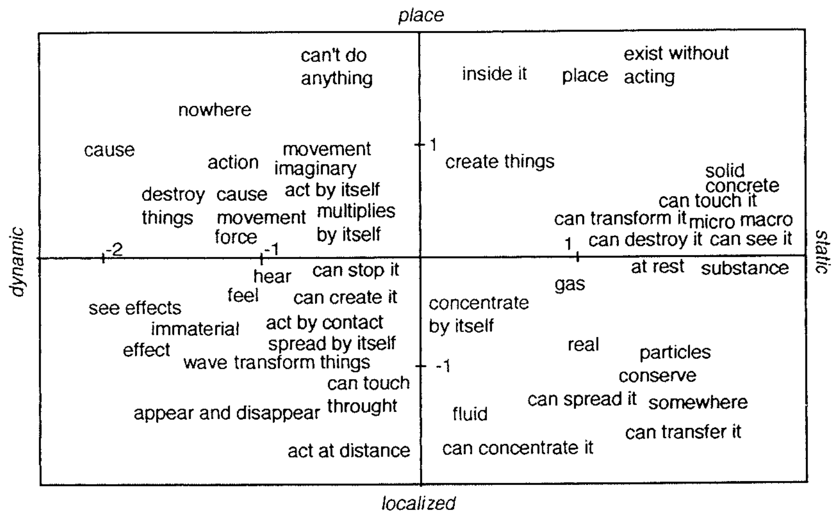


Figure 3.2 b. *The 4-dimensional space obtained for 8-10 year-old students showing the 32 features and 10 entities in the dimensions 3 and 4.*



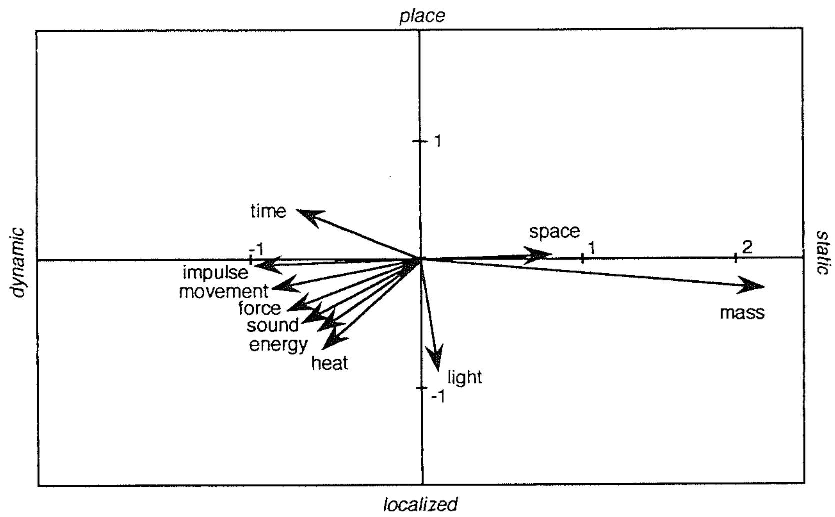
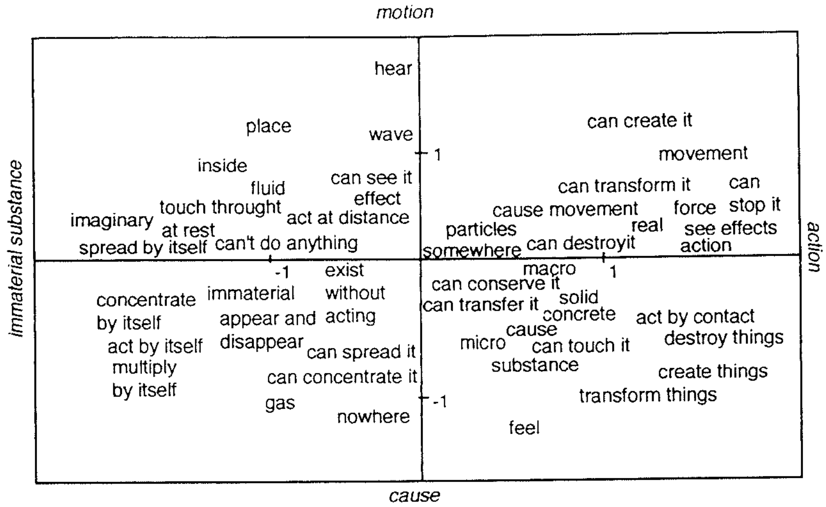


Figure 3.3 a. The 4-dimensional space obtained for 13-14 year-old students showing the 49 features and 10 entities in the first two dimensions.



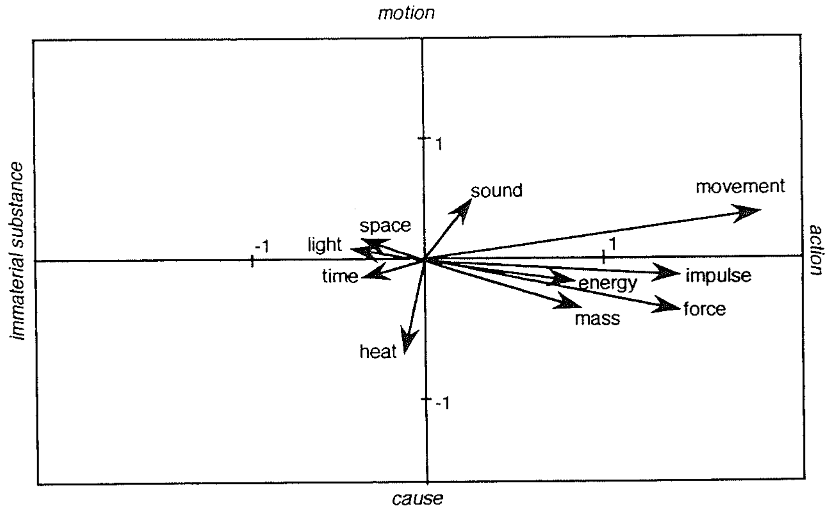


Figure 3.3 b. *The 4-dimensional space obtained for 13-14 year-old students showing the 49 features and 10 entities in the dimensions 3 and 4.*

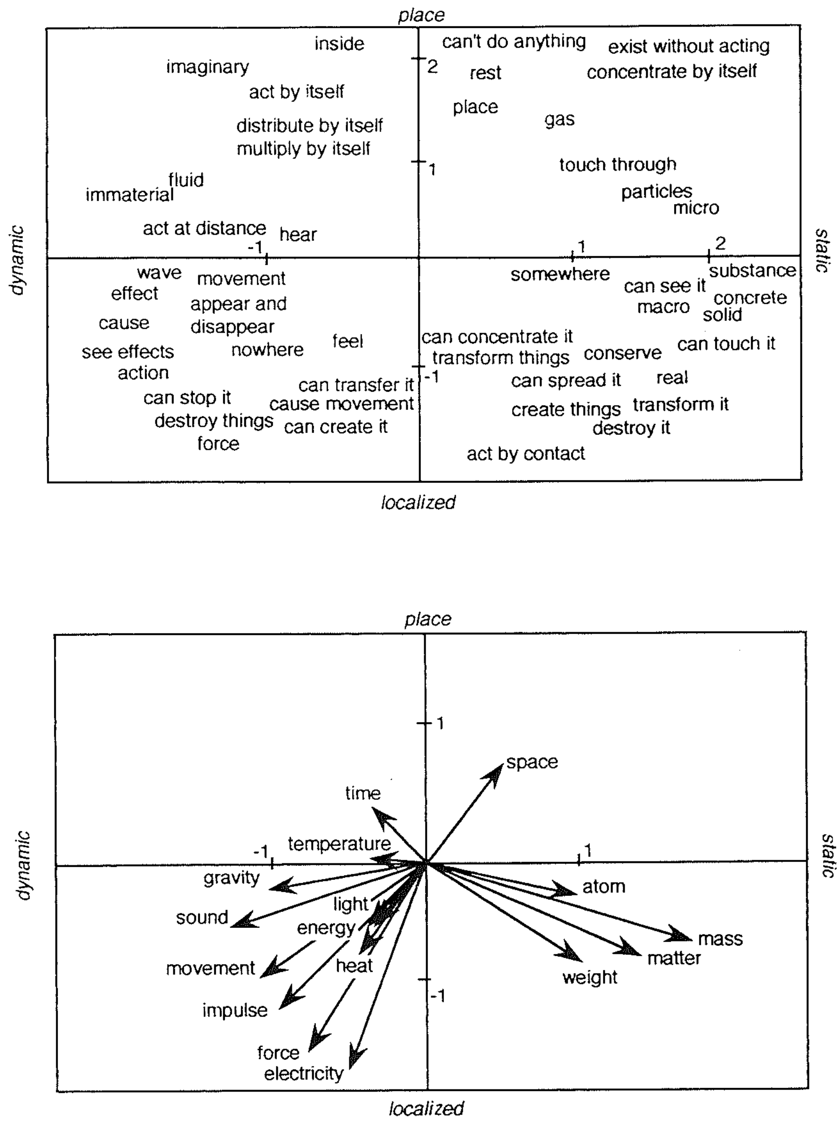
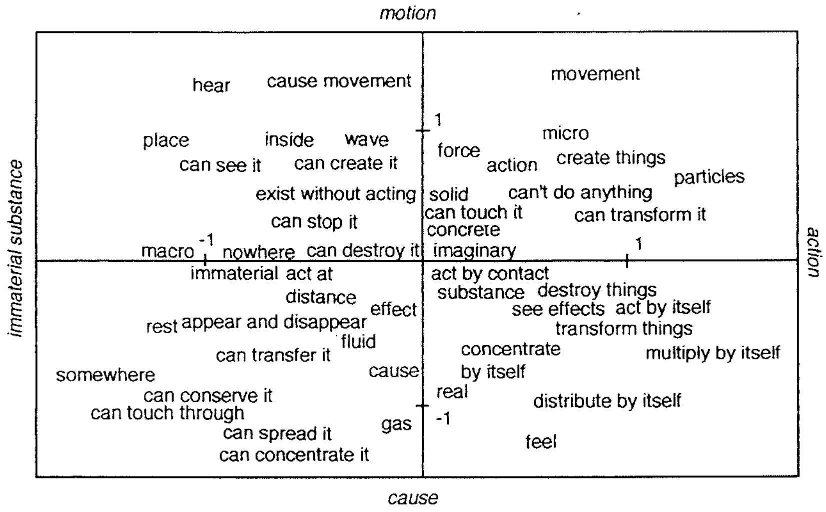


Figure 3.4 a. *The 4-dimensional space obtained for young working adults showing the 49 features and 16 entities in the first two dimensions.*



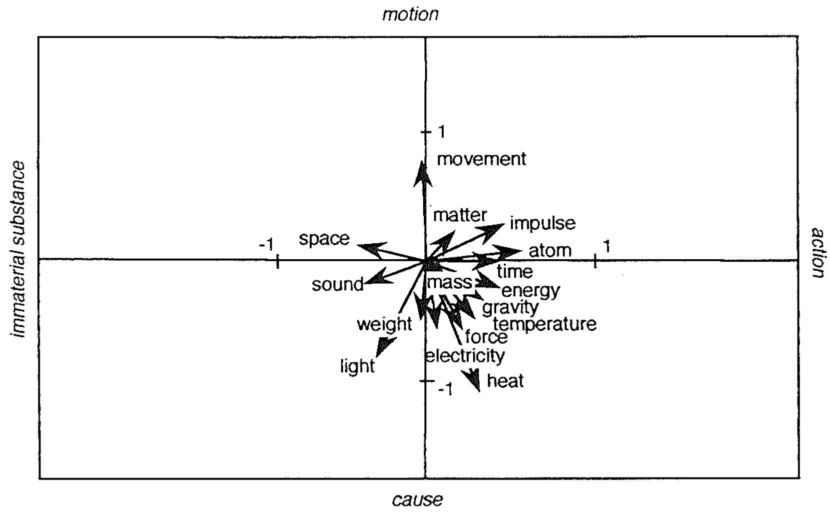


Figure 3.4 b. The 4-dimensional space obtained for young working adults showing the 49 features and 16 entities in the dimensions 3 and 4.

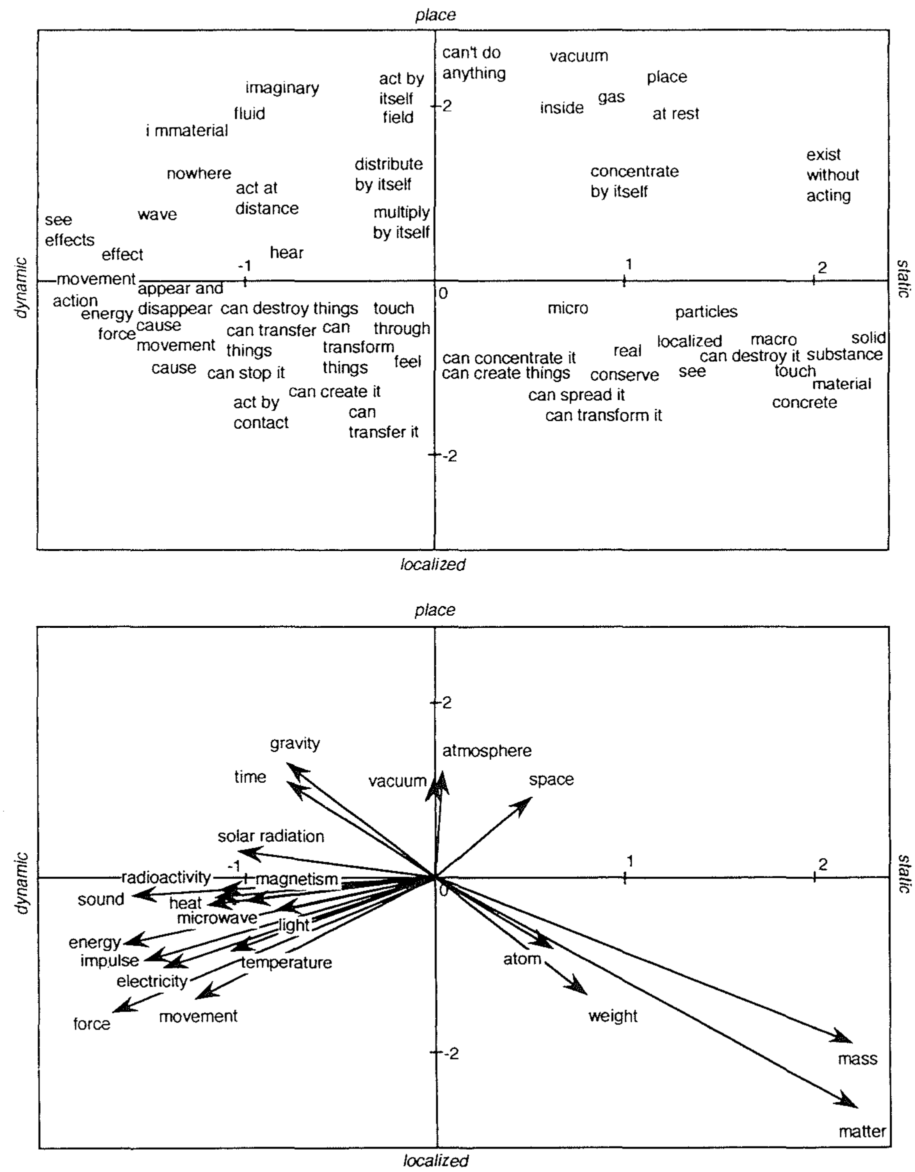
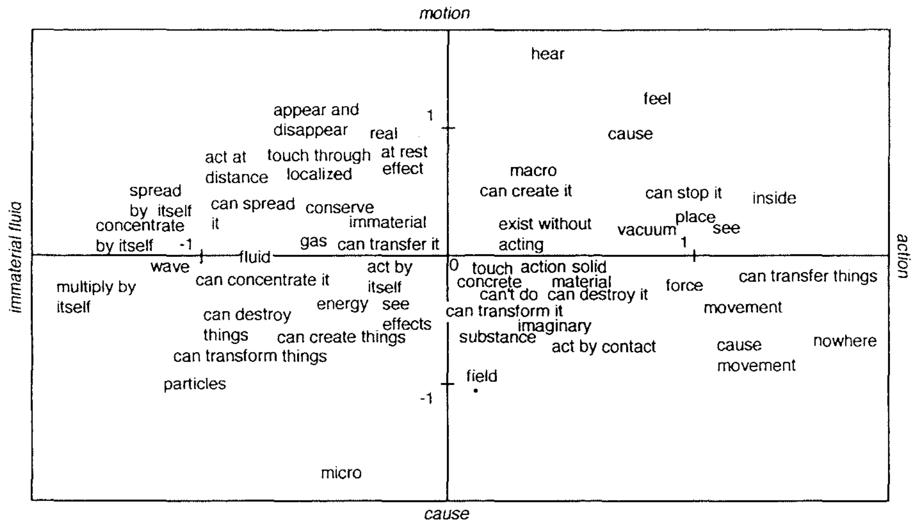


Figure 3.5 a. *The 4-dimensional space obtained for 16-18 year-old students showing the 54 features and 22 entities in the first two dimensions.*



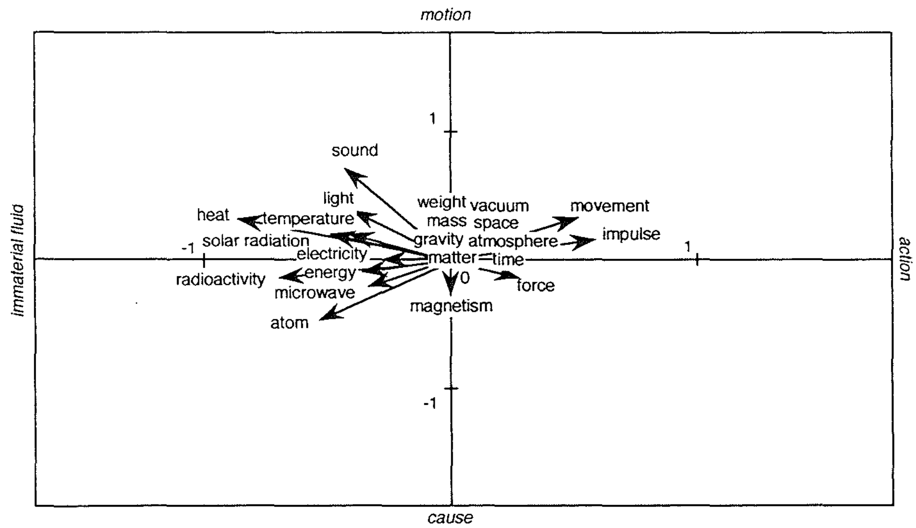


Figure 3.5 b. The 4-dimensional space obtained for 16-18 year-old students showing the 54 features and 22 entities in the dimensions 3 and 4.

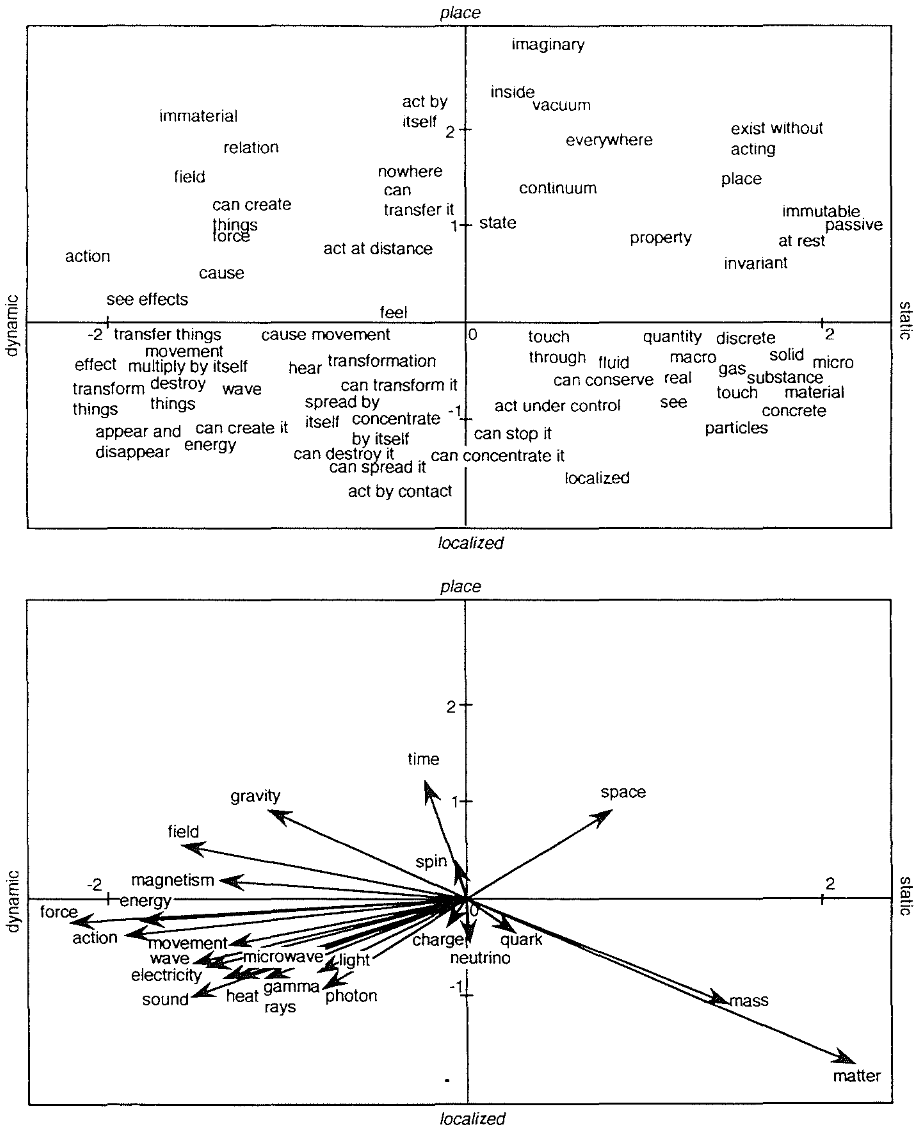


Figure 3.6 a. *The 4-dimensional space obtained for undergraduate physicists showing the 65 features and 23 entities in the first two dimensions.*

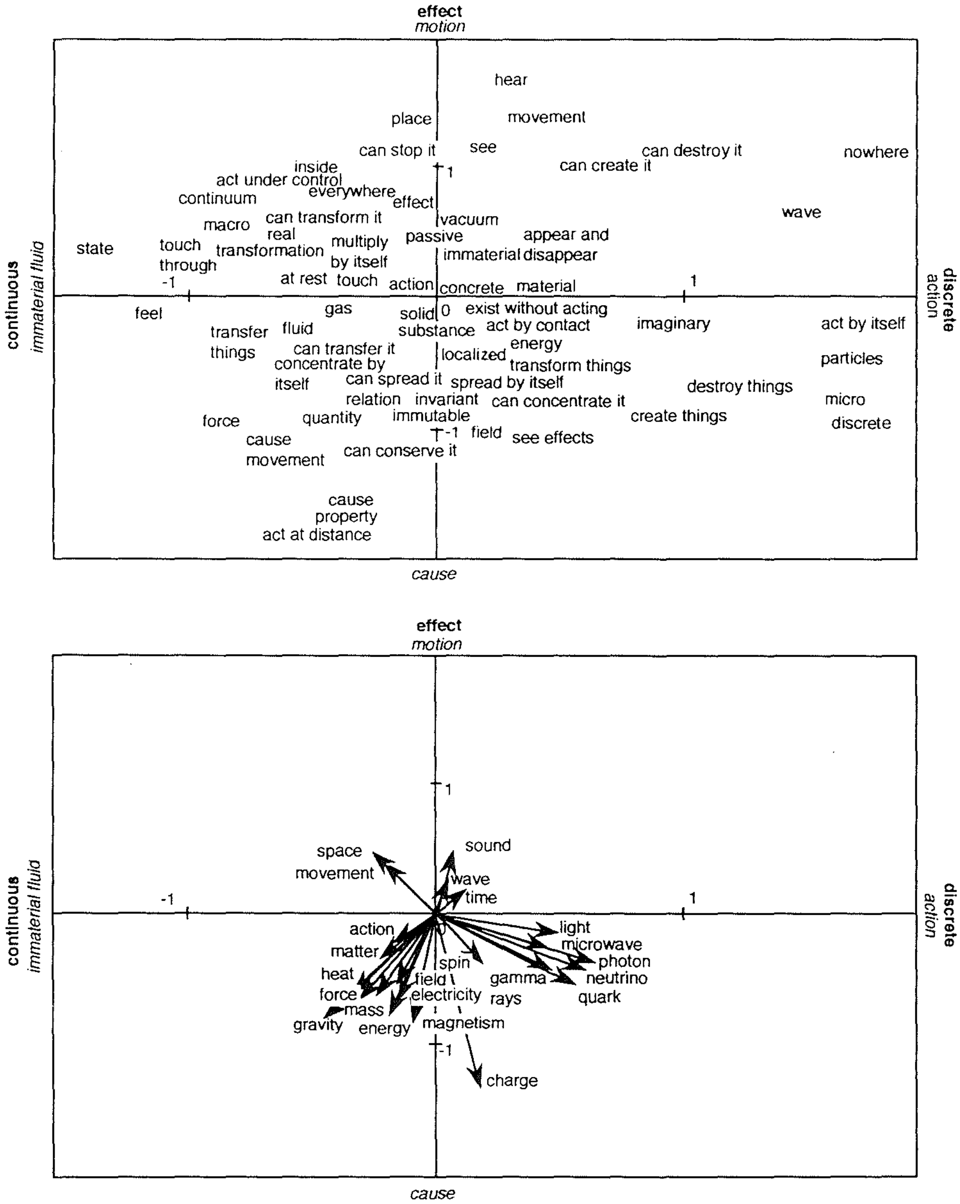


Figure 3.6 b. *The 4-dimensional space obtained for undergraduate physicists showing the 65 features and 23 entities in the dimensions 3 and 4.*

like actions. The undergraduate physicists consider space, movement, heat, force, mass and energy to be continuous and light to be discrete.

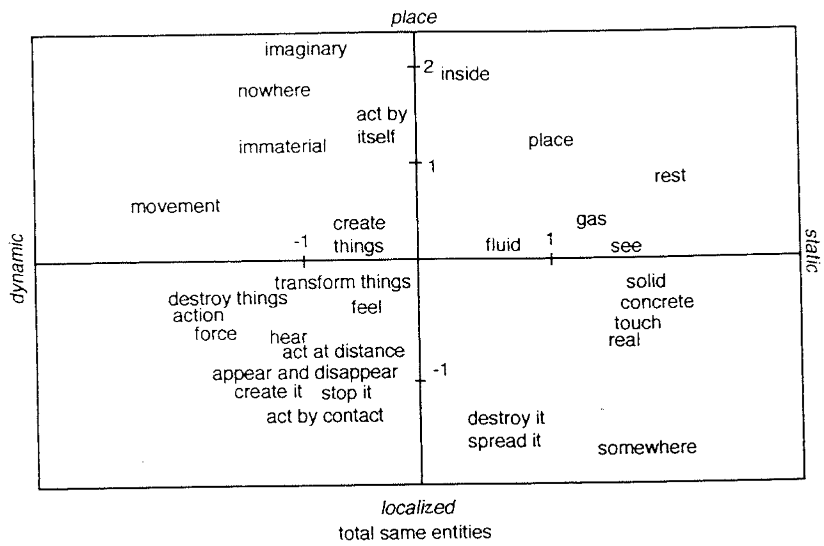
Heat, time, energy, mass and force are causes for the 8-10 and 13-14 year-olds, whilst movement, space, light and sound are like motion. Movement and space are like motion, and light, heat, force, sound, energy and mass are like a cause, for the young working adults. For the 16-18 year-olds sound, light, movement and heat are like motion and force and energy a bit like a cause. For undergraduate physicists sound, movement, space and time are like motion, and the others like a cause.

The location of other entities and a more detailed description of these spaces will be the subject of the next Section.

The common spaces obtained with the use of INDSCAL are shown in figure 3.7a, 3.7b, 3.8a and 3.8b. The weights which can be attributed to each dimension by each group can be seen in table 3.3. These weights measure the importance of each dimension to each subject. Squared weights sum to RSq. A group with weights proportional to the average weights has a 'weirdness' of zero, the minimum value. A group with one large weight and many low weights has a 'weirdness' near one. Thus weirdness indicates departures from the importance generally given to the dimension by all groups taken together.

It can be seen in table 3.3 that all groups attribute similar weights to each dimension, the only exception being for undergraduate physicists in relation to the dimension action/immaterial fluid. In fact the fourth dimension was re-interpreted as discrete/continuous for this group.

An important result is that the common spaces obtained with INDSCAL are quite similar to the spaces obtained with ALSCAL, particularly the ones for the 8-10 and 13-14 year-olds and the young working adults. Because all dimensions are weighted in a very similar way by all groups there are no significant distortions of the common spaces obtained for each group. So the common spaces can be taken to represent each group's space. The dimension immaterial fluid/action will substitute continuous/discrete for undergraduate physicists for comparison, and in



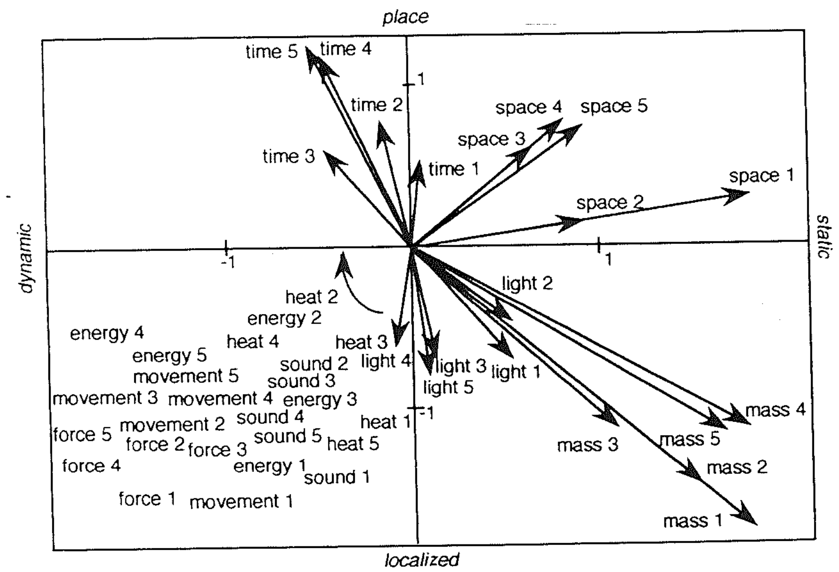


Figure 3.7 a. *The common 4-dimensional space (INDSCAL) obtained with the use of common entities showing the 30 features and 9 entities in the first two dimensions.*

(vectors in the low - left quadrant are too crowded to be shown)

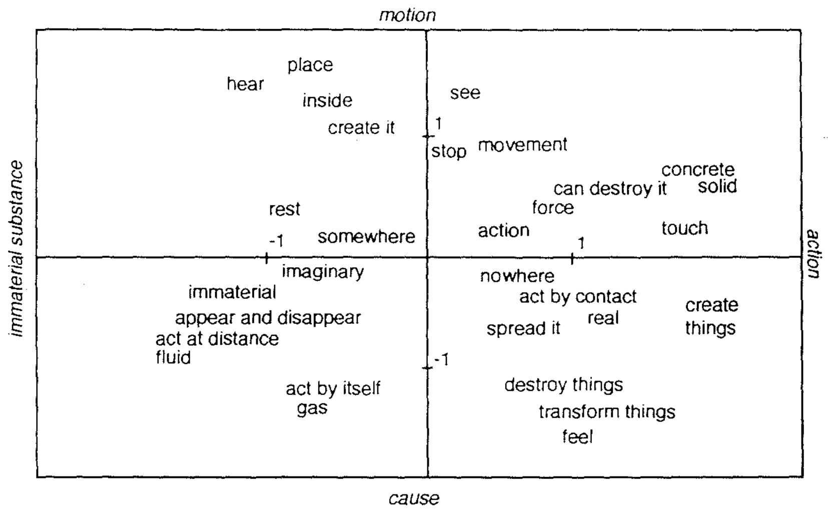
1: 8-10 year-olds

2:13-14 year-olds

3: young working adults

4:16-18 year-olds

5: undergraduate physicists



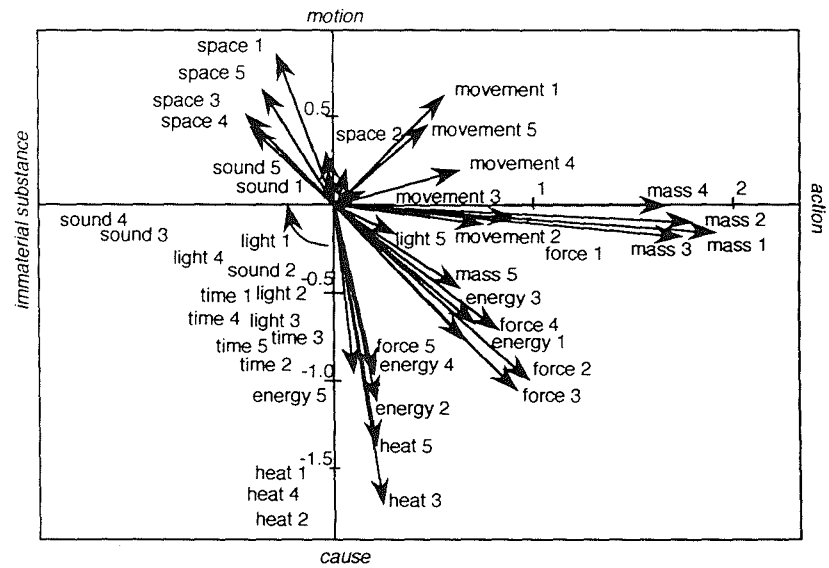


Figure 3.7 b. *The common 4-dimensional space (INDSCAL) obtained with the use of common entities showing the 30 features and 9 entities in the dimensions 3 and 4.*

(vectors in the low - left quadrant are too crowded to be shown)

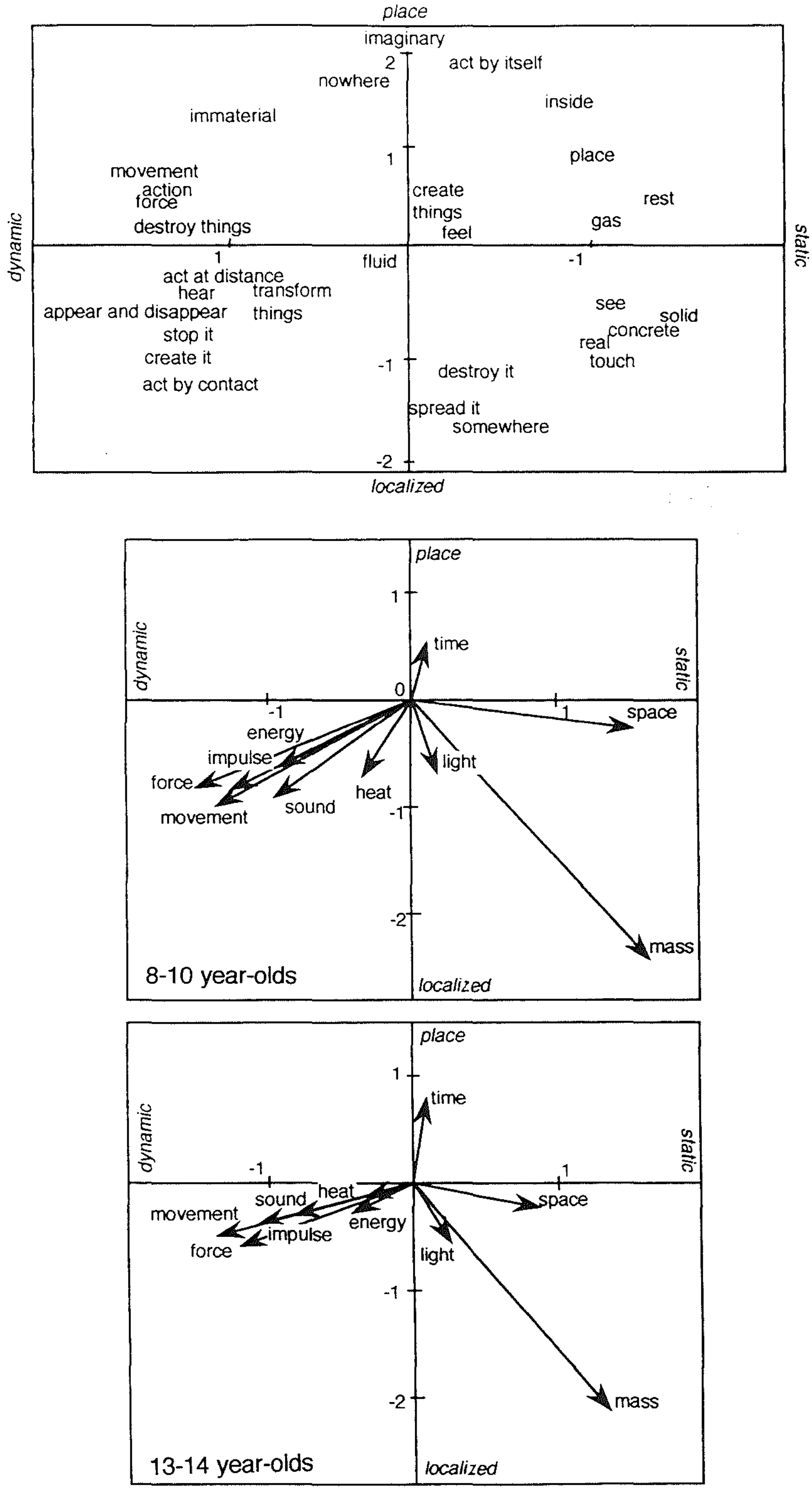


Figure 3.8 a. *The common 4-dimensional space (INDSCAL) obtained with the use of all entities showing the 30 features and the display of entities for each group in the first two dimensions.*

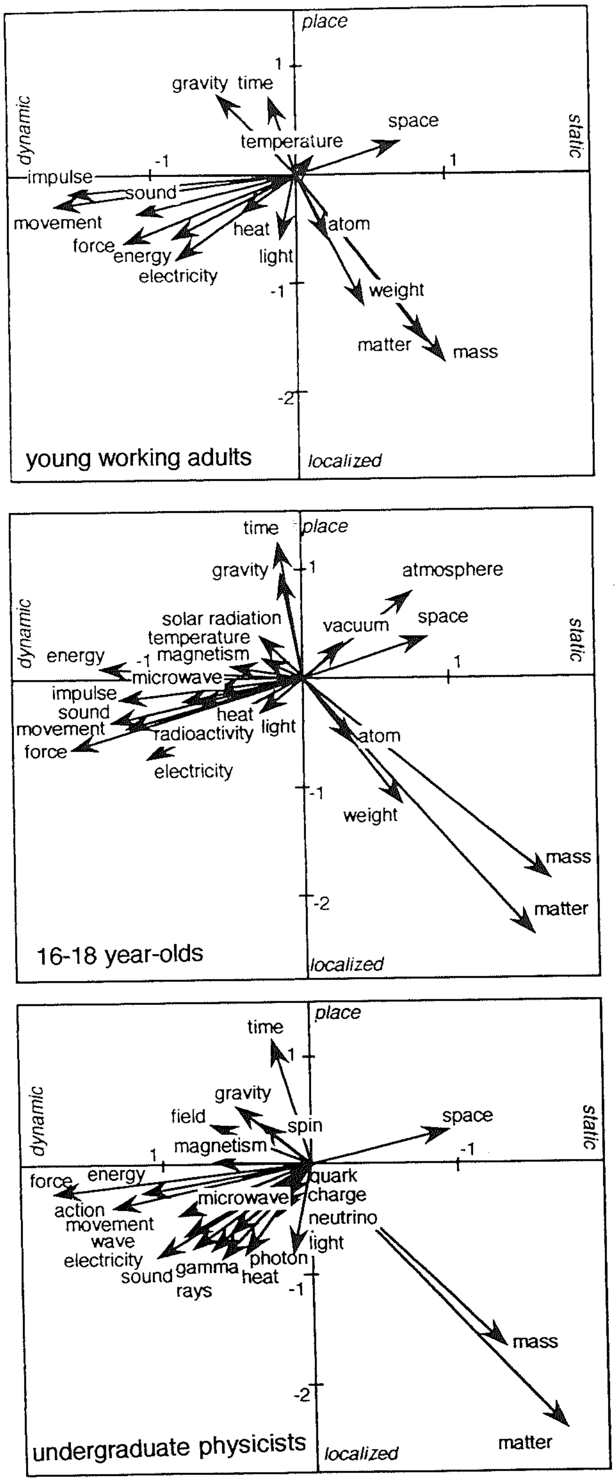


Figure 3.8 a. The common 4-dimensional space (INDSCAL) obtained with the use of all entities showing the 30 features and the display of entities for each group in the first two dimensions. (continued).

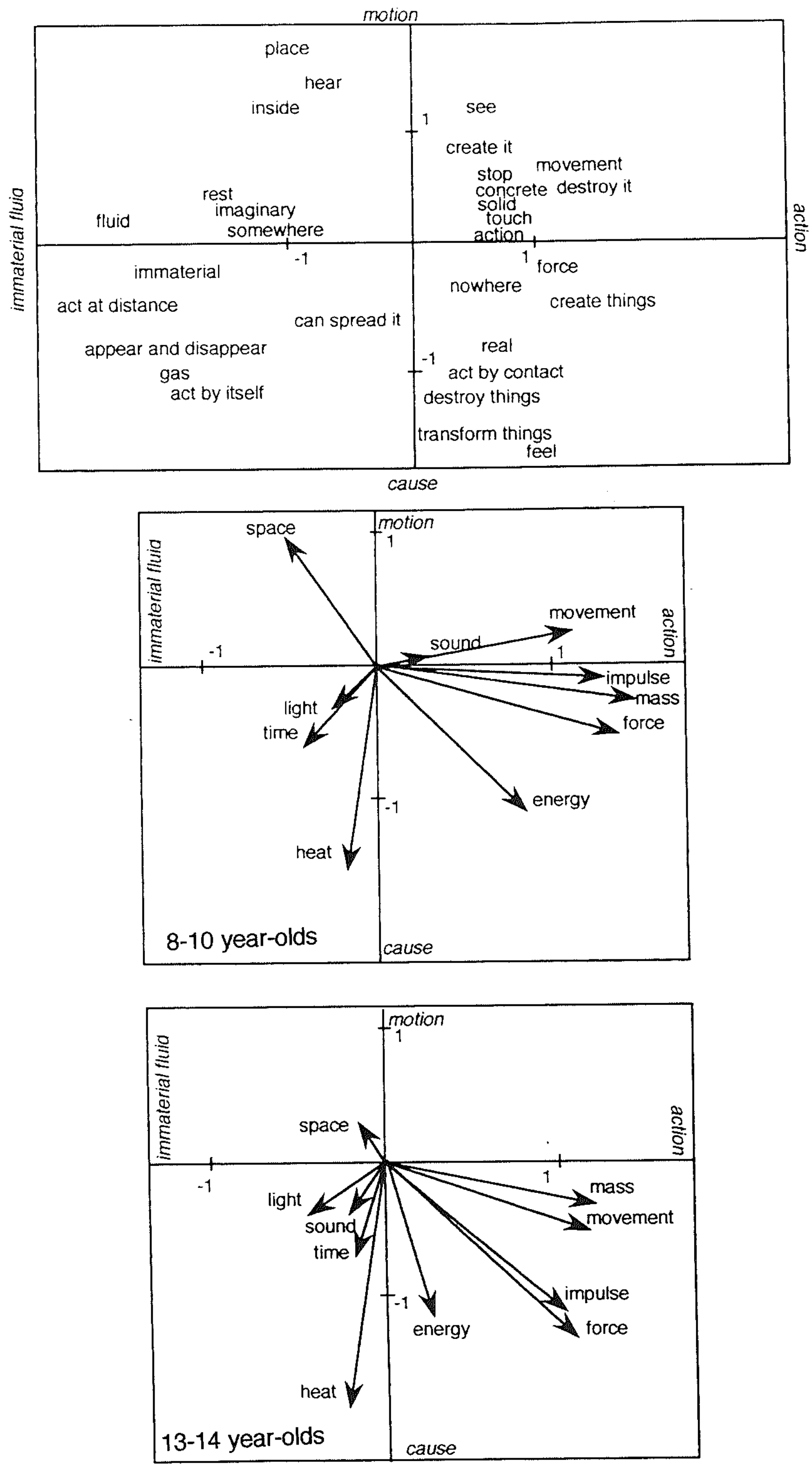
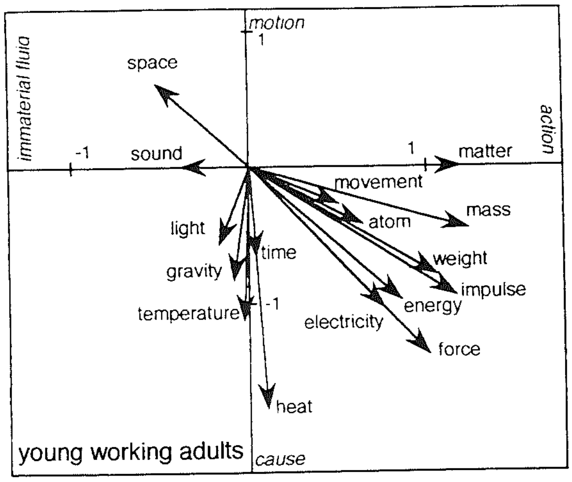
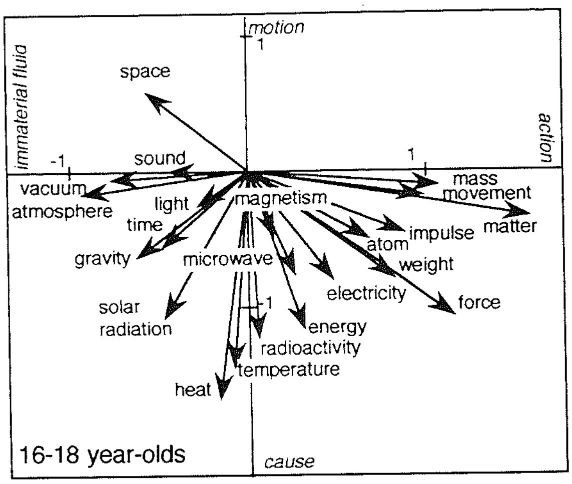


Figure 3.8 b. *The common 4-dimensional space (INDSCAL) obtained with the use of all entities showing the 30 features and the display of entities for each group in dimensions 3 and 4.*





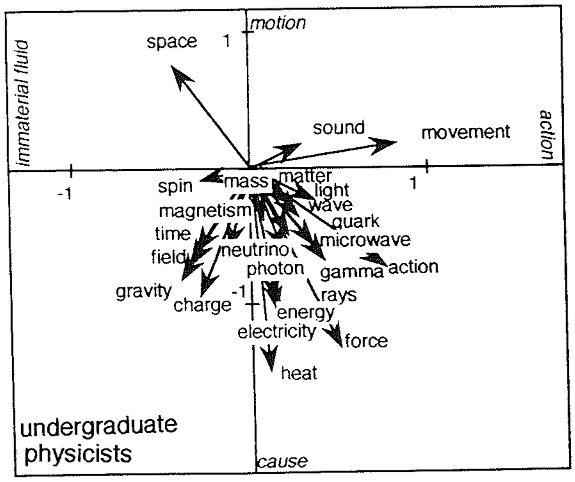


Figure 3.8 b. The common 4-dimensional space (INDSCAL) obtained with the use of all entities showing the 30 features and the display of entities for each group in dimensions 3 and 4 (continued).

this case considering the common space as the group's space is not a very good approximation.

Indscal weights using nine common entities

Group	weirdness	dynamic/ static	place/ localized	cause/ effect	action/ imm. fluid
1	0.0979	0.5234	0.3949	0.2804	0.4168
2	0.0363	0.5608	0.4859	0.3542	0.4068
3	0.1372	0.5514	0.3687	0.3519	0.4598
4	0.0457	0.5803	0.4409	0.3133	0.4105
5	0.2888	0.5772	0.5385	0.2995	0.1660

Indscal weights using all entities

Group	weirdness	dynamic/ static	place/ localized	cause/ effect	action/ imm. fluid
1	0.0983	0.5295	0.3981	0.2993	0.4374
2	0.0776	0.5397	0.4742	0.3616	0.4445
3	0.0689	0.5808	0.4311	0.3184	0.4138
4	0.0619	0.5538	0.5244	0.2771	0.4221
5	0.2259	0.4537	0.5585	0.2393	0.2322

Table 3.3. The weights and weirdness obtained for each group in the common space using common entities and all entities.
Groups from 1 to 5: 8-10 year-olds, 13-14 year-olds, young working adults, 16-18 year-olds and undergraduate physicists.

The 9 fundamental entities are displayed in a similar way for all groups in these common spaces (figure 3.7 and 3.8; with positions of entities calculated as for ALSCAL; see page 83). Space for all groups is static and like a place, time is dynamic and like a place (for 8-10 year-olds time is a bit static in figure 3.7a; in figure 3.8a, the position of time and space for 8-10 and 13-14 year-olds suggests that a rotation of the dimensions would be necessary for this interpretation to be possible, but rotations are not allowed in this case).

Mass for all groups is localized and static (figures 3.7a and 3.8.a). The other entities are all localized and dynamic, except light which is not dynamic but static (except for 16-18 year-olds in figure 3.7a, and also young working adults and undergraduate physicists in figure 3.8a).

Movement and space are like a motion (except for 13-14 year-olds) in figure 3.7b. Movement, space and sound are like a motion for 8-10 year-olds and undergraduate physicists in figure 3.8b. Only space is like a motion for all groups in figure 3.8b. Sound is like a cause for 13-14 year-olds in figure 3.8b, and also for young working adults and 16-18 year-olds in figure 3.7b. Sound is an immaterial fluid for all but 8-10 year-olds and undergraduate physicists.

Light is an immaterial fluid except for undergraduate physicists (like action or discrete). Mass is like an action. Energy and force are like action and cause (energy is only a cause and not an action for undergraduate physicists in figure 3.7b). Time is a cause and an immaterial fluid (only a cause and not an immaterial fluid for young working adults in figure 3.8b). Heat is only a cause.

The use of only nine common entities or of all entities in obtaining correlations between features has not affected very much the common spaces obtained. But it is interesting to note that a small rotation of the dimensions place/localized and static/dynamic would have provided a better representation of entities and features in figure 3.8a. Time and space can be considered to be a bit out of place for 8-10 year-olds and 13-14 year-olds in figure 3.8a.

It is also interesting to note the way in which further entities are added to the common space. Weight, matter and atom are very much like mass; gravity and time are very close; solar radiation, temperature, field are like a place and also dynamic. Most of the other entities added are dynamic and localized.

In the dimensions movement/cause and action/immaterial fluid, the entities sound and movement change their positions in the space for different groups: from being both like action, to sound being like an immaterial fluid; and also from both being like a movement to being like a cause. The other fundamental entities are displayed in almost the same way for all groups excepting undergraduate physicists.

All other entities added are like causes (figure 3.8b). Gravity is also like an immaterial fluid, as are atmosphere, field and vacuum. Weight, atom and impulse are closer to being like an action.

These results confirm the possibility of finding a common ontological space for a wide range of age/instructional levels and also of changing the number of features and entities used. This space is quite stable in relation to these sorts of change.

3.2.2 Results obtained for each group

In this Section the individual spaces obtained for the five different groups will have their results presented in greater detail.

3.2.2.1. Group 1: 8-10 year-old students

The first group is a small sample of 8-10 year-old students (N:23) attending primary school in Brazil. The size of this sample is a result of the method chosen to collect the data. These children were interviewed for about 50 minutes. During the interview they were asked to give a 'yes' or 'no' answer to a series of possible features (N:32) of a number of events (N:10). A description of this sample and the collection of data was given in the previous Chapter.

In the previous Section the general results for this group were presented together with the results for the other groups. It is intended here to describe figure 3.2 in more detail. For this purpose the clustering of the features in this space (Appendix I) will also be considered.

The clusters of features in the space help to understand the distribution of entities in the space in the following ways:

1. An entity is represented by a vector pointing towards the region of features which were most often chosen to describe that entity. These features are also clustered and used to add to the interpretation of the dimensions of the space. By looking into the clusters of features associated with the dimensions it is possible to recover information about what it means for an entity to be considered static (for example being 'at rest') or dynamic (for example being 'in motion');

2. Clusters which appear close to each other when projected only onto the first two dimensions, may be seen to be distinct when projected onto dimensions 3 and 4. These changes can be used to understand the change of relative positions of the projected vectors related to entities as well.

Concerning the first two dimensions there seems to be a tendency for the vectors related to the ten entities to point towards being static (space and mass) or dynamic. Time slightly points towards being like a place. Light and heat more clearly point towards being localized and dynamic. To try to understand these vectors a little better it is useful to look into the clusters related to each dimension and also to look into the features which were chosen most often by the subjects to describe each entity.

The cluster analysis of results for 8-10 year-olds in Appendix I show a cluster 'a' associated with being localized (features in this cluster are: appear and disappear, act at a distance, immaterial and nowhere) which also associates with being an immaterial fluid. This fact can be seen to explain the position of light in the dimension place/localized (figure 3.2a). Light being very much like an immaterial fluid possibly caused it to be very much localized.

Cluster 'g' is also associated with being localized (features are: transform things, feel it, destroy things and act by contact) and being a cause, which may explain the position of heat (very much like a cause) in the dimension place/localized (figure 3.2a).

Cluster 'd' is associated with being localized (features are: somewhere, can destroy it, concrete, solid and can spread it) but it is also strongly associated with being static, which explains the position of mass in the space (figure 3.2a).

In the third and fourth dimensions space, light and time are immaterial fluids. Movement, impulse and sound as opposed to force, mass and energy, considered all to share features of being an action, are associated with the motion of an action or with the cause of an action. Heat is a cause but not very much associated with action. The separation of clusters 'c' (features are: at rest, like a fluid) and 'd' in the dimension action/immaterial fluid ('c' being associated with an immaterial fluid and 'd' being associated with action) may explain the split between mass and space in this dimension.

Figure 3.9 shows for each entity those features whose frequencies of 'yes' responses are above the upper quartile. The box plots with the distributions of 'yes' responses are in Appendix H. The upper quartile contain the features whose frequency of 'yes' responses has a value between the upper hinge and the adjacent or outside values.

It is possible to see how the sizes of the vectors relate to the distribution of these features for each entity. A small vector size very much reflects the fact that these features are spread all over the space, as is the case for time. It is also the case that features in quite opposite positions in the space are often used by the subjects to describe an entity.

A general result for each entity may be:

Light: more static than dynamic, localized, it is like an immaterial fluid;
Sound: dynamic and more like a localized than place-like entity, it is like an action;
Movement: dynamic and more like a place than localized, it is like an action and motion;
Force: dynamic and like an action and a cause;
Mass: static and localized, not an immaterial fluid, it shares features with actions;
Time: more like a place than localized, dynamic, it is like an immaterial fluid;
Impulse: dynamic and like an action;
Heat: dynamic and localized, a cause but with some features of an immaterial fluid;
Energy: more like a dynamic than a static entity, it is like a cause;
Space: like a place, an immaterial fluid and in motion.

3.2.2.2. Group 2: 13-14 year-old students

The second group is a group of 13-14 year-old students attending primary school in Brazil (N: 33) having some basic knowledge in Science. This group answered a questionnaire with 49 features asked about the same 10 entities presented to the previous group. The questionnaire was answered in 50 minutes. The space obtained for this group is shown in figure 3.3. The cluster analysis is in Appendix I. The

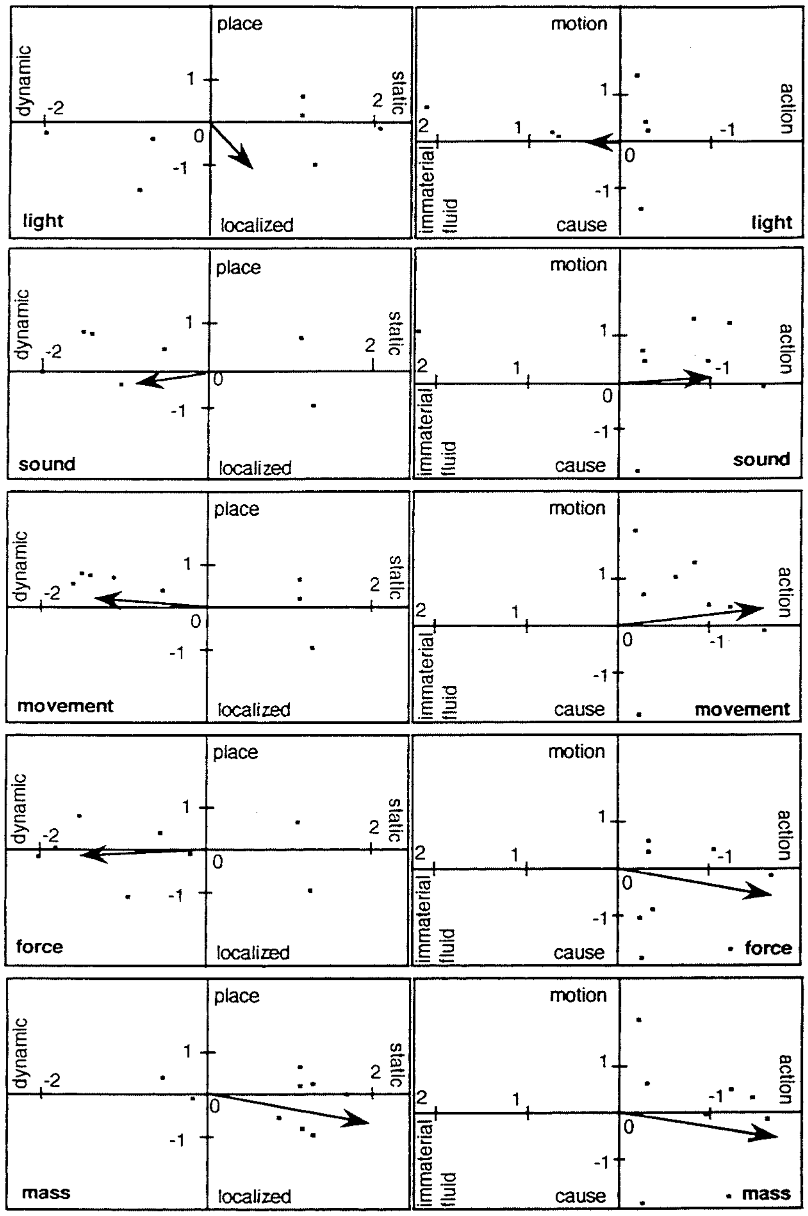


Figure 3.9. Features with a frequency of 'yes' answers above the upper quartile for each entity (8-10 year-olds).

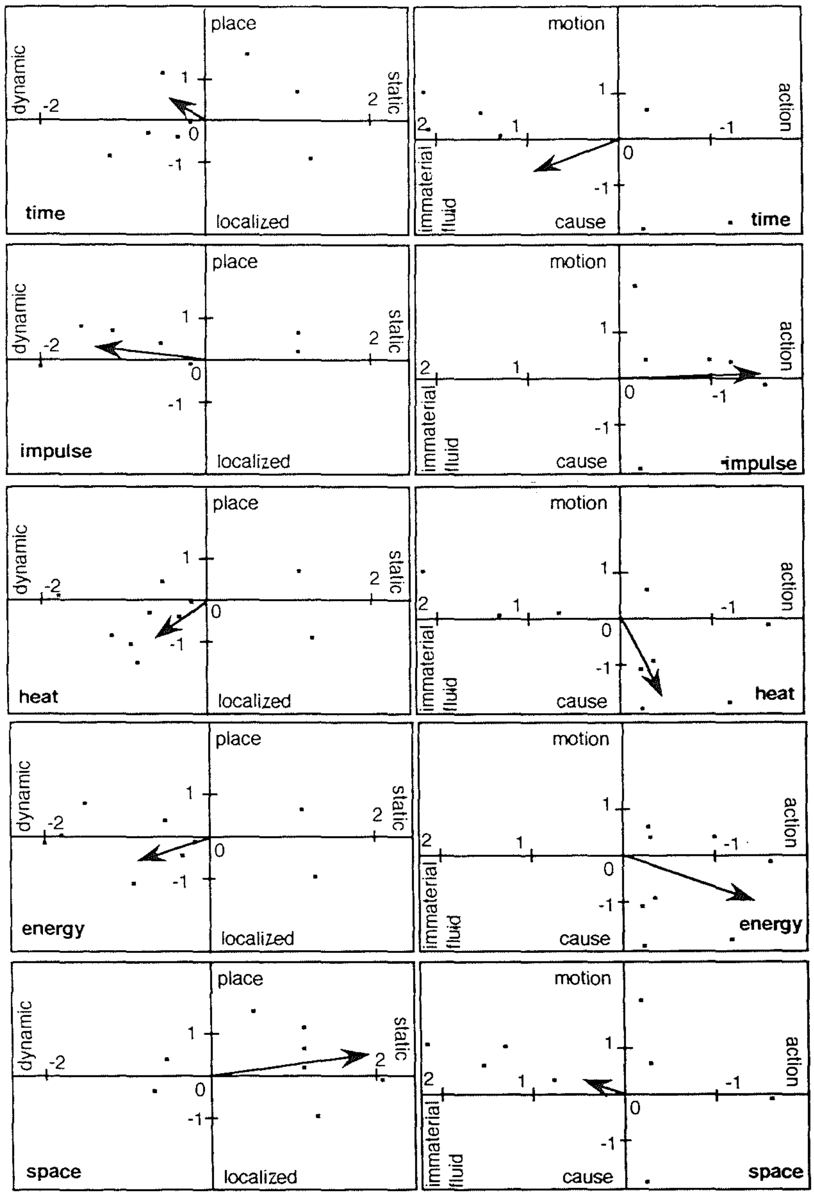


Figure 3.9. *Features with a frequency of 'yes' answers above the upper quartile for each entity (8-10 year-olds)(continued).*

features with a frequency of 'yes' answers above the upper quartile for each entity can be seen in figure 3.10. The box plots with the distributions of 'yes' responses are in Appendix H.

Time in the first two dimensions appears to be clearly like a dynamic place. Space is not really like a place or a localized entity, but is only static, like matter. Light and heat are clearly localized, light being static and heat being dynamic like all the other entities. This space is very much the same as the one obtained for 8-10 year-olds concerning the position of the entities and features.

Being localized is related to a cluster 'c' of features (features in this cluster are: fluid, can touch through, can transfer it, can spread it, can concentrate it, it appears and disappears, act at a distance) which also relates to being like an immaterial fluid, explaining the positions of heat and light in the dimension place/localized (figure 3.3a). The close relationship between cluster 'd' and being static (features are: gas, can see it, it is at rest) may explain the position of space in the first two dimensions (static but not place or localized).

In dimensions 3 and 4, space, light and time are like immaterial fluids, heat is a bit like an immaterial fluid and very much like a cause; sound is a motion and an action; movement, impulse, energy, force and mass share the features of an action. There is a split of the entities mass and space in the dimension action/immaterial fluid which can be explained by a split of the clusters 'e' (features are: somewhere, can conserve, like particles, real, can destroy it, can transform it, microscopic, like a substance, can touch it, macroscopic, concrete and solid) and 'd' from being associated with being static to 'e' being associated with action and 'd' associated with being an immaterial fluid.

Using also figure 3.10 it is possible to give a general account of entities. Some representative responses from students' own descriptions of these entities are given in italic:

> **Mass:** static but sharing features of being an action;
> *" It can be changed, touched; it is an object in space; it exists, it is a thing; something solid, material, which we can transform"*

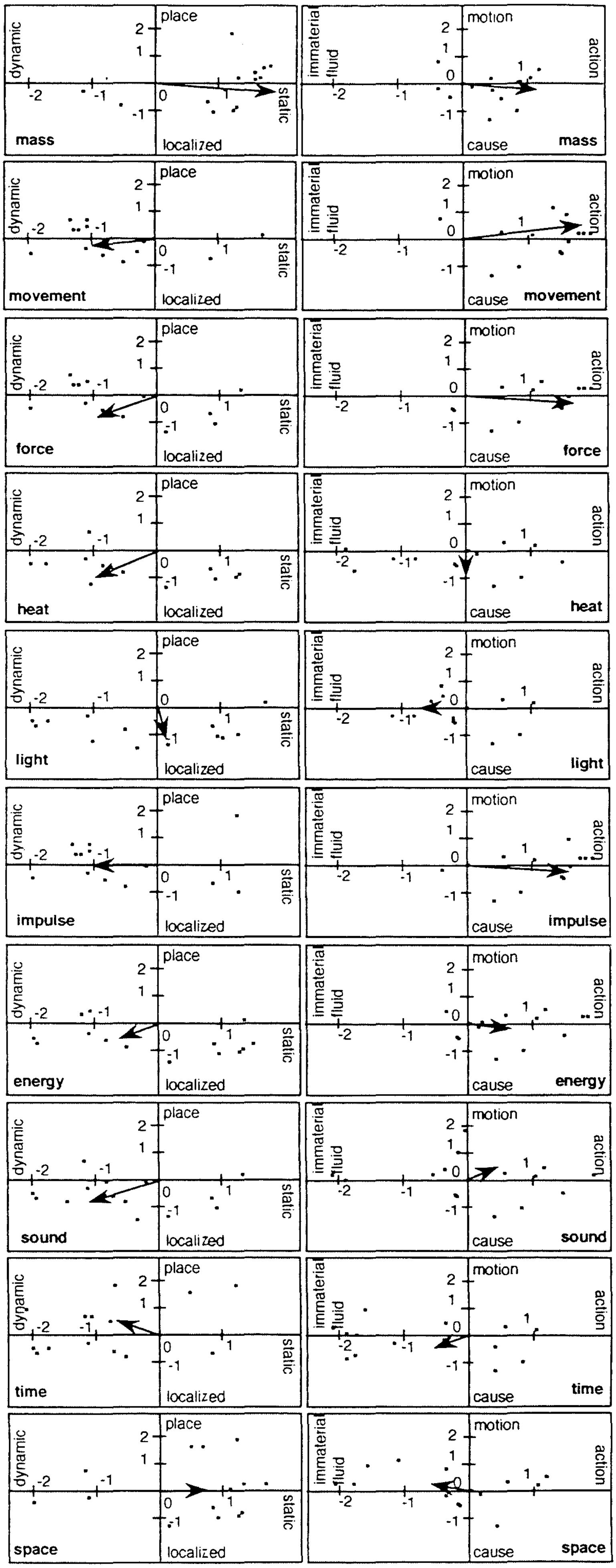


Figure 3.10. *Features with a frequency of 'yes' answers above the upper quartile for each entity.*

Movement: dynamic and like an action;

"It is caused by a force on a body, it can be changed or stopped; it is a force which is able to do things; it is an action which make things move; it is an action which can transform things; it is when you move; a thing which moves and you can see; everything we do"

Force: dynamic and localized, it is like an action;

"It is an action which can transform things; it is something you do to move; it is a kind of an action of a movement"

Heat: dynamic and localized, it is a cause;

"It is an energy we can feel the effects; something which transforms matter and can be felt as a hot wave; something hot; it heats up; something we do or something which appears by itself"

Light: localized, it is an immaterial fluid;

"It is a fluid, a group of particles, it can be manipulated in different ways; something you can see; something that makes you see; it is an energy; it illuminates"

Impulse: dynamic and like an action;

"A force that acts in the sense of the motion; it gives a sense of motion; something you do in order to jump; it is an action of motion"

Energy: more like a dynamic entity, it has also features of being static; it is related to action;

"It looks like particles which help a certain action; something which surrounds everything; we have a lot of energy; something we feel; precursor of everything related to action"

Sound: like a dynamic entity, it is like a motion;

"It is like a wave which cannot be stopped; something you hear; it acts when one thing hits another; a fluid you can hear but not see; an action we hear"

Time: a dynamic place-like entity, it is like an immaterial fluid;

"Something imaginary that exists; something which flows, we do not see it; space determined by the motion of bodies; it cannot be changed; it is a natural agent; we are inside it"

Space: static, it is like an immaterial fluid.

"It is an empty place which can be filled; a place where we do a lot of things; it is the basis for all actions; it is a place or an environment"

3.2.2.3. Group 3: young working adults

The third group is a group of young working adults, working during the day and attending secondary school in the evenings. Two questionnaires were given to two similar groups, in terms of age, year and period of course at a public school in Brazil (N: 2 X 31 subjects; the schools involved have similar curriculum and social environment). Each questionnaire presented 49 features to be asked about 8 entities (to be answered in 50 minutes). The space obtained for this group can be seen in figure 3.4. The cluster analysis can be seen in Appendix I.

The features with frequency of 'yes' answers above the upper quartile for each entity are shown in figure 3.11. The box plots with the distributions of 'yes' responses are in Appendix H.

A different format from the previous groups is used for the representation of this data due to the increased number of entities to be analysed. This format will also be used for 16-18 year-olds and undergraduate physicists. In these plots the coordinates of features in each of the four dimensions are represented by four vertical lines for each entity. The features above the upper quartile are highlighted (circles). Each of the four vertical lines displaying the coordinates for each entity is identified (static/dynamic and so on). Positive coordinates lie towards the first-named pole of the dimension; negative towards the second named. For example for static/dynamic, the positive coordinates lie towards being static.

For example for mass (figure 3.11: upper-left) in the first dimension named as static/dynamic, features highlighted tend to lie towards the static end of the dimension. In the second dimension named place/localized, features highlighted tend to lie towards being localized.

The first notable change in relation to the previous groups is the fact that entities are not confined mostly to the direction dynamic/static but are also differentiated more clearly as being like a place or a localized entity. Space and time are like a place while the other entities are localized, except for temperature. Atom, mass, matter, weight and space are like static entities while the others are like dynamic entities.

The changes in the positioning of entities in relation to the third and fourth dimensions is even more noticeable: space, sound and light are immaterial fluids, light being also a cause; movement is not action anymore but pure motion; weight and electricity are pure causes; heat,

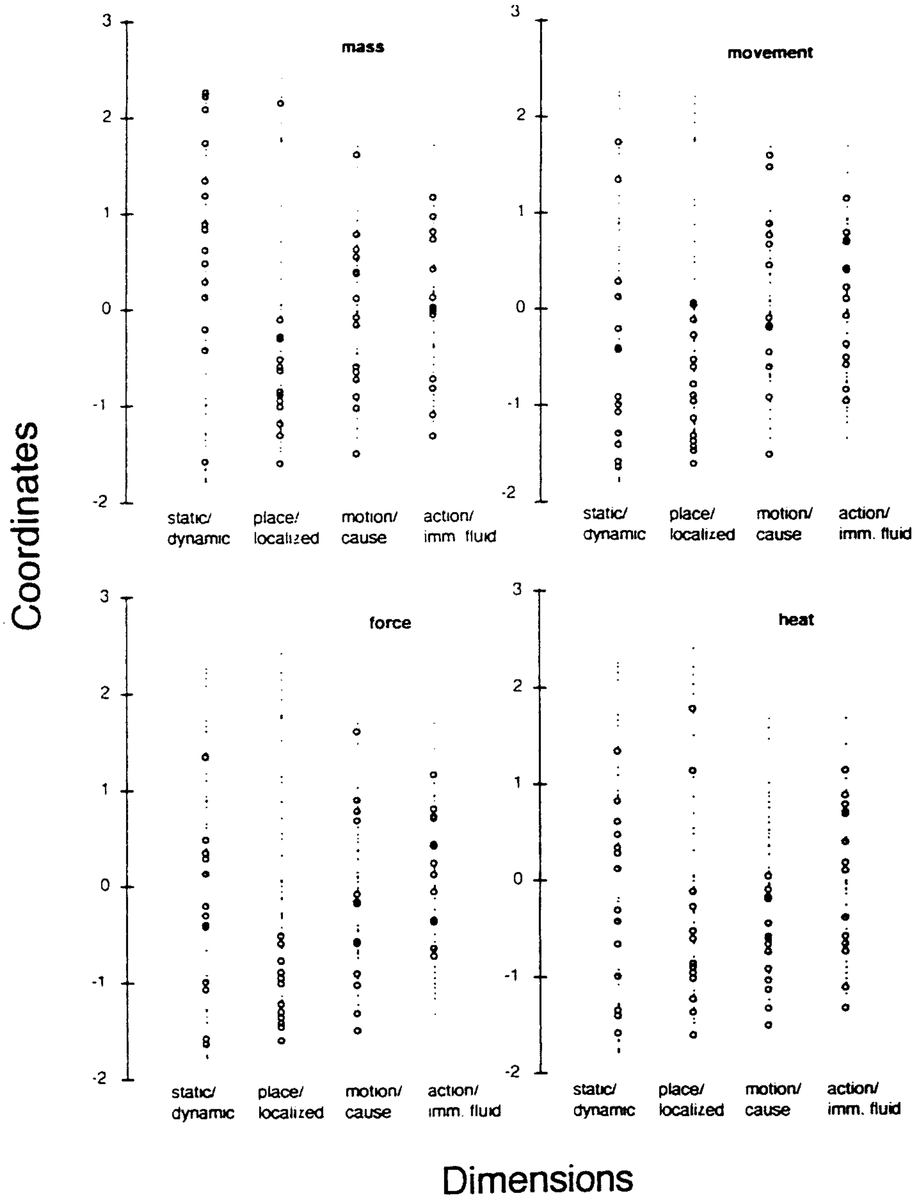


Figure 3.11. Features with a frequency of 'yes' responses above the upper quartile for each entity are highlighted as circles (young working adults).

(positive values related to static, place, motion and action (discrete); negative values related to dynamic, localized, cause and immaterial fluid (continuous))

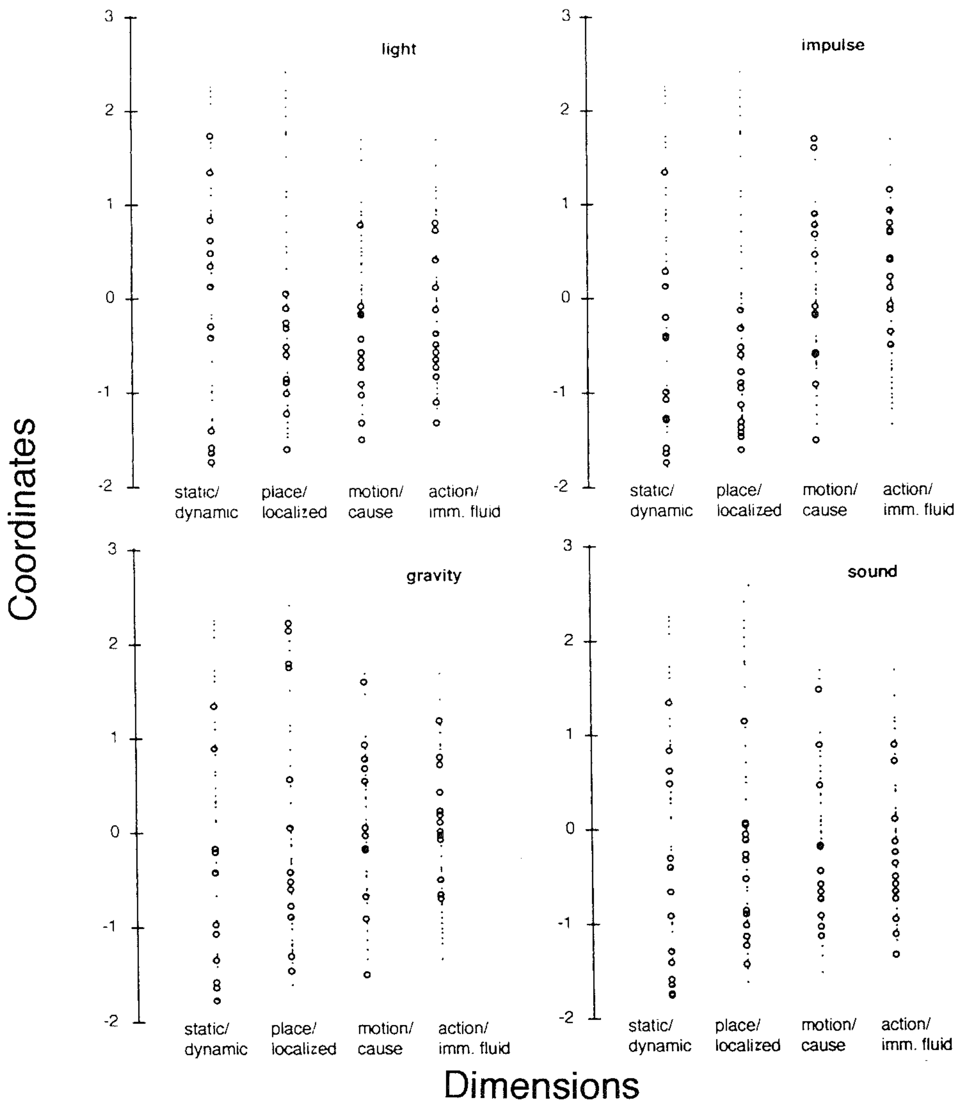


Figure 3.11. *Features with a frequency of 'yes' answers above the upper quartile for each entity (young working adults) (continued).*

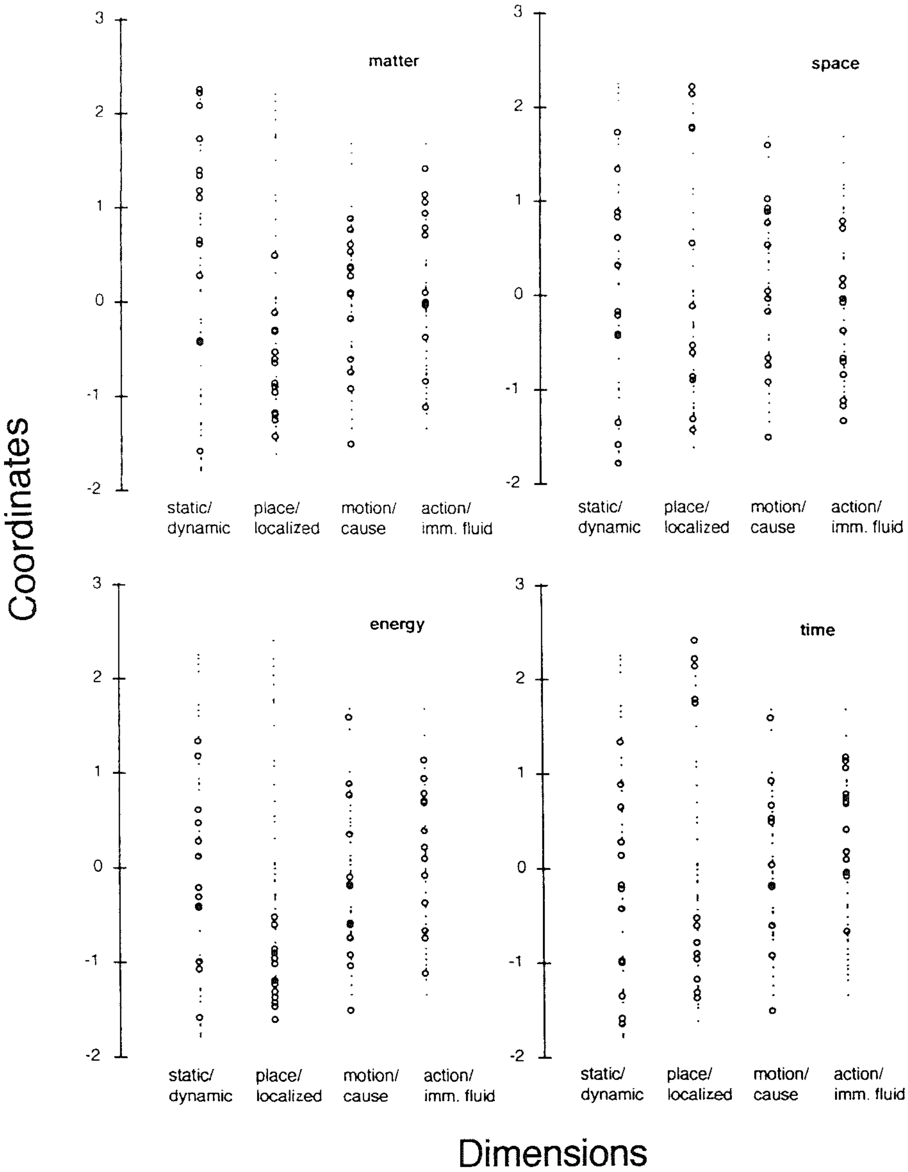


Figure 3.11. Features with a frequency of 'yes' answers above the upper quartile for each entity (young working adults) (continued).

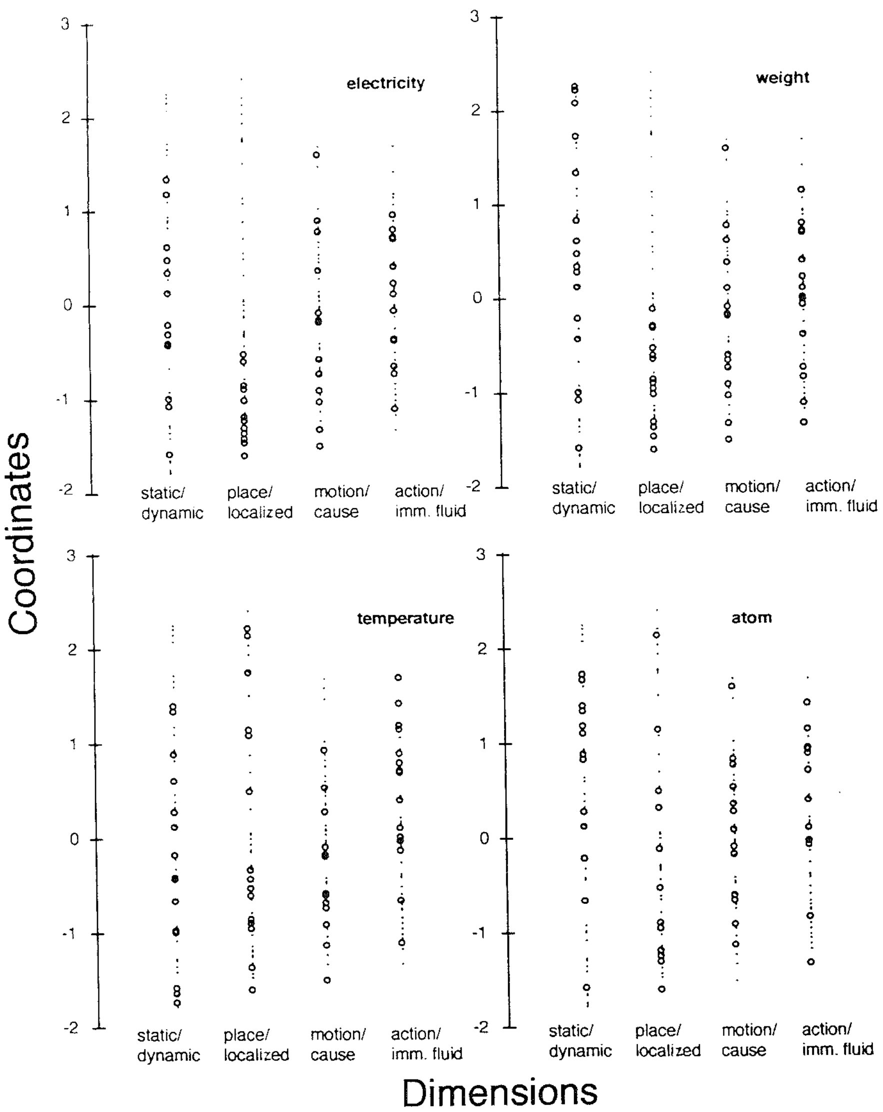


Figure 3.11. *Features with a frequency of 'yes' answers above the upper quartile for each entity (young working adults) (continued).*

force, temperature, gravity, energy are like causes and also related to action; impulse, atom and time are related to action.

By looking into the cluster analysis it is possible to understand some of the changes. Cluster 'f' (features are: microscopic and like particles) is strongly related to being like an action instead of an immaterial fluid, or of being discrete rather than continuous. This may explains why an atom is rather like an action.

At the same time cluster 'd' (features are: like a wave, can hear it, like an action, like a force, can create it, can stop it, can cause movement, like movement) strongly relates to being like a motion but with some features which can also be seen to be related to action, which could explain why movement now is strongly related to being like a motion (in this case also associated with action).

This space and the one obtained for 16-18 year-olds can be understood as like a mixture of the spaces obtained for 8-10 and 13-14 year-olds and the one obtained for undergraduate physicists. The first two dimensions are not very much affected from the first group of 8-10 year-olds to undergraduate physicists, except that the distinction place/localized starts to be more relevant with age/instructional level, but dimensions three and four seem to be largely affected, dimension four being changed from being a distinction between action/immaterial fluid to a distinction between 'discrete/continuous' entities.

Figure 3.11 shows how features with frequency of 'yes' answers above the upper quartile are spread for each entity. This figure together with the previous discussion can generate a general account of each entity in the space obtained (individuals' representative descriptions of these entities in italic):

> **Mass:** static and localized, it has features spreading all over the space of the third and fourth dimensions;
> *"Something concrete; it is something I see; it is something with a form; it is a kind of solid"*
> **Movement:** dynamic and localized, it is like motion, but it has features of a cause, an action and an immaterial fluid;

"Action, a force that modifies the position of a body; we can feel the movement; it is a change"

Force: dynamic and localized, it is like a cause and an action, with some features of being motion and immaterial fluid;

"Something which acts on bodies; it is an action; it seems imaginary, it is felt and touched"

Heat: a bit more dynamic than static, it is localized, it is a cause and like an action, but with some features of being like an immaterial fluid;

"It modifies the bodies transforming them, changing their colour, it is perceptible; I can spread it; a form of energy causing a thermal change in a body"

Light: more dynamic, with features of being static, it is localized, it is a cause in the form of a immaterial fluid;

"I can see with it; it can act at a distance; it can be seen; form of luminous energy; it is the force which make us see; it is a cause and can be felt"

Impulse: dynamic and localized, it is a bit more like a motion than a cause, it is like an action;

"It is a force on a body; it is an action on a body; a force applied somewhere"

Gravity: dynamic and with features of a place and of being localized, it is more like a cause than a motion, it is an action but has some features of an immaterial fluid;

"Force pulling the bodies to the centre of the Earth; it surrounds us, our weight changes with it; it is a cause"

Sound: dynamic, localized, it is a bit like a cause and an immaterial fluid;

"Something we hear; it acts as waves; it moves in space; we perceive effects, we can spread it"

Matter: static and localized, it is not a cause or a motion, with some features related to action;

"Linked to our daily life; something concrete we can touch; something solid with a form; all that exists"

Space: static with some dynamic features, like a place, with some features of being localized, like an immaterial fluid, has features of a cause and of a motion;

"Something empty; occupied by a body; I can't touch it; something abstract but can be seen; it is where we are"

Energy: dynamic with some features of being static, localized, a bit more like a cause than motion, it is like an action but also associated to some features of an immaterial fluid;

"It is a force caused by an impulse; something we can feel; it causes effects on things"

Time: more dynamic than static, it is like a place but has features of being located, with features of being a cause and a motion, it is related to action;

"Something you perceive in your daily life; we cannot see it but we can feel it flowing; it is a space which flows; the interval between one action and another; event which does not stop; you can't act upon it"

Electricity: dynamic with some features of being static, it is localized, it is a cause with some features of motion, it has features of being an action and an immaterial fluid;

"It is an energy; energy flowing from one wire to another; you can feel it, create it; a kind of force; not a natural force, it is caused; it has an effect on us"

Weight: with more features of being static than being dynamic, it is localized, a cause with only some features of a motion, has features of being an action and an immaterial fluid;

"It is the mass of each body; something material; a force upon something; I can feel it; heavy things"

Temperature: more dynamic than static, it has features of being a place and of being localized, it is a cause and related to action;

"Kind of energy; we can feel it by the effects it causes; sensation of hot or cold; it is real; source of heat; it is a climate"

Atom: static and localized with a few features of a place, it has features of a cause and of a motion and it is related to action.

"Microscopic particles; very small and alive particles in motion; real but we cannot see; something nearly non-existent"

3.2.2.4. Group 4: 16-18 year-old students

The next group is a group of 16-18 year-old students attending secondary school in Brazil. These subjects have some basic knowledge of Physics. The sample is divided in four similar smaller samples (N:50 x 4) answering four complementary questionnaires, presenting the same 54 features for a different selection of entities. Each small sample is similar to the overall sample in terms of the age of students involved, period and year of course. All students are from public school in Brazil; all schools involved have similar curriculum and social environment. A total number of 22 entities were investigated (divided in groups of 7-8 entities for each questionnaire, to be answered in 50 minutes).

The space obtained can be seen in figure 3.5. The cluster analysis can be seen in Appendix I. The features with frequencies of 'yes' answers above the upper quartile for each entity are shown in figure 3.12. The box plots with the distributions of 'yes' responses are in Appendix H.

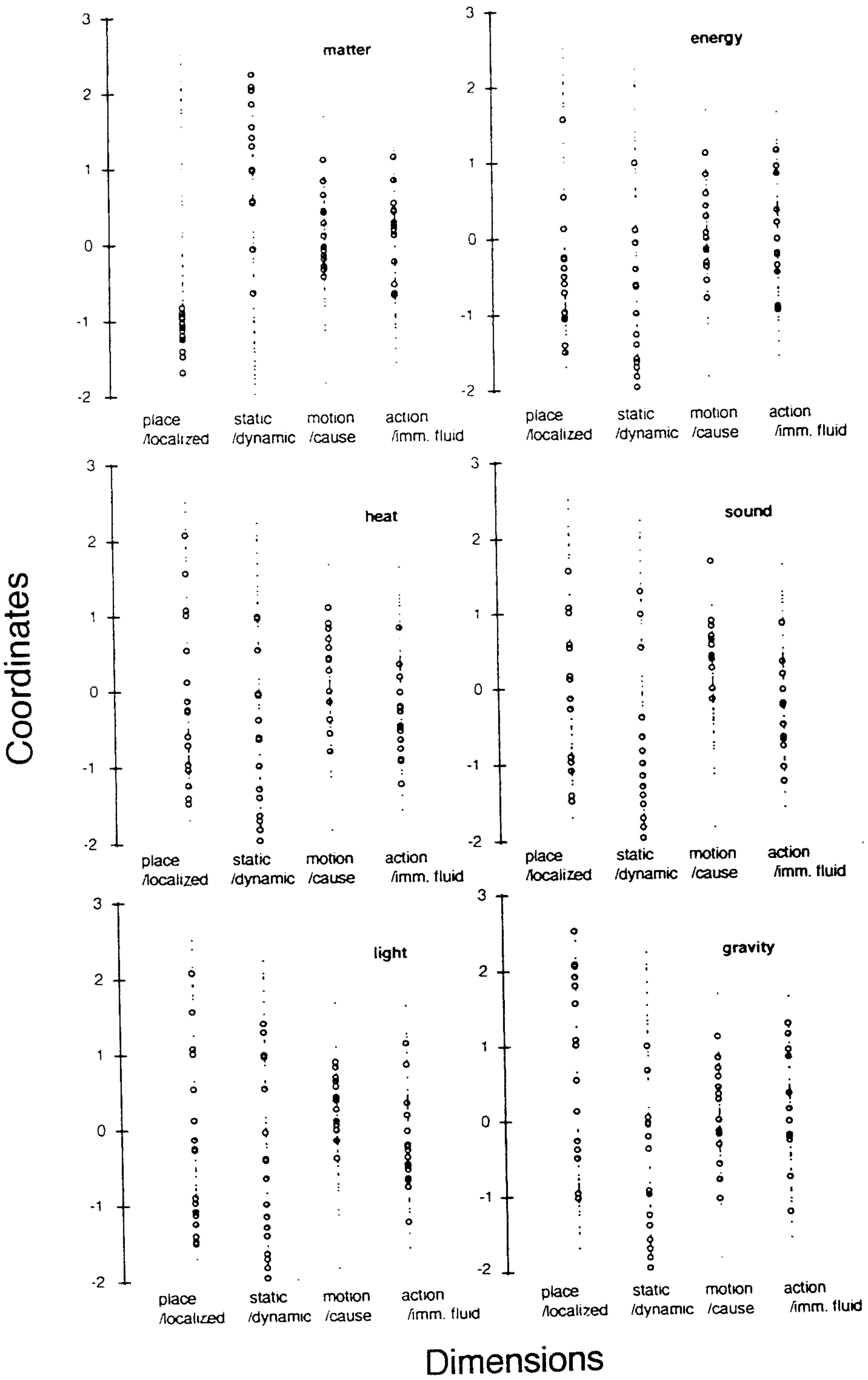


Figure 3.12. Features with a frequency of 'yes' responses above the upper quartile for each entity are highlighted as circles (16-18 year-olds).

(positive values related to static, place, motion and action (discrete); negative values related to dynamic, localized, cause and immaterial fluid (continuous))

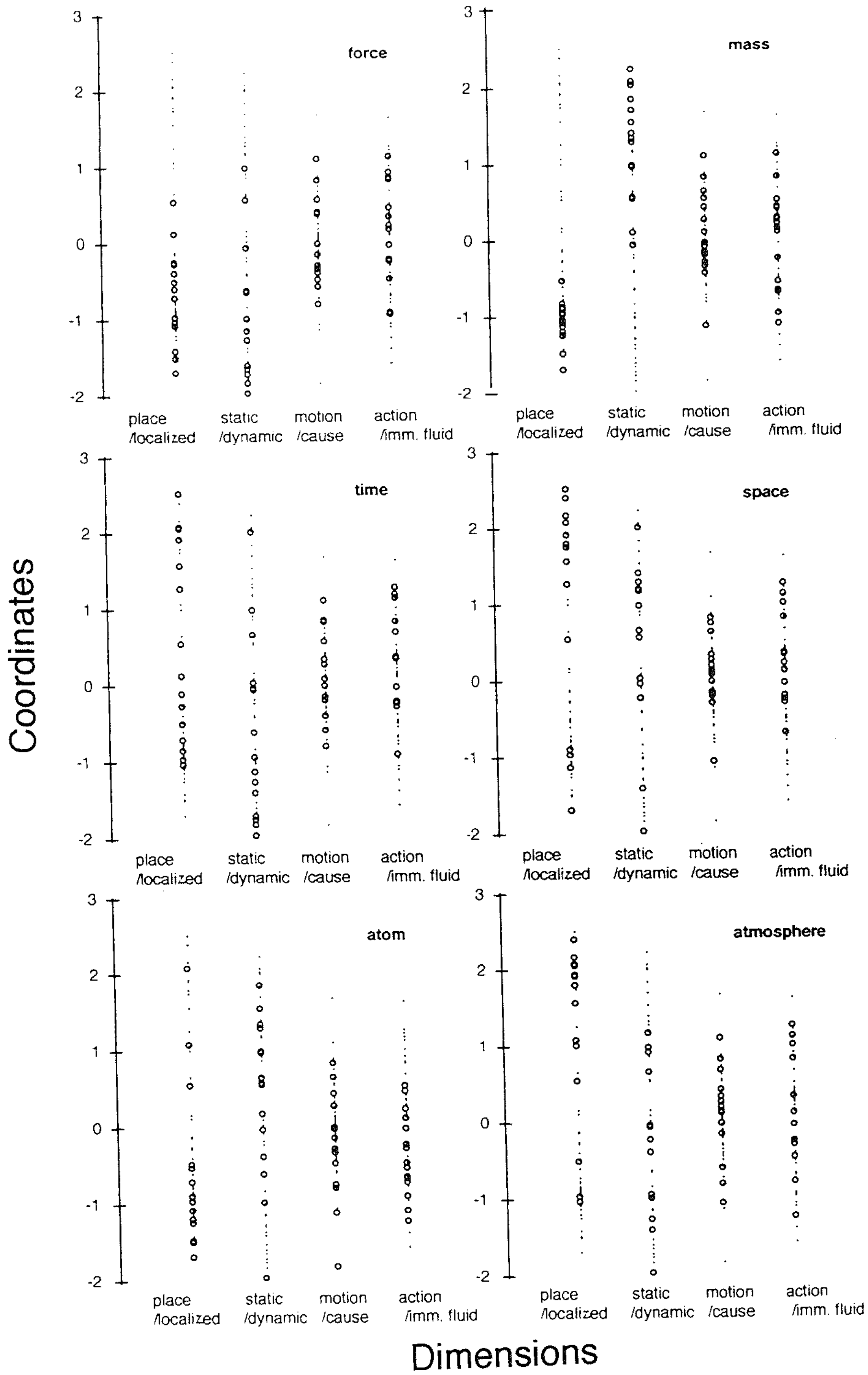


Figure 3.12. *Features with a frequency of 'yes' answers above the upper quartile for each entity (16-18 year-olds) (continued).*

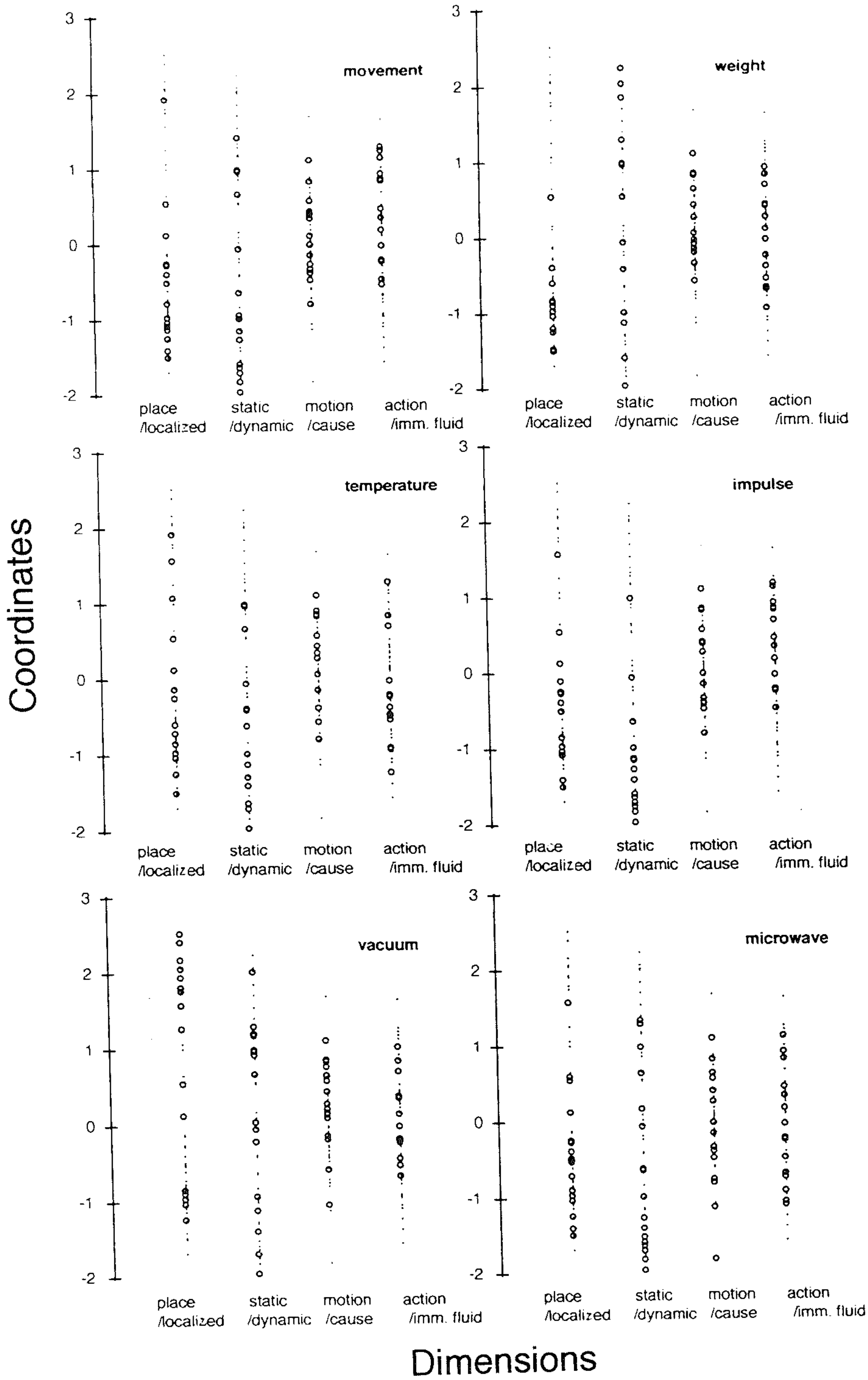


Figure 3.12. *Features with a frequency of 'yes' answers above the upper quartile for each entity (16-18 year-olds) (continued).*

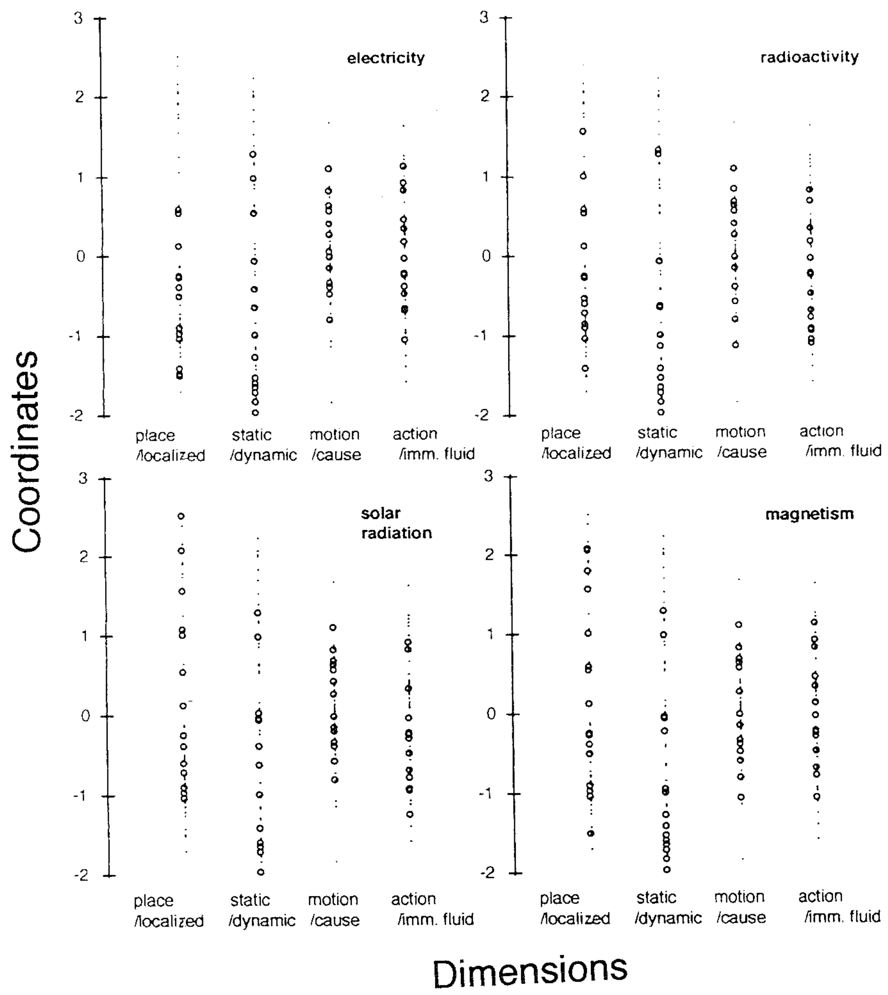


Figure 3.12. *Features with a frequency of 'yes' answers above the upper quartile for each entity (16-18 year-olds)(continued).*

The first interesting aspect of the distribution of the entities in the first two dimensions of this space is how the new entities introduced occupy certain positions without disturbing the positions of the nine fundamental entities presented to all groups in the pilot study for the same age group (Mariani and Ogborn 1991; see Appendix D.2.).

Time is still like a place and dynamic, space is like a place and static, mass is static and localized, and the other six fundamental entities are localized and dynamic. Gravity, vacuum, atmosphere and solar radiation are also like a place, gravity and solar radiation being also dynamic. Atom, weight and matter are localized and static. All other entities are dynamic and more localized than like a place.

Of the clusters obtained, cluster 'f' is clearly composed of features related to being localized and like a static entity (features are: can create it, can transfer it, act by contact, can transform it, real, localized, can spread it, conserve it, touch through it, material, can touch it, solid, concrete, substance, can destroy it and macroscopic). Cluster 'd' has to do with being like a place (features are: like a vacuum, like a place, can be inside it, act by itself, gas, can't do anything to it, exist without acting and at rest).

Some new small clusters appeared ('a': microscopic and particles; 'b': imaginary and field; 'g': multiply by itself and concentrate by itself). The introduction of new features and entities can be seen to be causing a different clustering than the one obtained in the pilot study.

The introduction of the new entities and features affected the distribution of entities and features in dimensions 3 and 4, but without the necessity of a new interpretation of these dimensions. Sound and movement are still like motion rather than cause, sound being like an immaterial fluid (or continuous) and movement being like an action (or discrete). Force is still like an action, and like a cause. Time, space and matter are still not well represented in these two dimensions.

Light is still an immaterial fluid, but also like a motion. Energy and heat change from being cause and discrete to be immaterial fluids, the first like a cause and the other like a motion. The distribution of clusters in these two dimensions can explain this change. Most features related to being a 'source' in the pilot study appear now to be related to being an immaterial fluid, cause or motion (clusters 'e', 'j' and 'h'). So there is a new distribution of features without this affecting the general interpretation of these two dimensions in relation to the other groups and to the pilot study.

Temperature, solar radiation, electricity radioactivity, microwave and atom are all immaterial fluids in this space, the last one being like a cause. The position of atom can be explained by the presence of the cluster 'a' in this region of the space ('a': microscopic and particles). Magnetism is a cause. The other entities are not well represented in these two dimensions.

The general account for the entities with a basis also in figure 3.12, with some representative responses obtained from these students in italic, is:

Matter: localized and static, some features of motion and action;
" Something concrete you can touch; it is visible; all we can feel and see; it is a body at rest or in motion"
Energy: localized and dynamic, like a cause and immaterial fluid;
"A force of the bodies; it is everywhere but we can't see it; invisible; it generates life"
Heat: localized with features of being a place, dynamic, like motion and immaterial fluid;
"We can't see it but we can feel it; it is a field; it is an effect"
Sound: localized with features of being a place, dynamic, motion, like an immaterial fluid;
"We can hear it; waves in space; it travels; vibrational motion"
Light: localized with features of being a place, dynamic with features of being static, like a motion and immaterial fluid;
"An energy you see; it moves through things, kind of force"
Gravity: like a place, dynamic, features of motion and cause and of action and immaterial fluid;
"Something which pulls; kind of force; you can't see it; you can't act upon it"
Force: localized and dynamic, like a cause and action;
"Something which acts upon mass; immaterial; it acts by contact; something we only feel; causes an effect; like an effect"

Mass: localized and static, some features of motion and action;

"Quantity of substance; something concrete and material; it can be moved; the weight of a body"

Time: like a place and dynamic, some features of motion and action;

"Something which never stops, it can't be seen only felt; something which acts on everything...it transforms, destroys and creates material bodies; it exists everywhere"

Space: place with features of being localized, static with features of being dynamic, has some features of action;

"It is a place; empty vacuum; it is real but it seems imaginary; you can see it but it is not concrete; it is invisible"

Atom: localized with some features of a place, static with features of being dynamic, like microscopic particles;

"Invisible; a very small particle; causes effects on things; non divisible particle; it creates things"

Atmosphere: like a place, features of being static and dynamic, is not clearly represented in the last two dimensions;

"A place where the plants, the Moon and the Sun are located; it is a force which acts on Earth; we can see it and feel it and also we can act on it"

Movement: localized and dynamic, like motion and action;

"Something that happens to material things; we can see it, feel the movement, things acquire movement by contact; it is a kind of force; it is everything we do; it is an action"

Weight: localized, more static than dynamic, not clearly represented in the last two dimensions;

"Something with mass; causes various kinds of movements; it changes with the place"

Temperature: more localized than place, dynamic, more like an immaterial fluid;

"It changes by itself; waves which influence everything; a form of energy; it transforms and modifies things; it is a climate"

Impulse: localized and dynamic, it is like an action;

"It acts on other things; it is a force; it is a movement; causes effects; like giving a push; a force you do to move"

Vacuum: like a place with features of being localized, features of being static and dynamic, not well represented in the last two dimensions;

"Something empty, doesn't change, exists without acting; a place where there is no air; something which acts"

Microwave: localized and dynamic, with some features of being the opposite, it is like a cause and immaterial fluid;

" Waves of heat; transform things; a fluid or very small particles; an energy you can't see"

Electricity: localized and dynamic, a bit like an immaterial fluid;

" Like a gas; a wave of electric charges; kind of force; like an energy; we can't see it; it makes things move"

Radioactivity: localized and dynamic, with some features of being the opposite, is like an immaterial fluid;

" We can perceive its effects; invisible force which can destroy; like a ray; kind of field which acts by contact"

Solar radiation: more like a place than localized, dynamic, like an immaterial fluid;

"It is like a force acting upon all the planet; it gives energy, heats up; waves of light from the Sun"

Magnetism: with features of being localized and like a place, dynamic with features of being static, it is a bit like a cause.

"A force which attracts metal; we can perceive its effects without seeing it; invisible force; a field a magnet creates; attracts things, repel things"

3.2.2.5. Group 5: undergraduate physicists

The last group is a group of undergraduate physicists finishing the course of Bachelor and/or Licentiate in Physics at the University of São Paulo in Brazil. Two similar samples (N:32 x 2) were given a questionnaire with the same 65 features and having 11 and 12 different entities each (answered in 50 minutes). The samples were similar in terms of the age of students involved, period and year of study at the Institute of Physics, University of São Paulo. A total of 23 entities were investigated.

The space obtained can be seen in figure 3.6. The cluster analysis can be seen in Appendix I. The features with frequency of 'yes' answers above the upper quartile for each entity are shown in figure 3.13. The box plots with the distributions of 'yes' responses are in Appendix H.

Again as with the previous groups there is no change in the position of the nine fundamental entities in the first two dimensions. Gravity and field are like a place. Magnetism is a bit like a place, magnetism being dynamic. Matter and mass are localized and static. Other entities are dynamic and localized, except for a new set of entities: neutrino, quark, charge and spin which are not very well represented in these two

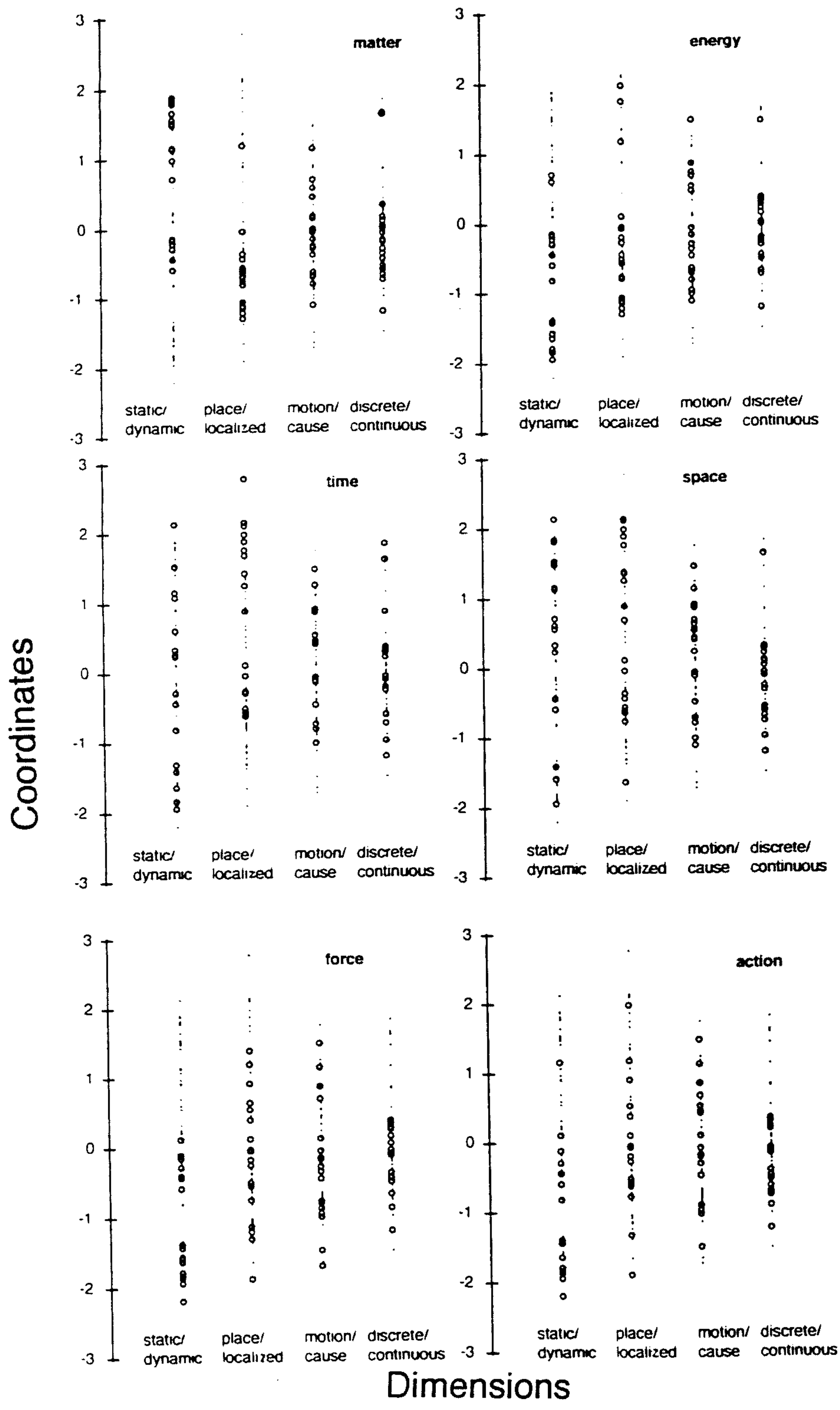


Figure 3.13. Features with a frequency of 'yes' responses above the upper quartile for each entity are highlighted as circles (undergraduate physicists).

(positive values related to static, place, motion and action (discrete); negative values related to dynamic, localized, cause and immaterial fluid (continuous)).

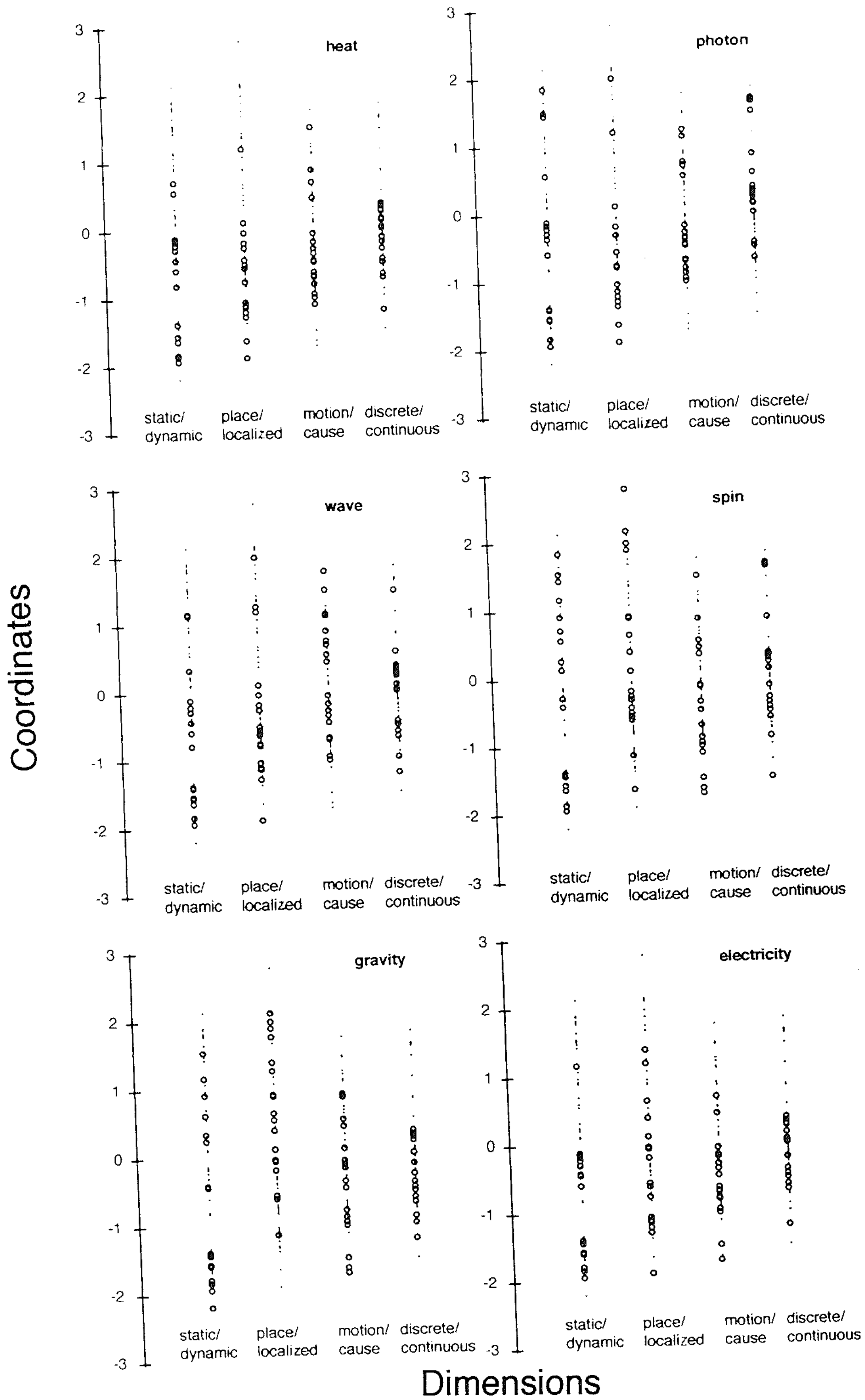


Figure 3.13. *Features with a frequency of 'yes' answers above the upper quartile for each entity (undergraduate physicists) (continued).*

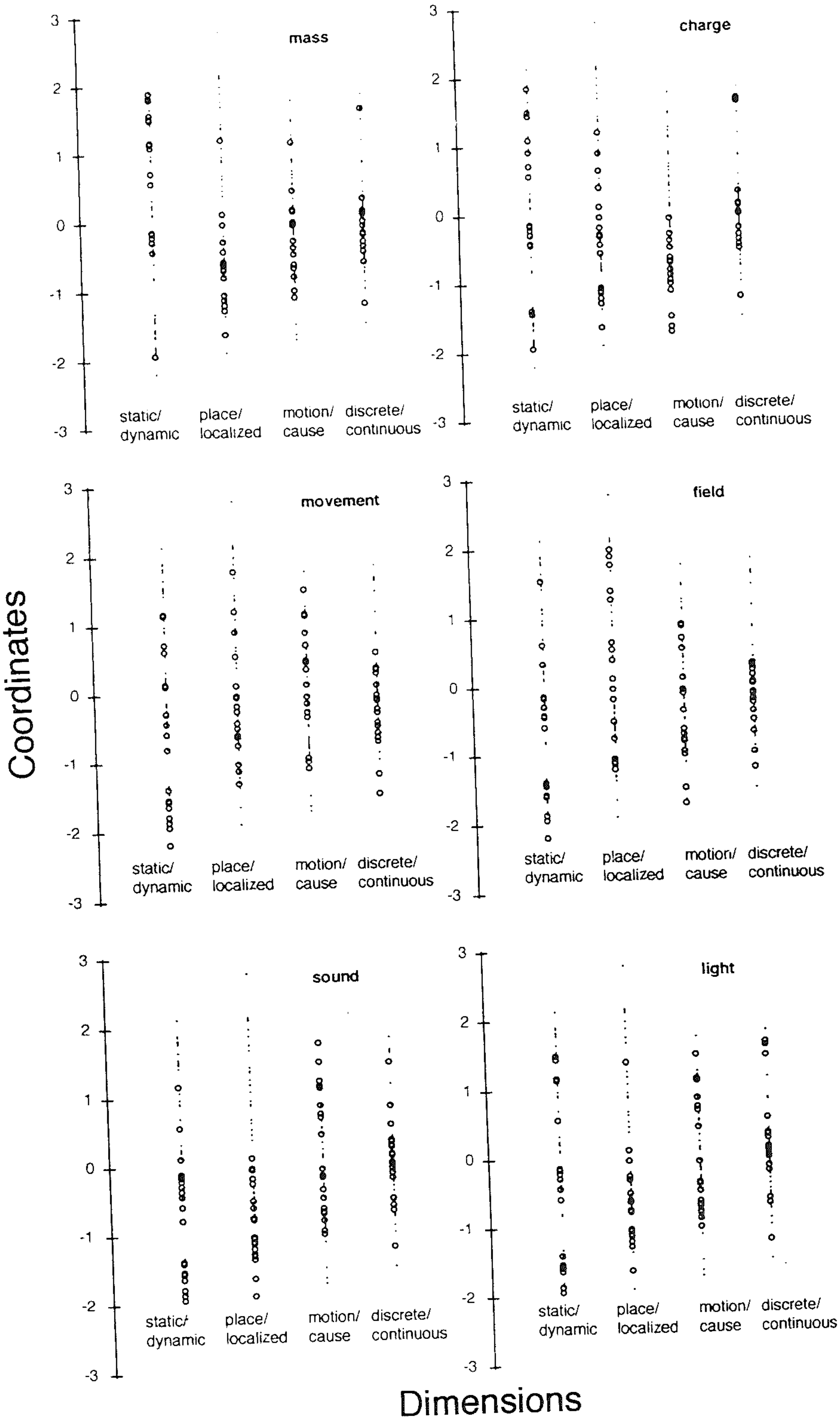


Figure 3.13. *Features with a frequency of 'yes' answers above the upper quartile for each entity (undergraduate physicists) (continued).*

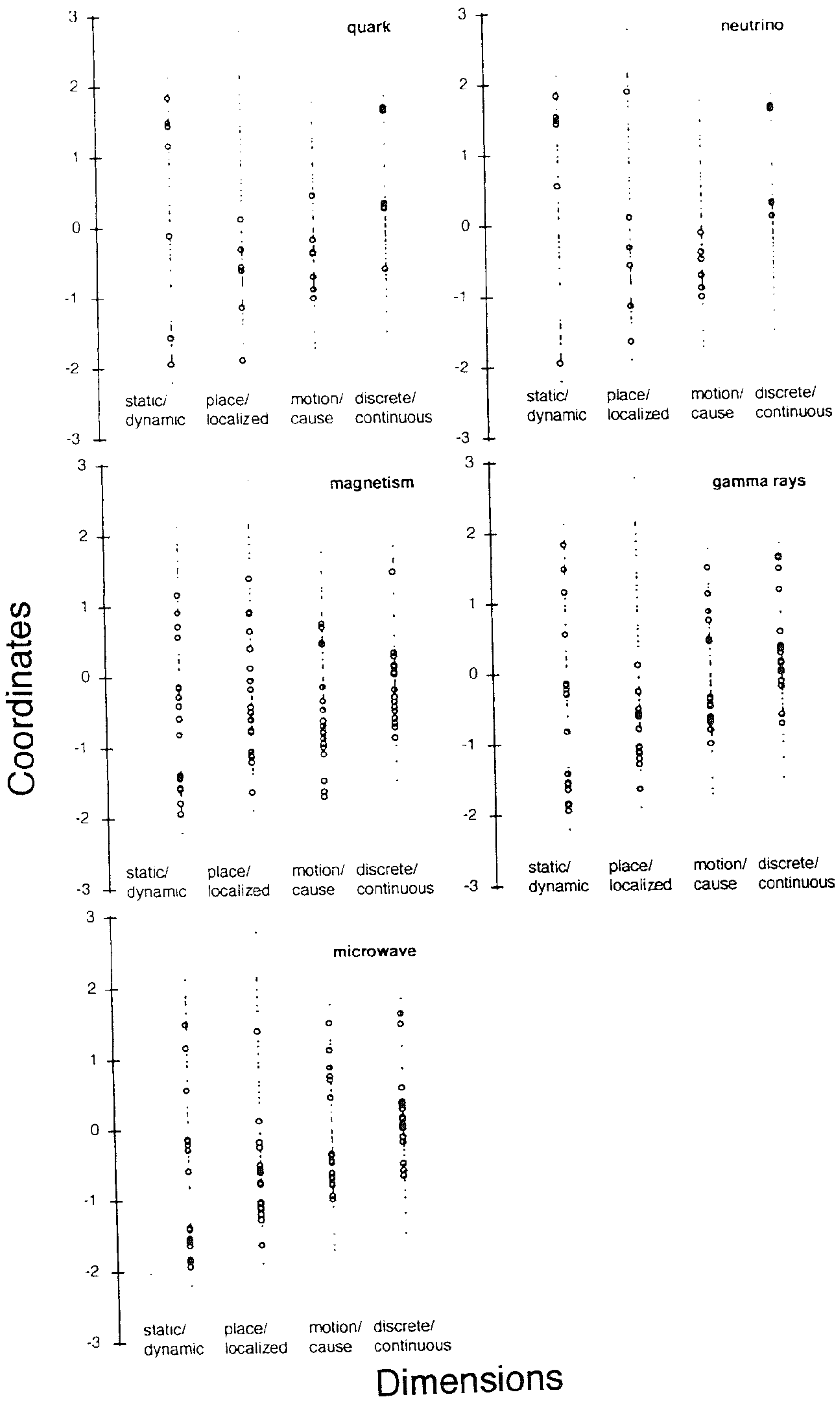


Figure 3.13. *Features with a frequency of 'yes' answers above the upper quartile for each entity (undergraduate physicists) (continued).*

dimensions. Charge is a bit localized and dynamic, neutrino a bit localized, quark a bit static and localized and spin a bit like a place and dynamic.

Concerning the last two dimensions a new interpretation of the fourth dimension as discrete/continuous in place of action/immaterial fluid seems preferable. Cluster 'e' (features are: microscopic, discrete and like particles) is strongly associated with the discrete side and cluster 'c' (features are: relation, field, can transfer it, immaterial, state, continuum, can feel it, can transfer things, action, transformation, can transform it, multiplies by itself, like an effect) is associated with the continuous side. Dimension three clearly splits the features effect and cause, and motion can be more generally seen as effect in this space (the same happens in the space obtained for 13-14 year-olds).

Like effect or motion are sound, movement, space, maybe wave and time. Space and movement are continuous. Discrete entities are light, microwave, photon, neutrino, quark, gamma rays, spin and charge. Charge is a cause, as are also magnetism, electricity, field, energy, mass, gravity, force, heat, matter and action.

The general description of each entity taking figure 3.13 into account is (with some representative responses in italic):

Matter: static and localized, it is like a cause and continuous;
" Things, objects you can touch; the touchable part of the Universe; condensed energy; cluster of particles; all that interacts in a detectable way"
Energy: dynamic, localized with some features of being static, it is a cause more than an effect, seen as continuous with a discrete feature;
"It is not here or there but it acts on everything; stored motion; causes natural events; discrete quantity"
Time: a bit more dynamic than static, it is like a place, a bit like a discrete motion;
"Where the Universe is immersed; always flowing, it never stops, but it can have different velocities; the periodic motion of a motion"
Space: more static than dynamic, more like a place than localized, continuous with a discrete feature, like a motion or an effect;
"Place where events happen; bodies and objects are inside it; has a structure similar to time, it fills the Universe"

Force: dynamic and localized, a cause and a continuous entity;
"Causes movement and transformation; relationship between two or more masses; can act by contact or at a distance; field, form of energy"

Action: dynamic and localized, a bit like a cause and continuous;
"The act of interacting; associated to motion and force; it is nowhere but it works; a manifestation of force"

Heat: dynamic, localized, cause with effect features, continuous;
"Sensory before anything, agitation of microscopic particles and electromagnetic radiation; a fluid which can be transferred; kind of energy that bodies have when heated up"

Photon: dynamic and localized, a bit like a cause and discrete;
"Particles which carry a certain quantity of energy; small packs of energy; imaginary concept to explain certain phenomena"

Wave: dynamic and localized, a bit like a motion;
"Form of propagation of energy; oscillations in time; curves, motion, transport of information"

Spin: more dynamic than static, more like a place than localized, like a cause and discrete;
"Intrinsic property of particles; the rotation of the electron; associated to motion, immaterial, localised; momentum associated to particles"

Gravity: more dynamic than static, like a place, it is a cause and continuous;
"Force of attraction between bodies; it is a field allowing action at a distance; related to the shape of space-time"

Electricity: dynamic and localized, it is a cause and continuous;
"Electric current or the motion of charges; property due to the existence of charges; a fluid which can be transferred and transformed"

Mass: static and localized, it is a cause and continuous;
"Property of bodies; quantity of matter; something solid; it is an abstraction; something we can feel, touch"

Charge: a bit more dynamic than static, localized, it is a cause and discrete with a few features of being continuous;
"Intrinsic property of matter; an active and immutable property; can be created by friction; electric entity, discrete"

Movement: dynamic and more localized than a place, it is motion or effect and continuous;
"A state of a body; change in space-time; change of position; it is relative; we can see and cause it; change of state"

Field: dynamic and like a place, it is a cause and continuous;

"Something which spreads everywhere generating certain effects; deformation of space; property of space; a property of bodies with mass or charge"

Sound: dynamic and localized, it is more like a motion than a cause and a bit more discrete than continuous;

"It is an effect; like a field it spreads; longitudinal wave; form of energy; movement of particles"

Light: dynamic with features of being static, localized, neither motion or cause, discrete with features of being continuous;

"Perceptible manifestation of energy; it spreads in space; electromagnetic wave; particles with field at a high velocity"

Quark: a bit more static than dynamic, localized, like a cause and discrete;

"Elementary blocks which constitute matter; theoretical model; kind of small colourful and tasty balls; postulated to explain certain phenomena"

Neutrino: features of static and dynamic, localized, cause and discrete;

"Elementary particle; particles without mass; they cause a certain phenomenon in the form of a perturbation"

Magnetism: more dynamic than static, more localized than a place, a cause and a bit continuous;

"Similar to a field; charges in motion; property of magnets; immaterial; it is a force; deformation of space"

Gamma rays: more dynamic than static, localized, a cause with features of motion, discrete;

"Non visible electromagnetic wave; particles with a field in high velocity; form of energy"

Microwave: more dynamic than static, localized, discrete.

"Electromagnetic radiation; use it to heat up frozen food; form of energy"

In the next Chapter these results will be discussed.

3.3. Results obtained in the second study

In this second study a questionnaire was given to a group of 16-18 year-old students (N:30) and undergraduate physicists (N:18) not coincident but similar to the previous samples. These questionnaires were described in the previous Chapter and can be seen in Appendix F. The objectives of these questionnaires were:

1. To apply an alternative technique to investigate further the space obtained in the first study, by now giving subjects explicit dimensions,

chosen with a basis on the results of the pilot study, and asking them to locate entities on these dimensions;

2. To be able to represent individual responses in this space;

3. To categorise individual interpretations of the dimensions given.

Considering objectives 1 and 2 a Principal Component Analysis was performed on the data obtained by asking individuals to locate a set of entities in a set of dimensions given to them. Considering objective 3 a systemic network was constructed in which to categorise individual responses interpreting the dimensions given. In the next Section the general results will be presented.

3.3.1. General results

Two groups equivalent to the groups of 16-18 year-olds and undergraduate physicists of the first study were given a questionnaire in which to locate a set of entities in a set of explicitly given dimensions. The questionnaires had a slightly different format for each group (see Appendix F). The 16-18 year-olds were asked to choose between six positions in a scale of 1 to 5 (with a position 6 for 'don't know'), in which to locate ten different entities in ten different dimensions. The entities given for the 16-18 year-olds were the nine fundamental entities of the pilot study (see Appendix D.2.), plus electricity.

The dimensions given were: a) equivalent to the four interpreted dimensions obtained in the pilot study: 'static/in motion', 'place/localized', 'effect/cause' and 'action/substance'; b) the interpretation of the diagonals in the space of the first two dimensions: 'passive/active', and 'material/immaterial'; and c) some additional relevant dimensions: 'conserved/not conserved', 'imaginary/real', 'object/vacuum' and 'concrete/abstract'. The tables with the data obtained can be seen in Appendix H.

The undergraduate physicists were asked to locate fourteen different entities (the nine fundamental entities of the pilot study and also including: mass, charge, gravity, photon and electricity) in ten given dimensions equivalent to the ones given to the 16-18 year-olds: only 'static/in motion' is substituted by 'static/dynamic' and 'object/vacuum' is substituted by 'discrete/continuous'. They could locate each entity in each dimension using a scale of -5 to +5. The tables with the data obtained can be seen in Appendix H.

In order to obtain a space in which to represent the data, the average position of each entity, calculated over each sample, in each dimension, was used. The correlations between pairs of dimensions across the averaged position of entities in these dimensions were obtained. The correlation matrix was used as input data for a Principal Component Analysis for each group (see also Appendix K).

By using a Principal Component Analysis the ten explicitly given dimensions will be related to a number of factors which will be the dimensions of a lower dimensional space. The ten dimensions will be related to these factors by factor loadings which can be understood as giving the correlation between these dimensions and the factors.

Visually, representing each of the ten dimensions by a vector, the projected 'size' or 'magnitude' of the vector on the space of the selected factors indicates how well that dimension is represented in the space of factors (an overall 'size' close to unity indicates that the dimension is well explained by the factors). The projections of the vectors on the factors indicate the correlation with the factors.

The orientation of the vectors has to be conventionally chosen. For example a dimension like real/imaginary presented as (see also figures 3.14 and 3.15):

1. Semantic differential for 16-18 year-olds: value (1) attributed to being real and value (5) attributed to being imaginary; the vector associated will be pointing towards being 'imaginary'. The same is assumed for the other dimensions (vectors will be pointing towards: not conserved, static, passive, action, localized, effect, immaterial, abstract and vacuum).

2. A dimension with coordinates ranging from (-5) for imaginary and (+5) for real for undergraduate physicists; the vector associated will be

Principal Component Analysis
EigenValues

	Values	Variance Proportion
e1	5.717	57.2
e2	2.726	27.3
e3	0.761	7.6
e4	0.299	3.0
e5	0.195	1.9
e6	0.172	1.7
e7	0.066	0.7
e8	0.042	0.4
e9	0.022	0.2
e10	0.000	0.0

EigenVectors

→	V1	V2
conserved/not conserved	-0.301	-0.168
in motion/static	0.343	-0.180
active/passive	0.322	-0.314
substance/action	-0.380	0.124
place/localized	-0.117	0.564
cause/effect	-0.271	0.385
material/immaterial	-0.391	-0.144
concrete/abstract	-0.374	-0.178
real/imaginary	-0.229	-0.465
object/vacuum	-0.333	-0.302

Unrotated Factor Matrix

→	F1	F2
conserved/not conserved	-0.720	-0.277
in motion/static	0.821	-0.298
active/passive	0.769	-0.518
object/vacuum	-0.797	-0.498
substance/action	-0.910	0.204
place/localized	-0.280	0.931
cause/effect	-0.649	0.635
material/immaterial	-0.934	-0.238
concrete/abstract	-0.894	-0.294
real/imaginary	-0.546	-0.767

Figure 3.14. *The result of the Principal Components Analysis for 16-18 year-olds. The ten dimensions are represented by vectors oriented as shown (left to right) and the factor loadings give the size and angle of these vectors in the space of factors.*

Principal Component Analysis

EigenValues

	Values	Variance Proportion
e1	3.639	36.4
e2	2.390	23.9
e3	1.940	19.4
e4	0.992	9.9
e5	0.473	4.7
e6	0.242	2.4
e7	0.148	1.5
e8	0.091	0.9
e9	0.082	0.8
e10	0.001	0.0

EigenVectors

⟶	V1	V2	V3	V4
immaterial/material	-0.448	-0.268	0.076	-0.147
imaginary/real	-0.281	-0.440	-0.200	0.070
effect/cause	-0.243	0.355	-0.049	0.668
passive/active	0.305	-0.084	0.429	0.397
static/dynamic	0.401	-0.277	0.234	-0.200
discrete/continuous	0.187	-0.096	-0.599	0.327
place/localized	-0.196	-0.173	0.554	0.216
abstract/concrete	-0.203	-0.530	0.008	0.335
action/substance	-0.482	0.071	-0.035	-0.253

Unrotated Factor Matrix

⟶	F1	F2	F3	F4
immaterial/material	-0.855	-0.414	0.106	-0.147
imaginary/real	-0.535	-0.681	-0.278	0.070
effect/cause	-0.463	0.548	-0.068	0.665
passive/active	0.583	-0.129	0.598	0.396
static/dynamic	0.765	-0.429	0.325	-0.199
discrete/continuous	0.357	-0.149	-0.834	0.325
place/localized	-0.373	-0.268	0.772	0.215
abstract/concrete	-0.388	-0.819	0.011	0.334
action/substance	-0.919	0.109	-0.049	-0.252
non-conserved/conserved	-0.472	0.690	0.299	-0.008

Figure 3.15. *The result of the Principal Components Analysis for undergraduate physicists. The ten dimensions are represented by vectors oriented as shown (left to right) and the factor loadings give the size and angle of these vectors in the space of factors.*

pointing towards being real. The same is assumed for the other dimensions (vectors will be pointing towards: material, cause, active, dynamic, continuous, localized, concrete, substance and conserved).

So the directions in the space of factors associated with the projected vectors represent the projections of the ten dimensions in the space (continuous lines will be indicating the projected dimensions) ; the 'size' or 'magnitude' of the projected vectors indicate how well represented they are in the space of factors; the orientation of the projected vectors is conventionally chosen and applied to all ten vectors in each case.

The results of the Principal Component Analysis can be seen in Figure 3.14 for 16-18 year-olds and Figure 3.15 for undergraduate physicists. The criteria to select the number of factors to be used was that they had eigenvalues near to or bigger than one. Two factors were selected for 16-18 year-olds and four factors for undergraduate physicists (last factor had an eigenvalue very close to one).

In the space of factors it is possible to represent the entities used as points in this space. This can be obtained by multiplying the factor score weights of each of the ten dimensions on the factors by the average position of each entity in each dimension. The factor score weights can be seen in tables 3.4 and 3.5.

The principal component scores for each entity and the factor loadings for each dimension can be seen in Appendix H. The spaces obtained can be seen in figures 3.16 and 3.17. In these figures, the dimensions presented to the subjects appear as vectors. The 'size' of these vectors indicates how close to the plane of the figure they are (projection of an unity size vector). Their correlation with the factors is indicated by the factor loadings in figures 3.14 and 3.15. The position of entities in the space (represented as points) are obtained as factor scores.

The interpretation of the factors obtained was done in the following steps:

1. Considering the loadings of the ten vectors/dimensions on the factors;

Dimensions	Factor 1 score weights	Factor 2 score weights
conserved/not conserved	-0.192557	-0.155325
in motion/static	0.168621	-0.128356
active passive	0.152669	-0.215770
substance/action	-0.169394	0.079726
place/localized	-0.057600	0.401679
cause/effect	-0.225186	0.462223
material/immaterial	-0.177208	-0.094770
concrete/abstract	-0.187468	-0.129251
real/imaginary	-0.170898	-0.503353
object/vacuum	-0.183383	-0.240433
correction for interval	3.727115	0.428424

Table 3.4. Principal Component score weights for 16-18 year-olds.

Dimensions	Factor 1 score weights	Factor 2 score weights	Factor 3 score weights	Factor 4 score weights
immaterial/material	-0.115867	-0.085543	0.027032	-0.072934
imaginary/real	-0.127008	-0.246066	-0.123717	0.060756
effect/cause	-0.127497	0.230075	-0.035327	0.672367
passive/active	0.097667	-0.032957	0.187895	0.243406
static/dynamic	0.113783	-0.097123	0.090757	-0.108501
discrete/continuous	0.049519	-0.031488	0.217252	0.165601
place/localized	-0.067817	-0.074211	0.263217	0.143533
abstract/concrete	-0.066344	-0.213540	0.003604	0.209381
action/substance	-0.132459	0.024029	0.013154	-0.133106
non-conserved/conserved	-0.089299	0.198761	0.106035	-0.005335
correction for interval	0.085531	0.994983	0.704817	-1.029313

Table 3.5. Principal Component score weights for undergraduate physicists.

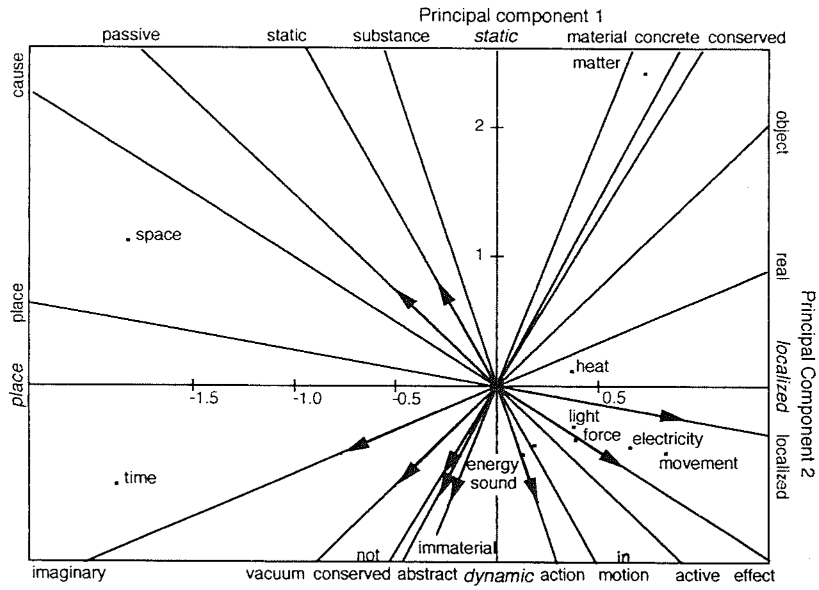


Figure 3.16. *Two-dimensional space of factors obtained for 16-18 year-olds. An interpretation of these factors is given in italic.*

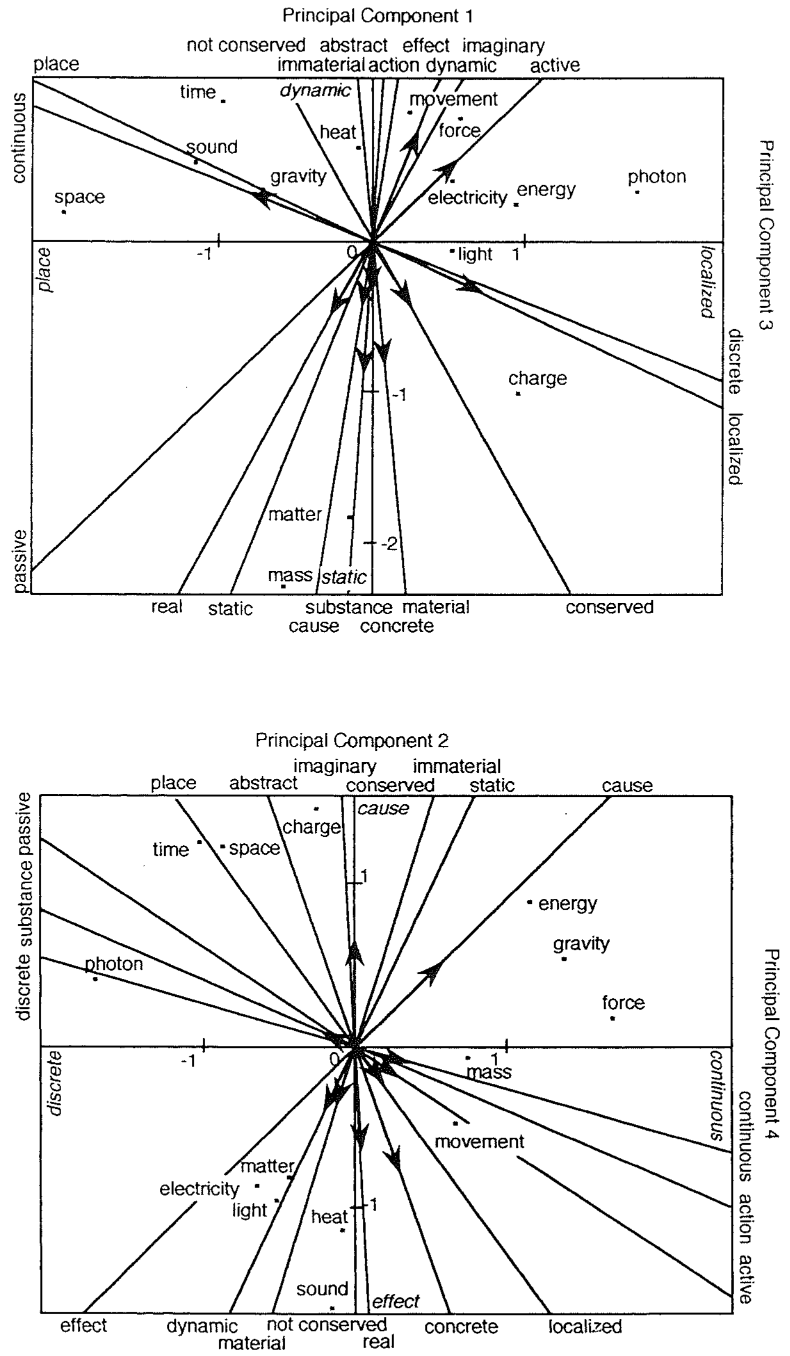


Figure 3.17. Four-dimensional space of factors obtained for undergraduate physicists. An interpretation of these factors is given in italic.

2. Considering the position of the entities (as points) in the factor space in relation to the position of the same entities in the space obtained in the first study (as vectors pointing to certain directions in that space).

A tentative interpretation of the factors is as follows:

For the 16-18 year-olds:

Principal Component 1: dynamic/static
Principal Component 2: place/localized

For undergraduate physicists:

Principal Component 1: static/dynamic
Principal Component 2: motion or effect/cause
Principal Component 3: place/localized
Principal Component 4: discrete/ continuous

The two factors obtained for 16-18 year-olds can then be related to the first two dimensions obtained in the previous study. The distribution of entities in this space strongly suggests the proposed interpretation: space and matter being static; space and time being like a place; other entities being dynamic and localized (heat a bit static).

The loadings also confirm this possibility, the dimensions given (static/in motion and place/localized) correlating highly with the factors. The other dimensions can be seen as giving an alternative and/or complementary interpretation of the space obtained. Being a substance, passive, material, concrete and conserved can be alternative complementary interpretations of being static for example. In this space cause/effect and action/substance also correlate with the first two factors. Dynamic and localized entities are more seen as effects than causes, a substance is static and an action is dynamic.

The distribution of entities on the factors 1 and 3 for undergraduate physicists also strongly suggests an interpretation similar to the one given in the first study. Space is like a place, matter and mass are static, time is a place and dynamic, force, movement, energy, electricity and photon are localized and dynamic. Actually in this space a small rotation towards the dimensions dynamic/localized and place/localized would reproduce more exactly the space obtained in the first study. The distribution of some entities also suggests the interpretation of factors 2 and 4: charge, energy and gravity are causes, photon, light and time are discrete, movement is effect or motion and continuous.

A second part of this study is a qualitative analysis of the way in which the subjects understood each of the dimensions given. They were asked to explain what they understood about something being static or dynamic and so on. They were asked to write one or two lines about each dimension.

These answers were categorised with the use of a systemic network of categories (Bliss, Monk and Ogborn 1983). The result can be seen in tables 3.6 and 3.7. The network organises categories in relation to one another. Entering the vertical bar with the recursive arrow a choice is made of one of the ways of thinking about something being conserved, not conserved, and so on (horizontal): what you can do to it, what it does or what it is made of. Opposite features are organised in pairs. The recursive arrow indicates that more than one choice can be made.

The categories chosen correspond to what is actually written by these subjects, being as close as possible to their own use of words. Examples of classified answers can be seen in Appendix J. The reduced number of categorised answers for undergraduate physicists is due to their use of specific language or definitions learned in the physics course. The categorisation works well for the 16-18 year-olds.

3.3.2. Results obtained for each group

3.3.2.1. Group 1: 16-18 year-old students

It was possible in the second study to obtain information about the way in which individuals localize entities in the space of the two factors obtained. This can be obtained by multiplying the factor score weights of each of the ten dimensions on the factors by the individual score attributed to an entity by a subject in each dimension.

The result can be seen in Appendix H and figures 3.18a to 3.18j. Each number represents the position of an individual (see description of

a)

Category	What you can think about something which is(like)...	conserved	not conserved	static	in motion	active	passive	substance	action	place	localized	cause	effect	material	immaterial	abstract	concrete	real	imaginary	object	vacuum
(what you can and cannot do...) accessibility – to sensory activity	see it							4		1				6			6	4		7	
	can't see it														2	2			1		2
	touch(hold) it							5						12			8	1		9	
	can't touch(hold) it														10	5					2
	feel it							1						3	2	1	4	3		2	
	can't feel it														2						
	perceive it													1	1		1	1		1	
	can't perceive it														3						
to motor activity	keep it	6												1						1	
	can't keep it	1	3																		
	transform it	2	3																		
	can't transform it		1																		
	do(create)it								2				1								
	can't do(create it)																				
	move(displace)it																				
	can't move(displace)it																				
to thought	understand it							1													
	imagine(in mind)/idea																		10	1	1
	can't imagine															4			1		1
	prove(explain)it																1	1			
	can't prove(explain)it															1			2		
	divide it																				
	can't divide it																				
	divide to a certain point																				
(what it does or not...) activity	changes/moves things					2			1												
	doesn't change/move things						2														
	act(react,interact) on things					10			1			2									
	doesn't act(react,interact)on things						10														
	makes something(effects) happen					5		1	1			4	1								
	doesn't make anything happen						7														
	it changes		12		3	2															
	doesn't change	8																			
	it disappears(finishes,destroyed,lost)		5																		
	it isn't destroyed(lost)	4																			
	stays the same(quantity)/constant	5					1														
	doesn't stay the same		3																		
(made of/ look like...) – relationships – causal	has cause												1								
	receives action						6						2								
	origin of action/event					6						1									
	consequence of action(force, agent...)		1		5				4			1	17								
	it isn't a consequence				1																
	needs cause to happen/change			4																	
	doesn't need cause to happen/change				1																
	reason (cause, agent) of action(event)					1						7									
temporal	before(beggining)											3									
	after(end)												1								
spatial	contains things/things(localized)in it									6											
	it is contained/somewhere										16										
	part of action											2									
	relative				2																
	do things in it									3											
	can't do things in it																				1
properties	it has form													2						5	
	has no form														2						1
	it is at rest			6																	
	it isn't at rest				1																
	it is fixed			2						2											
	it has mass(matter...)/solid(particle...)							5						4						1	
	doesn't have mass(matter...)														3						
	like a force								2												
	nothingness/empty														1						11
	full																			1	
	it (really)exists	1						3			1			1	1		7	14		2	
	it doesn't exist (by itself)								1							4			4		3
	has smaller unity																				
	support																				
	supported																				
	Sub-total 1	27	28	12	13	26	26	20	12	12	17	20	23	30	27	17	27	24	25	23	22

Table 3.6. Categorisation of responses obtained from 16-18 year-olds about what they thought about each of the ten given dimensions: a) these categories are structured in a systemic network on the left; b) Use of other dimensions in their responses and c) not categorised and total of responses analysed.

b)

How these dimensions... / Can be explained by the others...	conserved	not conserved	static	in motion	active	passive	substance	action	place	localized	cause	effect	material	immaterial	abstract	concrete	real	imaginary	object	vacuum
conserved																				
not conserved																				
static																				
in motion					1			8												
active				1				1												
passive																				
substance	1																			
action											1	2								
place																				
localized																				
cause								1												
effect															1					
material							1									3	1		5	
immaterial															3			1		1
abstract														5				3		2
concrete	1						4			1			7				4		1	
real													2			5			1	
imaginary														4	6					2
object													2			2	1			
vacuum														3	1			1		
Sub-total 2	2	0	0	1	1	0	5	10	0	1	1	2	11	12	11	10	6	5	7	5

(made of/ look like...) properties

c)

16-18 y.	conserved	not conserved	static	in motion	active	passive	substance	action	place	localized	cause	effect	material	immaterial	abstract	concrete	real	imaginary	object	vacuum
no answer				1	1	2	3	2	5	2	3	2	3	4	3	3	3	3	5	5
not classified	2		1				4	2	4	3	2	1					2	3	1	4
examples	2	2	2	3	2	2	4	4	5	2	2	2	2	2	2	2	2	2	2	1
tautology			14	18			1		6	6	2							1	1	
negation			1																	
Sub-total 3	4	2	18	22	3	4	12	8	20	13	9	5	5	6	5	5	7	9	9	10

16-18 y.	conserved	not conserved	static	in motion	active	passive	substance	action	place	localized	cause	effect	material	immaterial	abstract	concrete	real	imaginary	object	vacuum
Sub-total 1	27	28	12	13	26	26	20	12	12	17	20	23	30	27	17	27	24	25	23	22
Sub-total 2	2	0	0	1	1	0	5	10	0	1	1	2	11	12	11	10	6	5	7	5
Sub-total 3	4	2	18	22	3	4	12	8	20	13	9	5	5	6	5	5	7	9	9	10
TOTAL	33	30	30	36	30	30	37	30	32	30	30	30	46	45	33	42	37	39	39	37

a)

Category	What you can think about something which is(like)...	conserved	not conserved	static	dynamic	active	passive	substance	action	place	localized	cause	effect	material	immaterial	abstract	concrete	real	imaginary	discrete	continuous
(what you can and cannot do...) accessibility – to sensory activity	see it																3	2			
	can't see it																				
	touch(hold) it							3						8			4	4			
	can't touch(hold) it														6	4					
	feel it																2	3	1		
	can't feel it																				
	perceive it							1						1			2	2			
	can't perceive it															1					
to motor activity	keep it	1																			
	can't keep it		1																		
	transform it	3	2																		
	can't transform it	1																			
	do(create)it																				
	can't do(create it)	2																			
	move(displace)it																				
	can't move(displace)it			4																	
to thought	understand it															1					
	imagine(in mind)/idea		1													4	1	2	11		
	can't imagine																				
	prove(explain)it																				
	can't prove(explain)it																				
	divide it (as one wishes to)																				4
	can't divide it																			1	
	divide to a certain point																			5	
(what it does or not...) activity	changes/moves things					1			3												
	doesn't change/move things						1														
	act(react,interact) on things				1	6	2	1	7			1									
	doesn't act(react,interact)on things			1			6														
	makes something(effects) happen					1						7	2								
	doesn't make anything happen						1														
	it changes		4		2	1															
	doesn't change	2					1														
	it disappears(finishes,destroyed,lost)		7																		
	it isn't destroyed(lost)	5																			
	stays the same(quantity)/constant	3		1														1			
	doesn't stay the same		1		1																
(made of/ look like...) – relationships – causal	has cause																				
	receives action						5	2													
	origin of action/event					2		1				2									
	consequence of action(cause, agent...)												9								
	it isn't a consequence																				
	needs cause to happen/change								1			2	1								
	doesn't need cause to happen/change																				
	reason (cause, agent) of action(event)											1									
temporal	before(beggining)											2									
	after(end)												1								
spatial	contains things/things(localized)in it									7											
	it is contained/somewhere										9										
	part of action																				
	relative			1	1																
	do things in it									1											
	can't do things in it																				
properties	it has form													1							
	has no form														1	1					1
	it is at rest	1		7																	
	it isn't at rest				1																
	it is fixed																				
	it has mass(matter...)/solid(particle...)							3						8							
	doesn't have mass(matter...)														6						
	like a force																				
	nothingness/empty																			1	
	full																				
	it(really)exists														1			2			
	has smaller unity																			7	1
	doesn't have a smaller unity																				2
	support									1											
	supported										1										
	Sub-total 1	**18**	**16**	**14**	**6**	**11**	**16**	**11**	**11**	**9**	**10**	**15**	**13**	**18**	**14**	**11**	**12**	**16**	**12**	**14**	**8**

Table 3.7. Categorisation of responses obtained from undergraduate physicists about what they thought about each of the ten given dimensions: a) these categories are structured in a systemic network on the left; b) Use of other dimensions in their responses and c) not categorised and total of responses analysed.

b)

(made of look like...) properties

How these dimensions... Can be explained by the others...	conserved	not conserved	static	dynamic	active	passive	substance	action	place	localized	cause	effect	material	immaterial	abstract	concrete	real	imaginary	discrete	continuous
conserved																				
not conserved																				
static																				
dynamic					1			1												
active				1																
passive																				
substance																				
action																				
place																				
localized																				
cause				1	1		1	3												
effect			1																	
material							2									1				
immaterial								1										1		
abstract														2				2		
concrete							1										1			
real							1						1			4				
imaginary															3					
discrete							1													
continuous							1													
Sub-total 2	0	0	1	2	2	0	7	5	0	0	0	0	1	2	3	5	1	3	0	0

c)

physicists	conserved	not conserved	static	dynamic	active	passive	substance	action	place	localized	cause	effect	material	immaterial	abstract	concrete	real	imaginary	discrete	continuous
no answer							1				2	2					1			1
not classified	3	1	1	2	4	2	1	1	7	5		3	3	1	4	5	4	2	5	6
examples		1		1				1	2	1	1			1	1	1				2
tautology			2	7	1		1			2				1						1
negation		1	1				1							1				1		
Sub-total 3	3	3	4	10	5	2	4	2	9	8	3	5	3	4	5	6	5	3	5	10

physicists	conserved	not conserved	static	dynamic	active	passive	substance	action	place	localized	cause	effect	material	immaterial	abstract	concrete	real	imaginary	discrete	continuous
Sub-total 1	18	16	14	6	11	16	11	11	9	10	15	13	18	14	11	12	16	12	14	8
Sub-total 2	0	0	1	2	2	0	7	5	0	0	0	0	1	2	3	5	1	3	0	0
Sub-total 3	3	3	4	10	5	2	4	2	9	8	3	5	3	4	5	6	5	3	5	10
TOTAL	21	19	19	18	18	18	22	18	18	18	18	18	22	20	19	23	22	18	19	18

Figure a)
matter

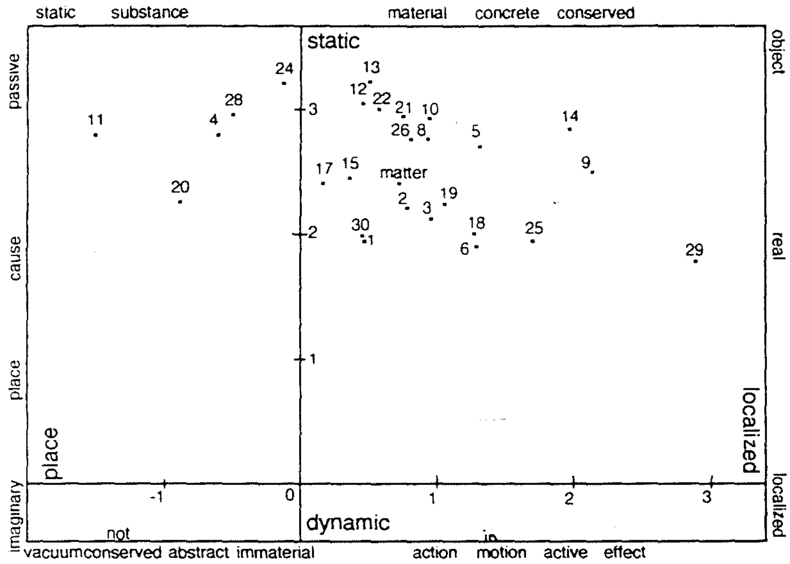


Figure b)
energy

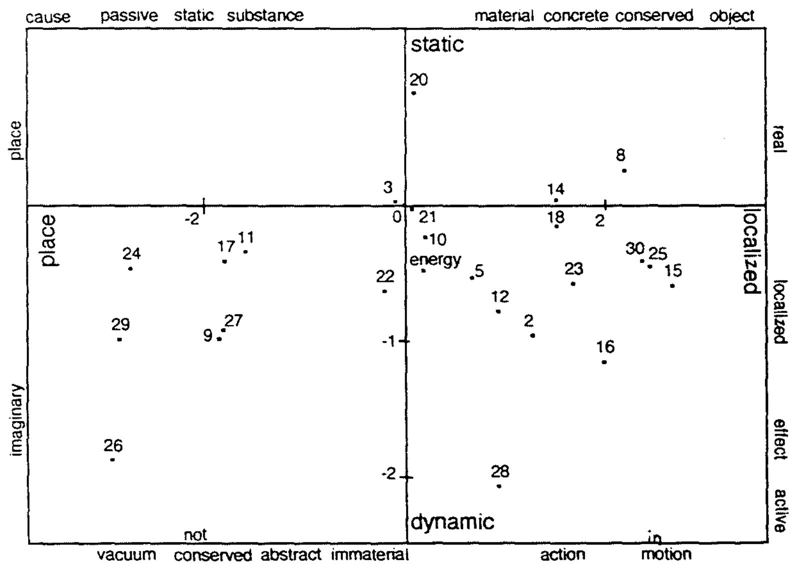


Figure 3.18. *Individual responses obtained for the positioning of entities in the space of the factors obtained for 16-18 year-olds. The average position is also shown. From 'a' to 'j' the results for the ten entities investigated are shown.*

Figure c)

time

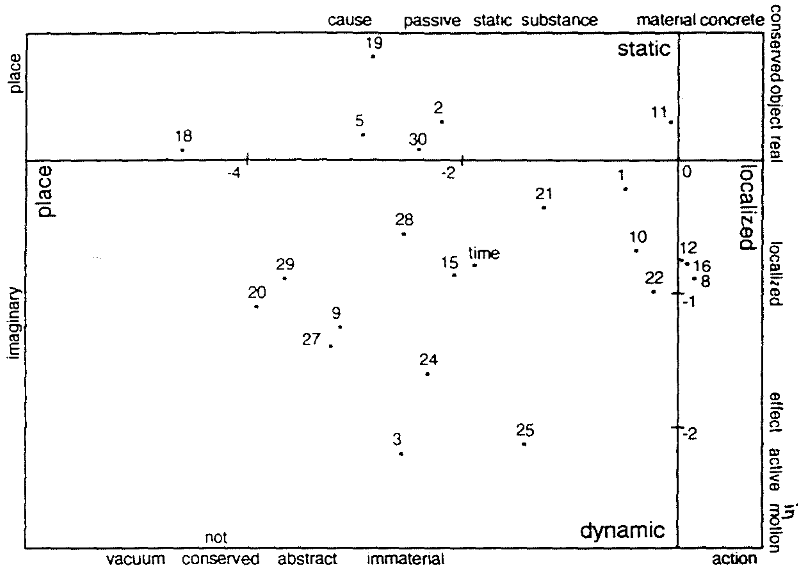


Figure d)

space

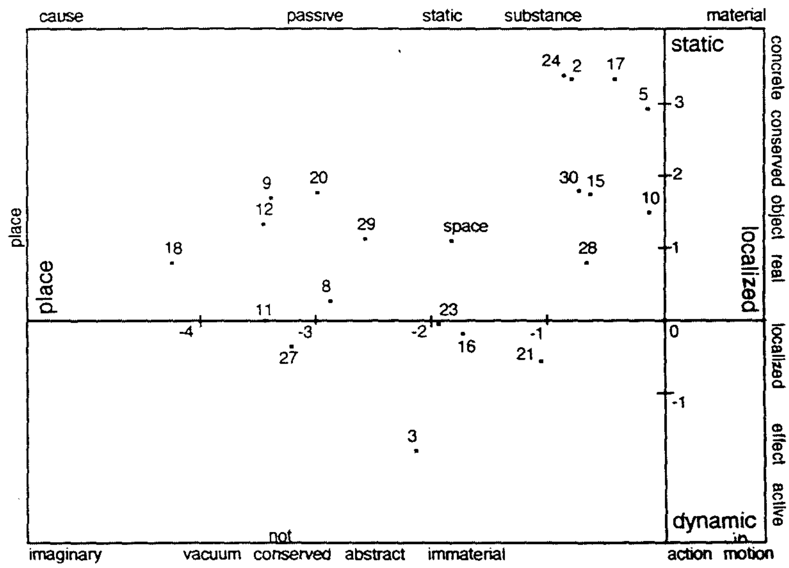


Figure e)

light

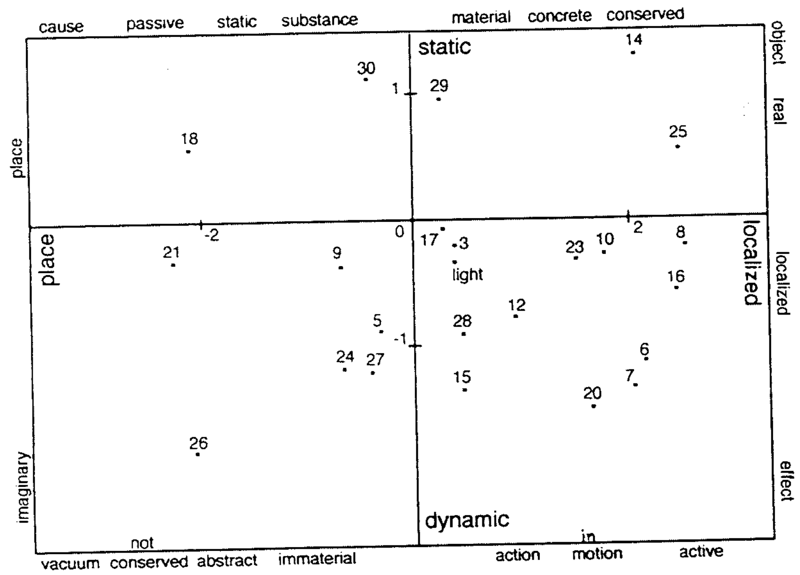


Figure f)

force

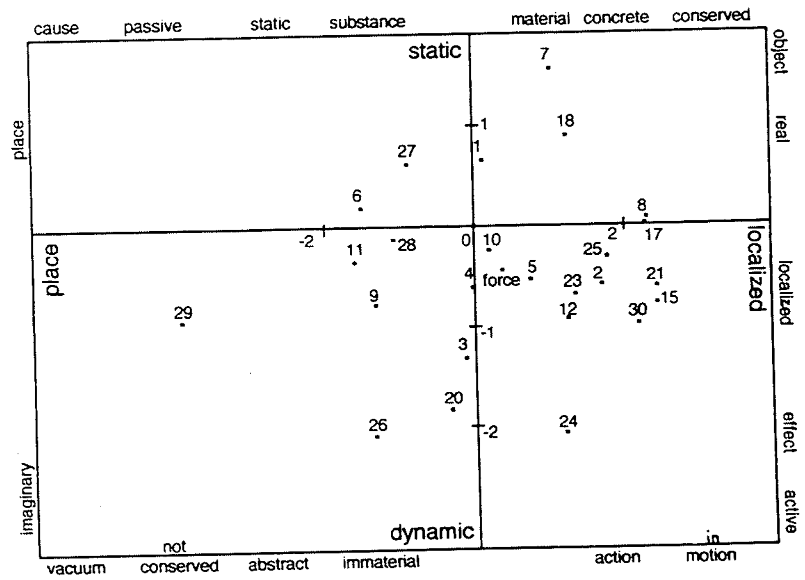


Figure g)

movement

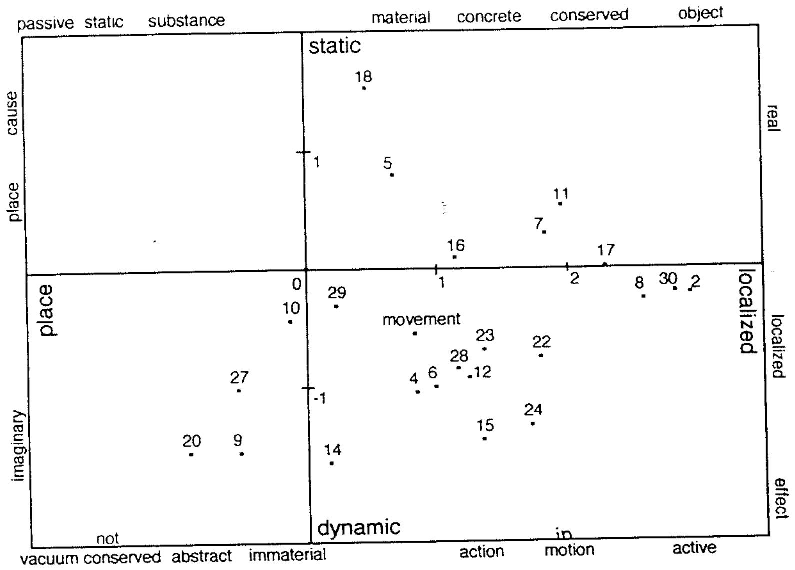


Figure h)

sound

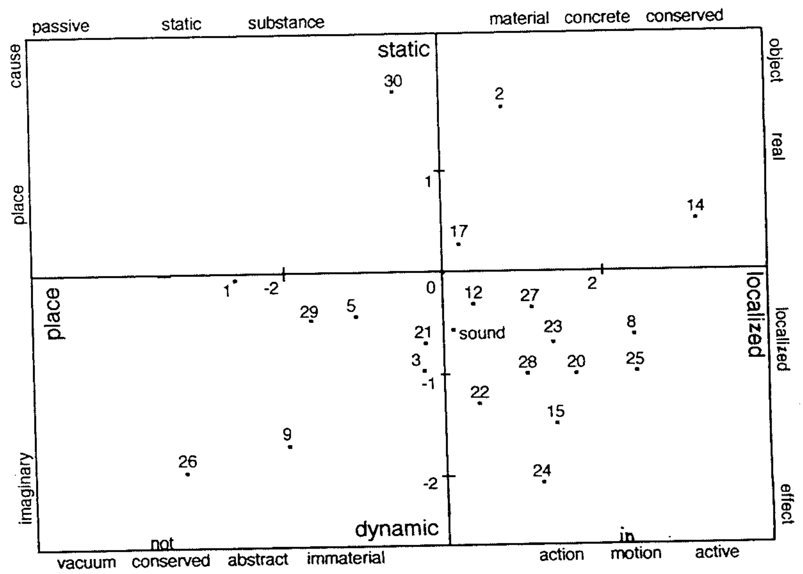


Figure i)

heat

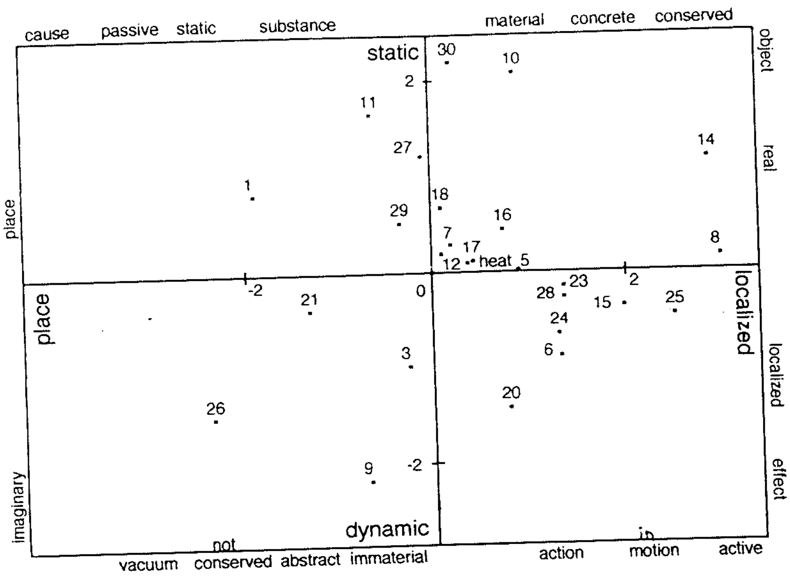
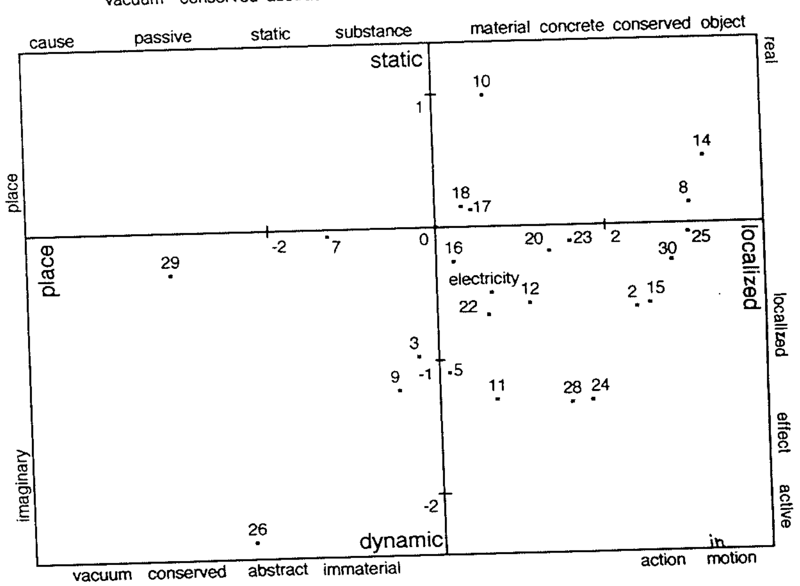


Figure j)

electricity



sample in the previous chapter or Appendix J for identification) in relation to the result obtained by using the mean of the positioning for the group.

Concerning matter most individuals seem to agree about it being static; concerning energy there is a split concerning it being localized or a place; there is agreement in seeing time as a place and dynamic; also for space there is substantial agreement in it being static and like a place; there are a few individuals with very different ideas about light, many agree in it being localized and dynamic; force is agreed to be dynamic by most subjects; movement is dynamic and localized for most of them; the same for sound; there is large disagreement about heat and electricity is mostly dynamic and localized.

Some individuals seem to have a different position in relation to the group in many cases (individuals indicated by the numbers 26, 14 and 29 for example) and others to have an opinion very close to the average (individual indicated by number 12 for example).

The individual responses, categorised in Table 3.6, show that certain ways of thinking are preferred depending on the dimension to be explained. Accessibility by the senses was largely preferred to explain what they understand by something being material/immaterial, substance, abstract/concrete, real/imaginary and object vacuum. They appeal also to some properties of existence or not. Activity was important for being conserved or not, static/in motion, active/passive, like action and cause/effect. Relationships were also important in their understanding of the dimensions, particularly place/localized. Most answers obtained could be categorised with the use of the network.

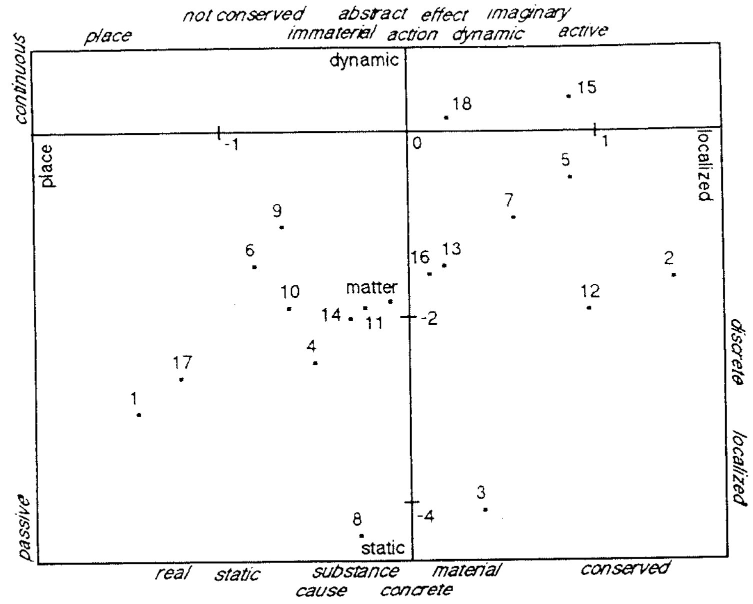
3.3.2.2. Group 2: undergraduate physicists

The tables with the results of the study of individuals' scores attributed to entities can be seen in Appendix H. The results can also be seen in figure 3.19a to 3.19n.

Most individuals agree that matter is static, but there are a number of disagreements about it being discrete/continuous or cause/effect. There is division between it being more localized or like a place. Energy is

Figure a)

matter



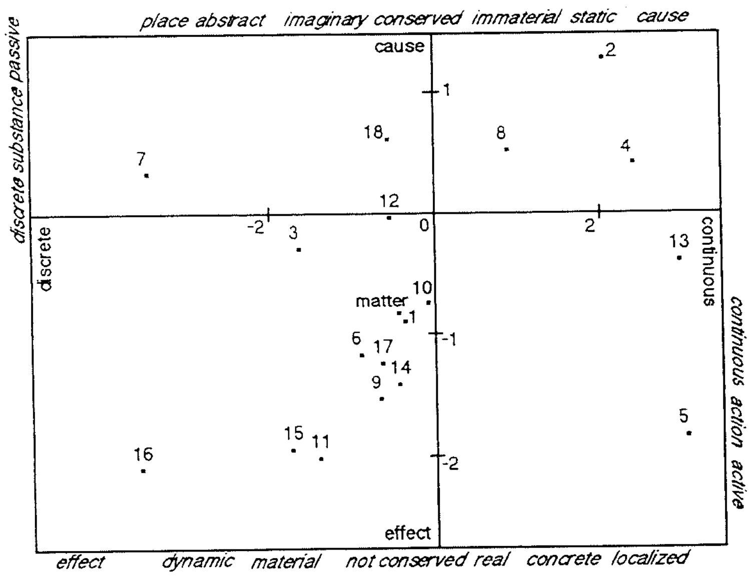
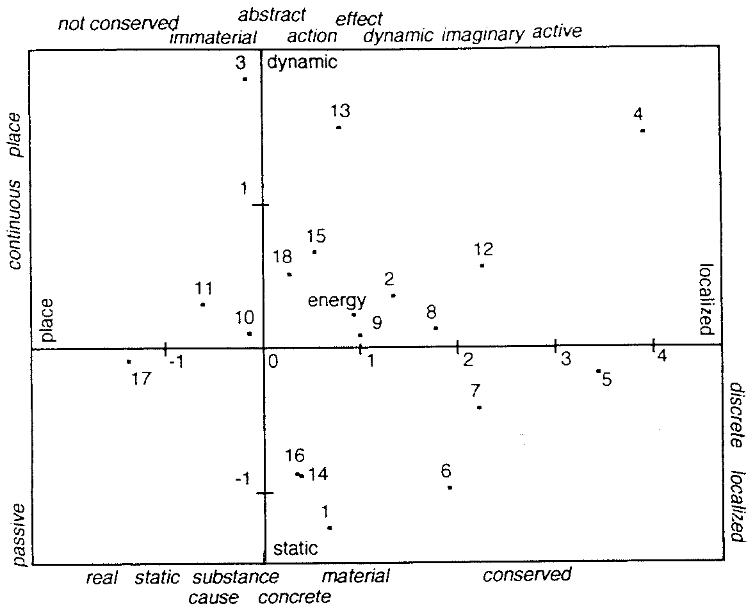


Figure 3.19. *Individual responses obtained for the positioning of entities in the space of the factors obtained for undergraduate physicists. The average position is also shown. From 'a' to 'n' the results for the fourteen entities investigated are shown.*

Figure b)

energy



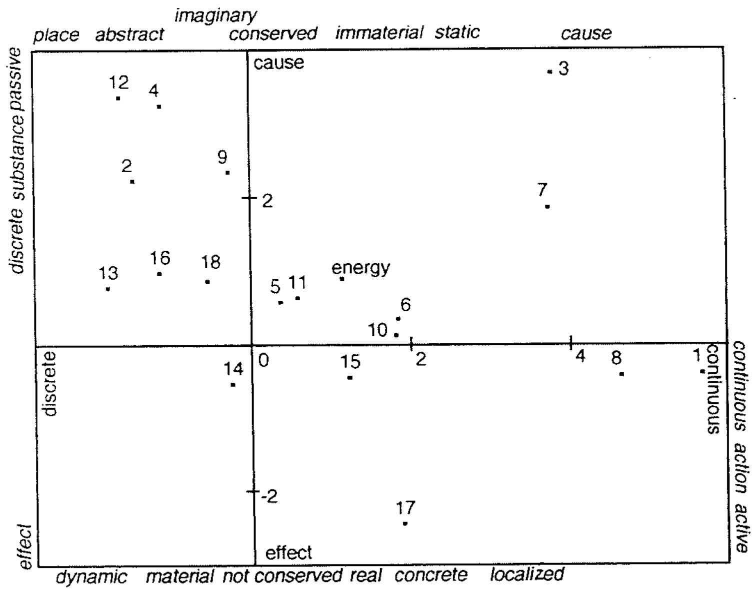
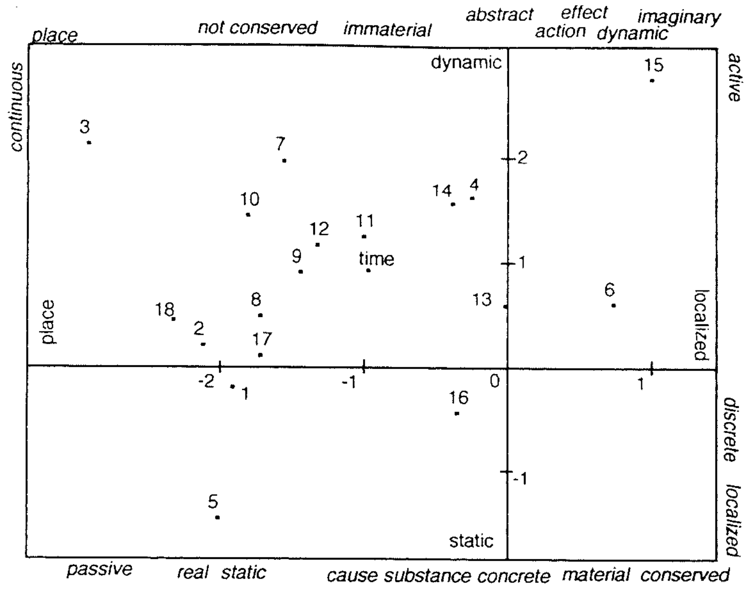


Figure c)

time



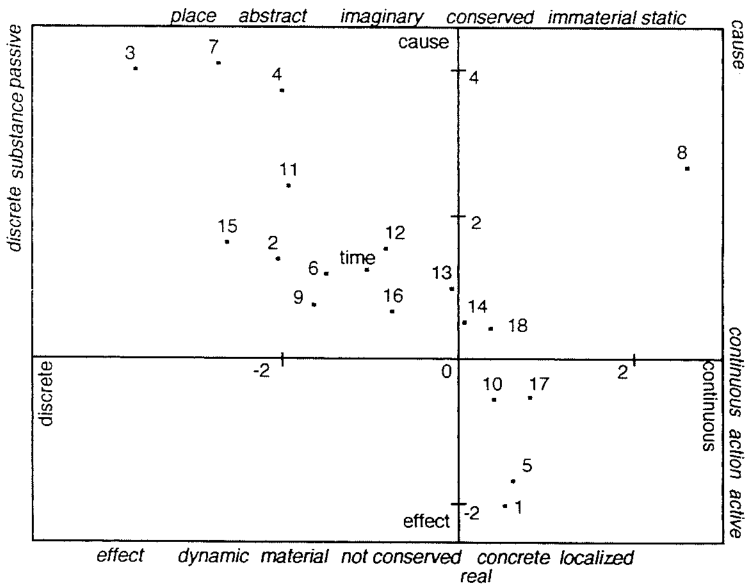
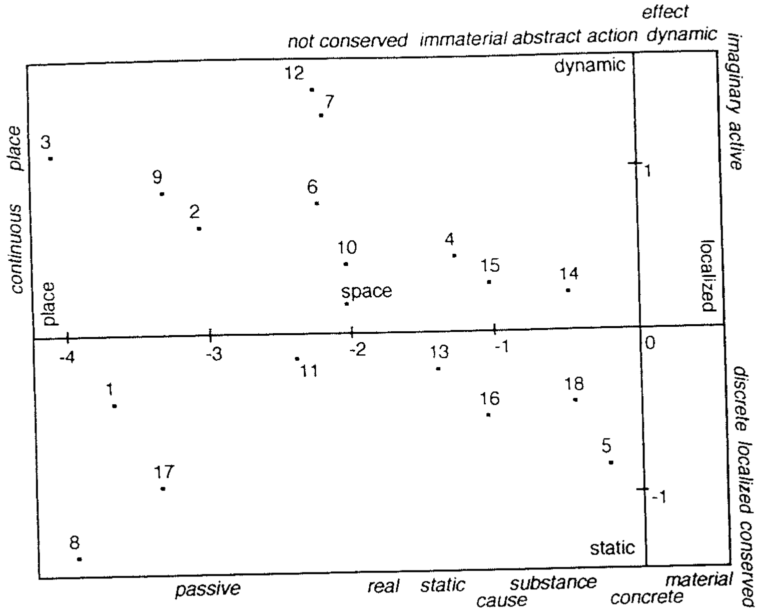


Figure d)

space



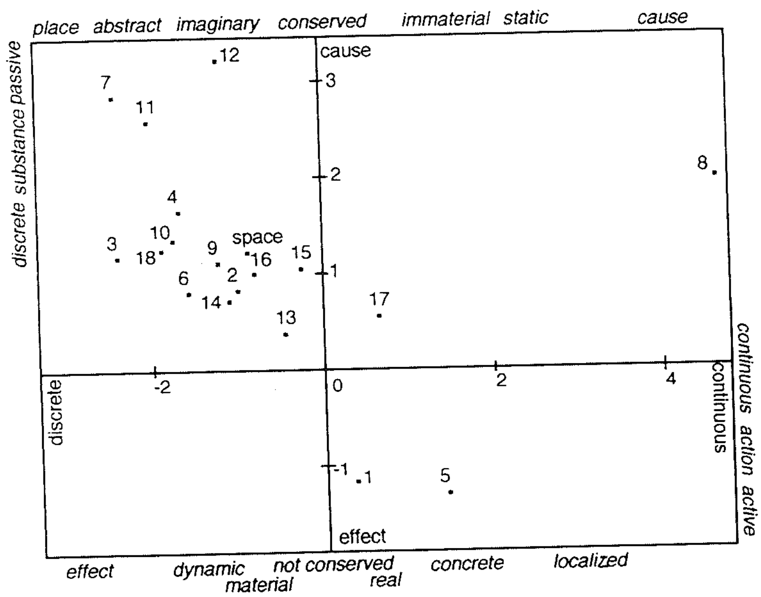
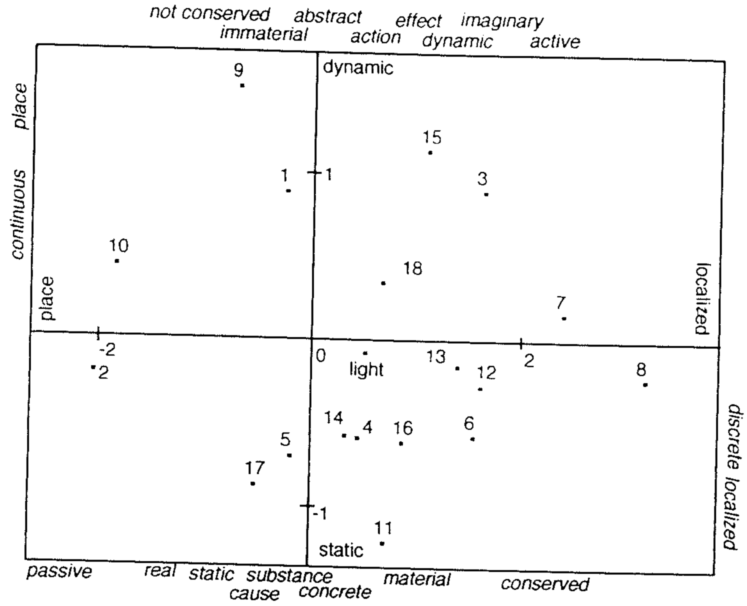


Figure e)

light



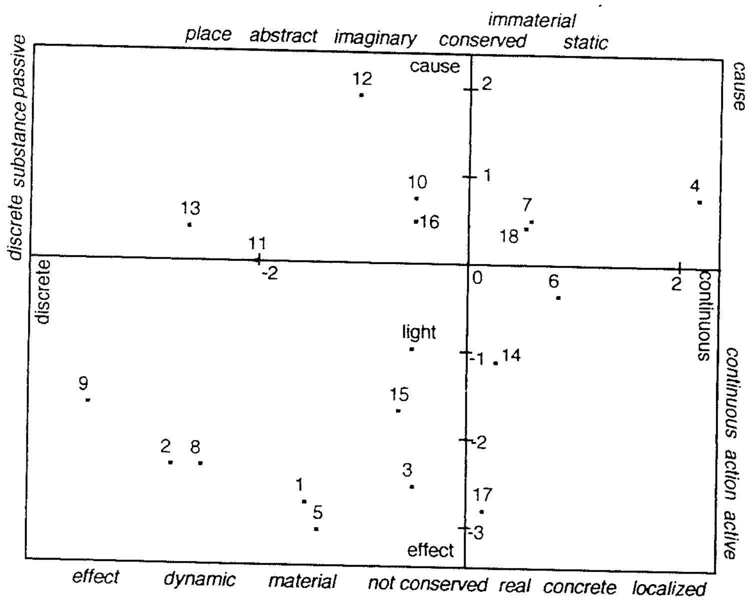
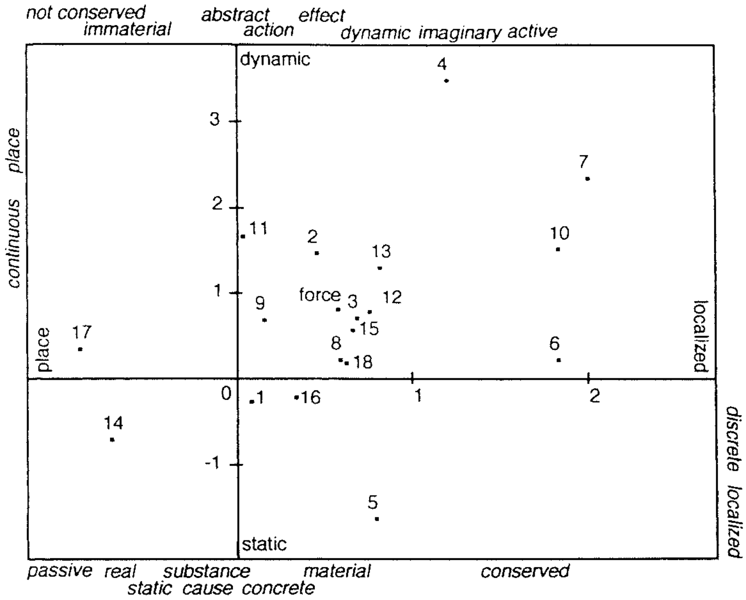


Figure f)

force



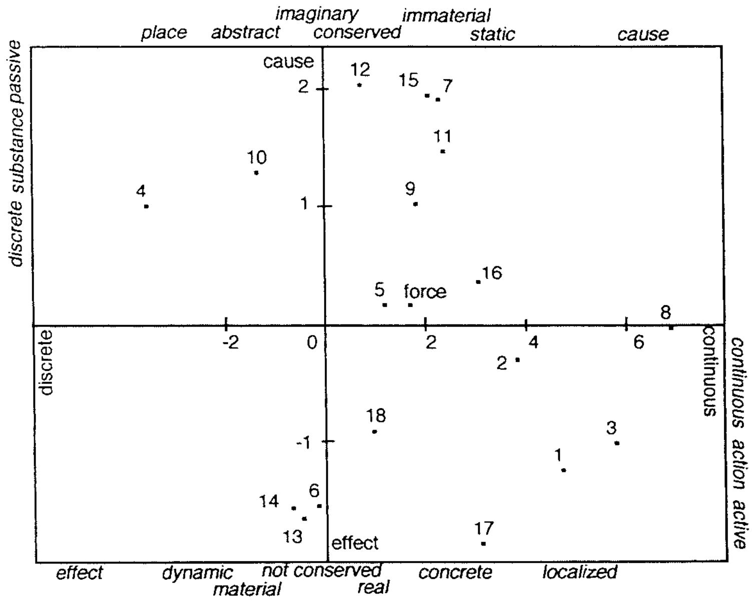
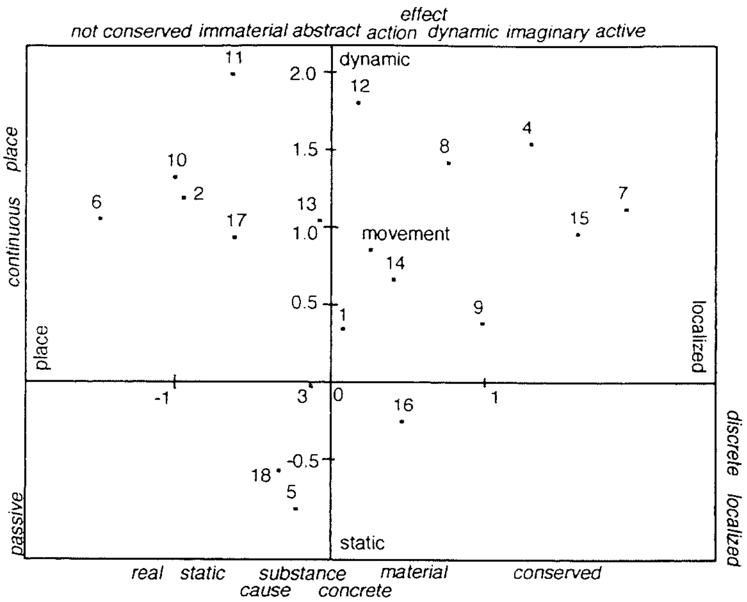


Figure g)

movement



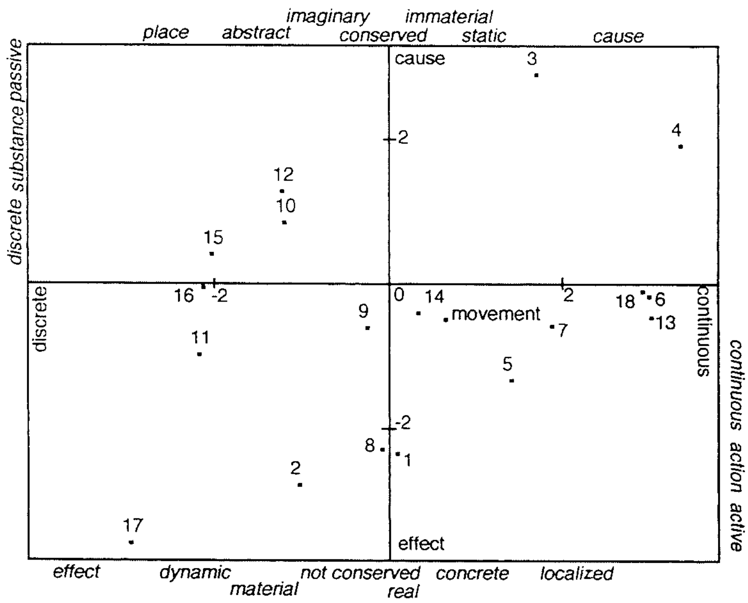
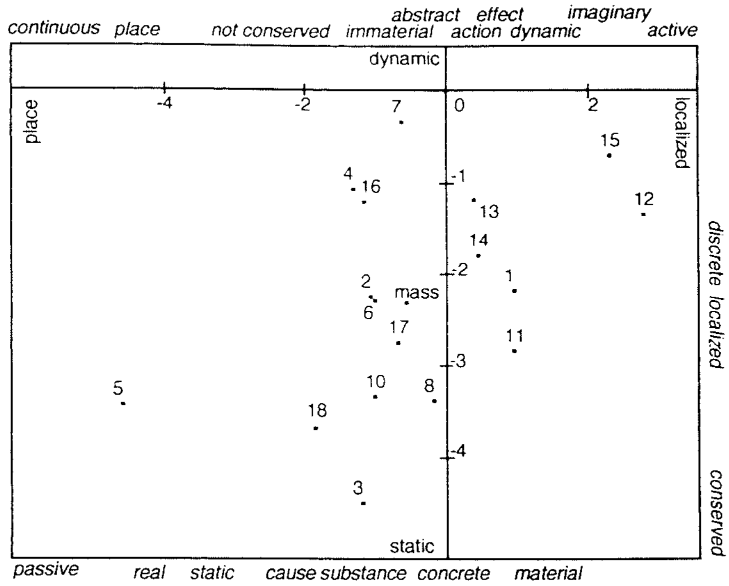


Figure h)

mass



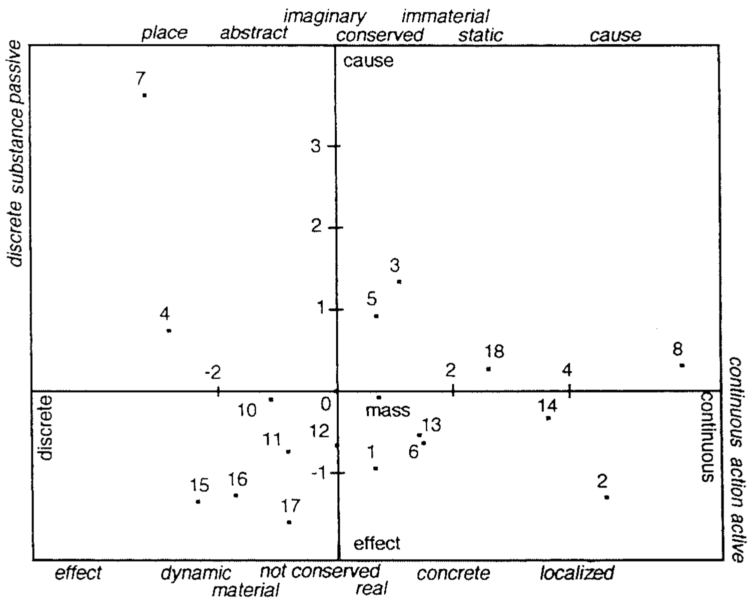
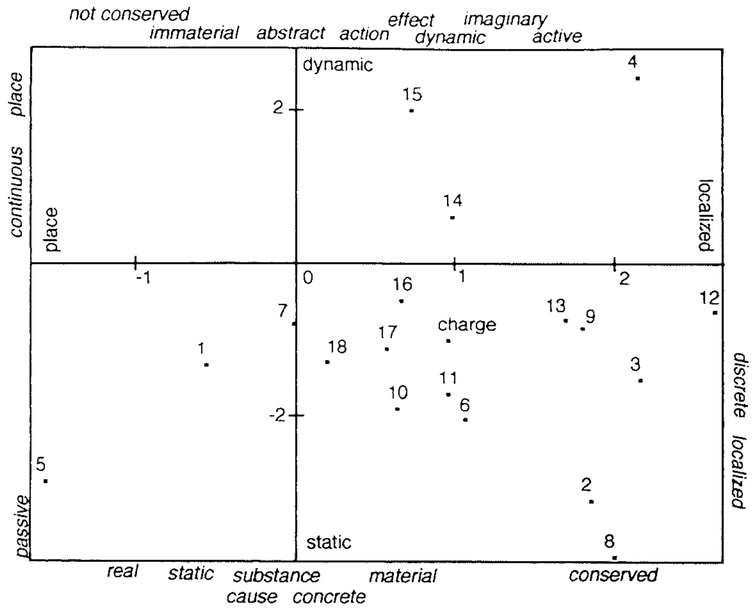


Figure i)

charge



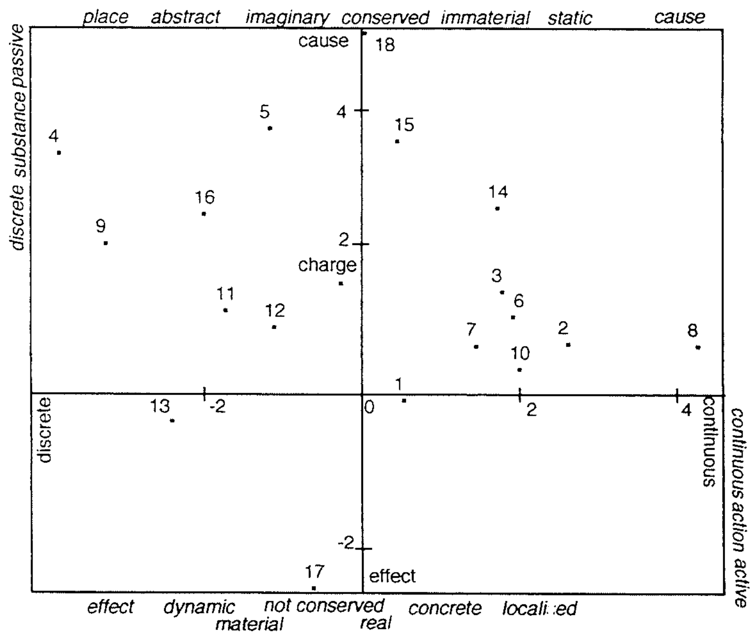
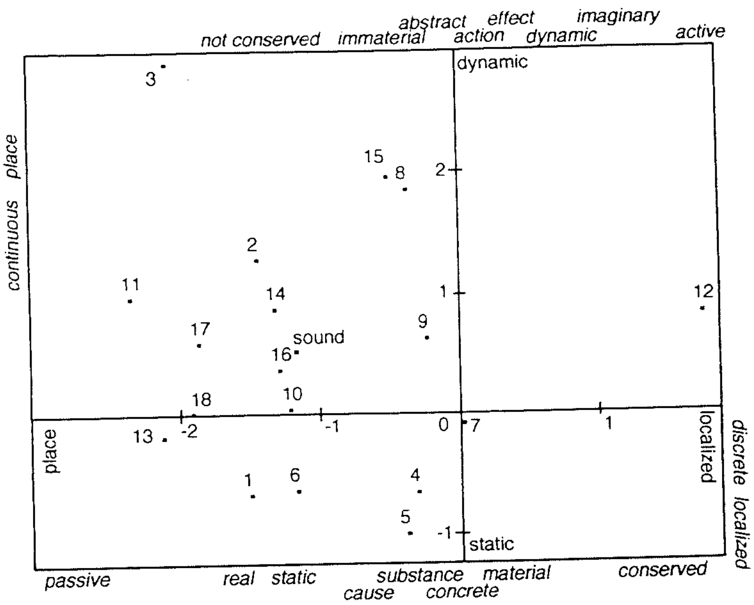


Figure j)

sound



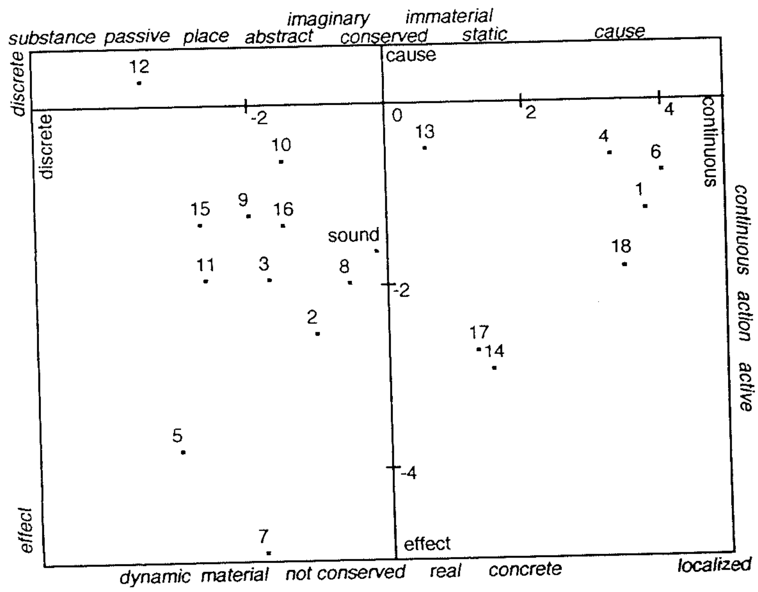
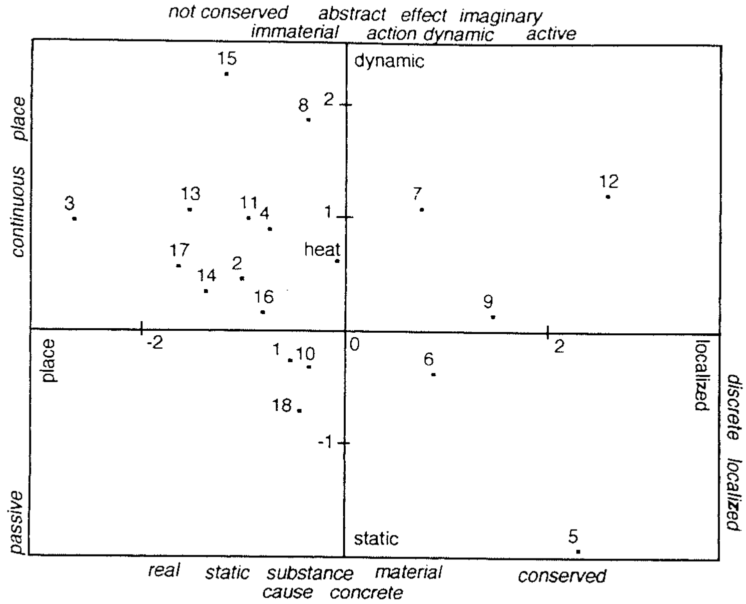


Figure k)

heat



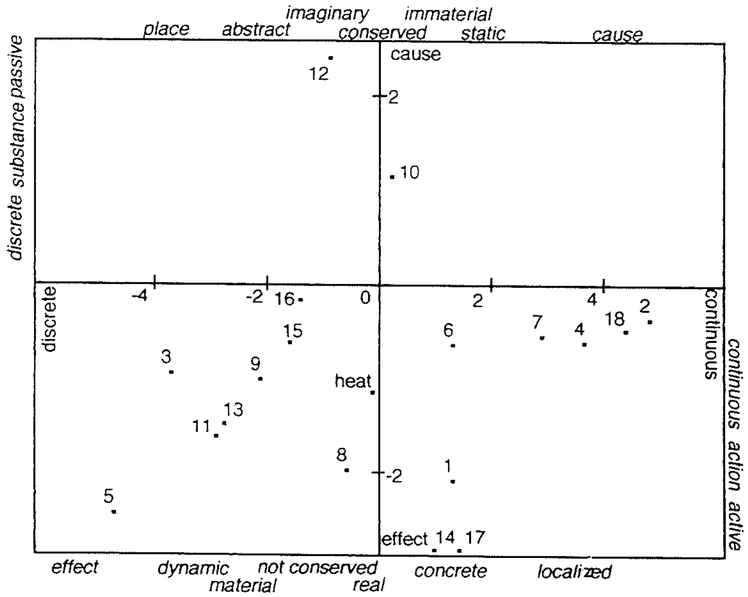
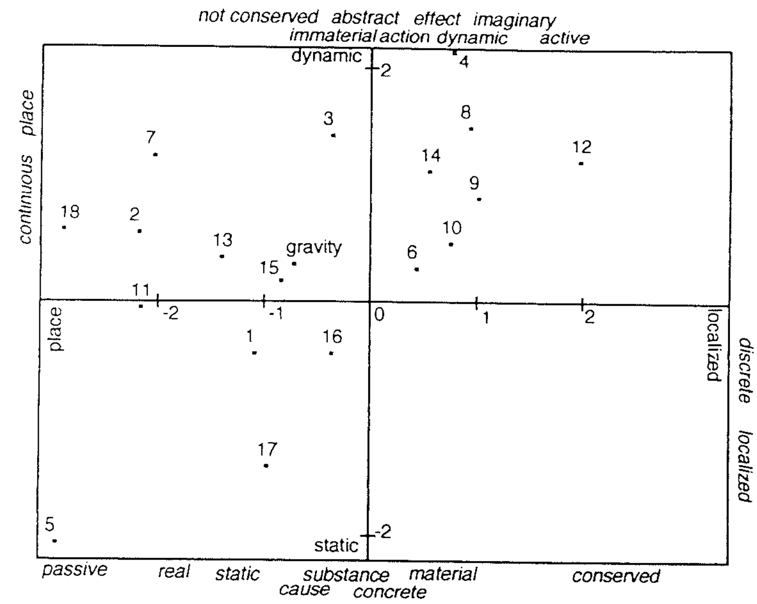


Figure I)

gravity



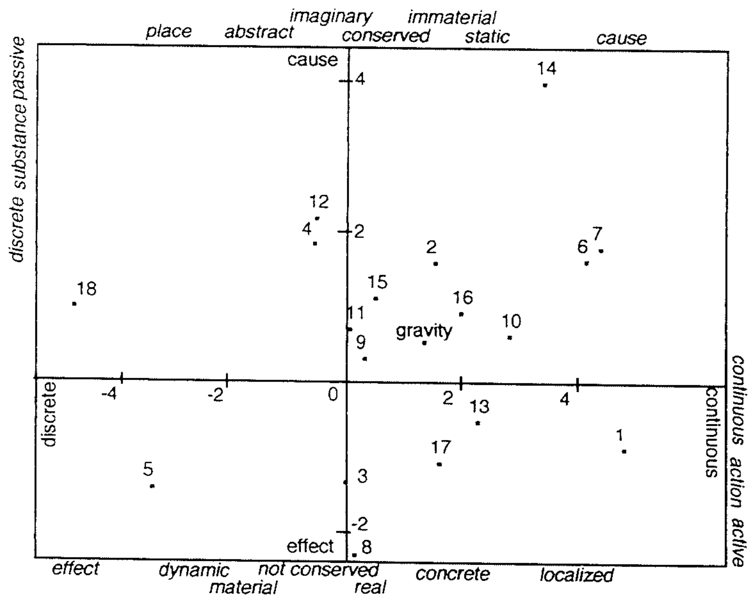
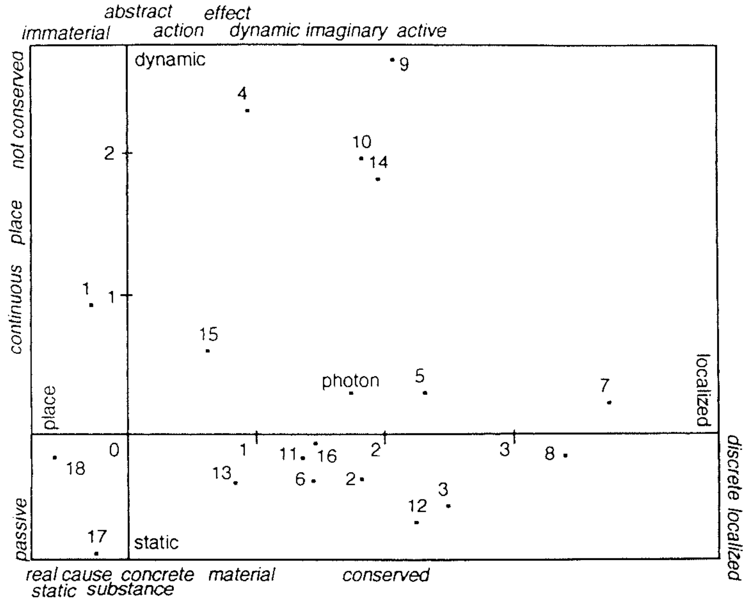


Figure m)

photon



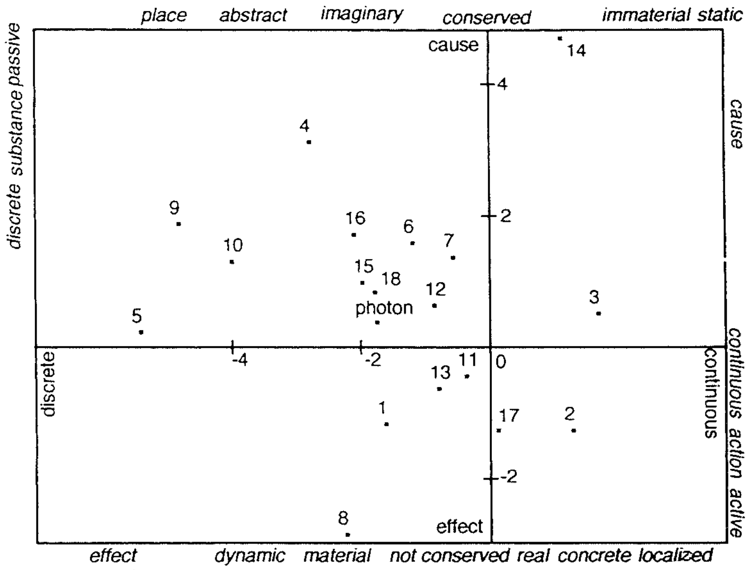
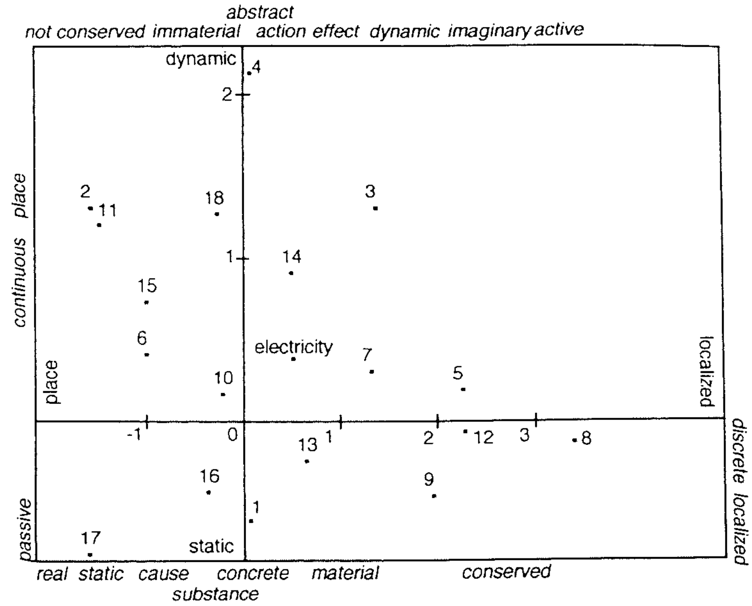
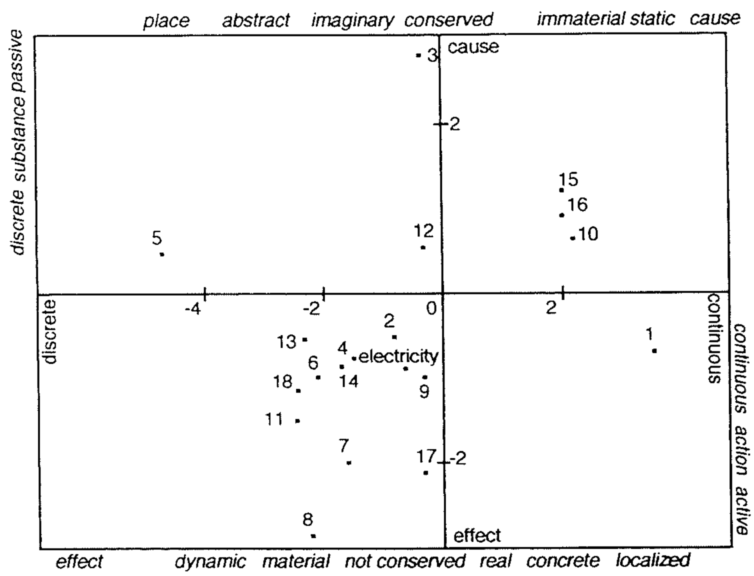


Figure n)

electricity





seen as being localized and like a cause. It can be discrete or continuous, dynamic or static. Time is mostly dynamic and a place, discrete and cause. Space is place but can be static or dynamic. It is a bit discrete (due to the dimensions which correlate with being discrete) and cause. Light is more localized, but can be dynamic/static, discrete/continuous and cause/effect. force is mostly dynamic and localized, continuous, but can be cause or effect. Movement is dynamic, but there is large disagreement about the other factors. Mass is static. Charge is mostly localized, static and cause. Sound is like a place and is an effect. Heat is dynamic and like a place, and also an effect. Gravity is dynamic and continuous. Photon is localized and discrete. Electricity is discrete and an effect.

In this group it was more difficult to find patterns of agreement or disagreement, maybe due to the size of the sample.

Concerning the categorisation of responses, a similar pattern as described to 16-18 year-olds seems to apply here. But there is a larger number of non categorised answers due to the specific knowledge of this group. Even so more than 80% of the responses obtained were able to be categorised.

3.4. Results obtained with interviews

Two groups corresponding to the 8-10 year-olds (same sample) and 16-18 year-olds of the first study were interviewed (N: 21 and 18; see description of sample in the last Chapter).

The general form of the interviews can be seen in Appendix G (see also previous Chapter). In these interviews the subjects were asked to:

1. First form groups with entities they consider to be alike;

2. To briefly explain how they decided about which entity would go with another one;

3. To form groups with similar entities and things one can think about them (only 16-18 year-olds).

There were two kinds of data to be analysed: first to compare the groups obtained by asking individuals to form them and the clusters of entities obtained with the use of the features in first study; and second to categorise the explanations given.

3.4.1. General Results

In Appendix G the transcriptions of the interviews about grouping entities, and the explanations categorised can be seen. The categorised explanations are underlined.

In figures 3.20a and 3.20b are shown numerical accounts of the frequency with which one entity is grouped with another, in the two samples. Figures 3.21a and 3.21b show how these numbers agree with the clustering of these entities, based on the features attributed to them in the first study. A network used to categorise the reasons for grouping two entities together is shown in figure 3.22.

There is substantial agreement between both results: two entities which were more often put together were also 'closer' to each other in the space of the features asked in the first study. It may thus be argued that the features asked reflected in a reasonable way the feeling of the subjects about which entities were similar to one another.

Also for the 16-18 year-olds it was possible to compare the result obtained by the subjects grouping both entities and features which were considered to be similar, and the results obtained previously with the questionnaire. Each time a feature was grouped with a certain entity it was considered to be like a 'yes' answer for that feature about an entity. The table with these results and the correlation of these results with those obtained via questionnaire is given in Appendix H.

The correlations were high for most entities. Exceptions were only a different profile of features selected for weight and light in the two studies.

a)

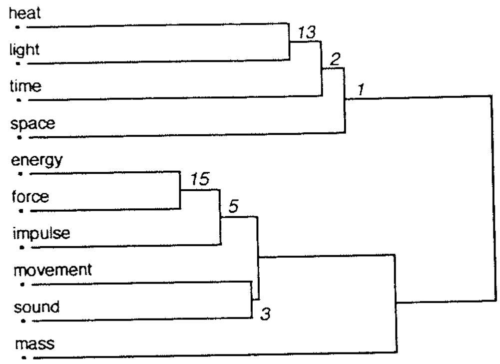
entities	mass	time	space	light	sound	heat	force	movement	energy	impulse
mass										
time	0									
space	*4*	*8*								
light	0	*5*	*7*							
sound	1	3	*2*	*4*						
heat	0	*7*	2	**13**	2					
force	3	1	1	3	3	2				
movement	3	2	1	2	3	2	**10**			
energy	1	1	2	*4*	*4*	3	**15**	*7*		
impulse	1	2	2	1	3	3	*8*	**14**	*5*	

b)

	mass	time	space	light	sound	heat	force	movement	energy	impulse	weight	temperature	gravity	atom	electricity	matter	atmosphere	vacuum	microwave	radioactivity	solar radiation
mass																					
time	3																				
space	*4*	*5*																			
light	0	3	0																		
sound	0	*4*	*4*	*6*																	
heat	0	1	0	**11**	2																
force	*7*	3	2	1	0	2															
movement	*7*	*6*	*5*	1	1	1	**10**														
energy	0	1	0	**12**	2	**15**	2	1													
impulse	*6*	2	3	0	0	1	**14**	**11**	1												
weight	**12**	2	3	0	0	0	**12**	*7*	0	**11**											
temperature	0	1	0	*7*	3	**12**	2	2	*9*	2	0										
gravity	*7*	3	*6*	0	2	0	*8*	*4*	0	*8*	**11**	0									
atom	*8*	0	1	3	1	3	2	1	3	1	*4*	2	2								
electricity	0	1	0	*6*	3	*8*	2	0	**10**	2	0	3	1	2							
matter	**14**	3	*5*	0	1	0	3	*5*	0	*4*	*9*	0	*6*	**10**	0						
atmosphere	0	3	**10**	1	*5*	1	0	0	1	0	0	1	*6*	2	0	1					
vacuum	0	2	*7*	1	*5*	2	0	0	1	0	0	2	*4*	2	0	1	**12**				
microwave	0	2	0	*7*	*6*	*5*	0	2	*5*	1	0	*5*	0	1	*7*	0	0	0			
radioactivity	0	1	0	*5*	1	*4*	0	0	*5*	1	0	*4*	1	3	*8*	0	0	1	**10**		
solar radiation	0	1	0	**10**	3	*7*	0	1	*8*	1	0	*4*	0	2	*7*	0	1	2	*8*	**12**	
magnetism	2	0	0	3	2	*5*	*4*	2	*5*	*4*	2	2	2	3	*9*	2	0	0	*6*	*9*	*6*

Figure 3.20. Number of times two of the entities were put together by a) 8-10 year-olds and b) 16-18 year-olds during interviews. Two digit results in bold; above average (Mean:3.77 and 3.09) in italic.

a)



b)

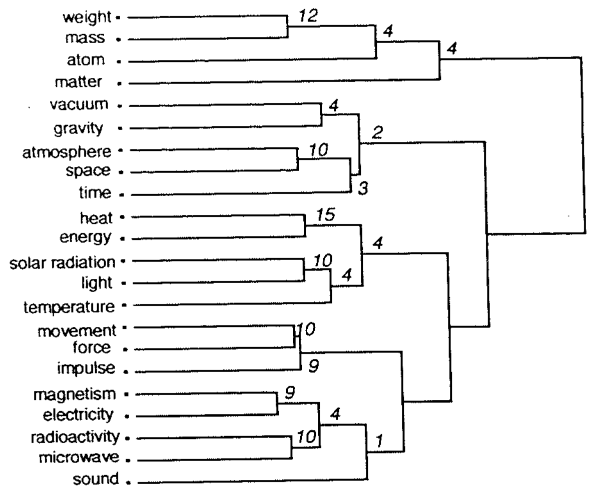


Figure 3.21. *Cluster Analysis (Complete linkage method) of the raw data obtained for a) 8-10 year-olds and b) 16-18 year-olds with 32 and 54 features asked via questionnaires. In italic the number of cases of these groupings obtained via interviews (N: 21 and 18).*

Reason why entities belong to same group...				cases	Number of cases: 8-10 y.	16-18 y.	total
relationship between entities	causal	correlational	qualitative	depends on	0	3	6
				one changes the other disappears	2	0	
				after...you feel...	1	0	
			quantitative	increases / will have more or less	0	2	7
				measures	0	2	
				related by formula or problem solving	0	3	
		strict causal		causes	0	1	2
				because of	0	1	
		material		transformed into / turned into	0	2	35
				acts on / influences / you apply to	2	4	
				makes / does / produces / gives	13	10	
				emits/transmits	0	3	
				obtained from	0	1	
	logically necessary	need		to have...you need...	0	1	8
				you do...you need...	0	1	
				you need...to have/do	4	0	
				without...there is no...	1	1	
		condition		if there is...then you have...	1	0	8
				if you have...you do...	0	1	
				if you find...you look for...	0	1	
				if you apply...you have...	0	2	
				if not...then not...	1	2	
	part/whole	spatial		is in / exists in / moves in / changes in / transmits in	6	8	22
				is a place in / occupies / inside	3	4	
				in...there is no...	0	1	
		material		constitutes / made of	0	3	26
				is part of	0	2	
				has	7	14	
		classificatory	similarity	similar / looks like	9	5	21
				is / equal / the same	4	2	
				is the opposite	0	1	
			derived	kind of / form of	2	9	11
	mental			reminds me of / thinking about...you think about...	0	2	27
				something to do / linked / related / refers	1	24	
shared properties	static	spatial		like place / environment / atmosphere / space	0	5	5
		material		have mass / matter	0	5	7
				concrete / what there is	0	2	
	dynamic			movement-like / move / flow	4	3	32
				changing	1	1	
				wave-like	0	4	
				force-like	0	4	
				energy-like	2	4	
				action-like	1	1	
				make things happen	4	0	
				electricity-like	0	1	
				strong	2	0	
accessibility				can hold	0	3	5
				can feel	0	1	
				can do it	1	0	
				None	3	2	
TOTAL of cases (number of subjects: 21 8-10 year olds; 18 16-18 year olds)					75	152	227

None: *8-10 year-old*

1. " We turn the radion on"(Gus;09;04)
2. "...gives day and night"(Mic;08;08)
3. "One goes other goes"(Car;08;11)

16-18year-old

1. "Take a ...to reach Earth"(She;16;05)
2. "It is ...acting upon ..."(Gla;18;02)

Figure 3.22. Network of categories to analyse the reasons given for grouping entities together during interviews with 8-10 year-olds and 16-18 year-olds.

Concerning the reasons given for putting two entities in the same group, a network of categories was again used to analyse the data. Each reason given which was analysed is underlined in the transcriptions given in Appendix G. The network used for both groups can be seen in figure 3.22.

Entering the vertical bar on the left with the recursive arrow a reason to put two entities together should be one of the cases on the right. More than one reason can be given at a time. The total number of cases analysed with this network were 227, all underlined in the transcripts shown in Appendix G.

In some cases individuals appeal to what the entities look like and to accessibility to them. More often the relationship is not very clear (mental) or involves a direct material causal link between entities (transform one into the other and so on). Part-whole relationships also seem to be important (one inside the other, one a kind of another and so on).

3.4.2. Results obtained for each group

3.4.2.1. Group 1: 8-10 year-old students

The entities most often grouped together were energy and force, impulse and movement and heat and light. Mass was often alone. Time would be grouped with space but quite often also with heat (because of time here being understood as 'weather' in Portuguese).

Some subjects had a tendency to group pairs of entities (for example individuals number 12, 13, 14, 15) and others to group a large number of them in one group (for example 16 and 20). The explanations vary: causal links, shared properties or by no special reason ("they are similar").

Many of the explanations given by 8-10 year-olds appeal to a material causal link between entities of the kind "one makes, produces, does, gives the other". A causal sequence of the type of one entity creating the other make them look alike. A part-whole relationship of one containing the other seem also important. Relationships of the 'mental' kind were hardly used. Only a small number of reasons could not be classified.

Some individuals were quite reticent to give any reason at all (for example individual number 6). In many cases there is some hesitation, suggesting the difficulty of the task. However, in most cases students were able to formulate a reason.

3.4.2.2. Group 2: 16-18 year-old students

The entities most often put together were energy and heat, matter and mass and impulse and force. Space would often appear with atmosphere and a very few times with time, which would often be alone. Heat and light are also very often together as in the previous group. Some students would make very large groups (for example individuals number 5 and 6) others would leave many entities alone (for example individual number 16).

The explanation most often used was a 'mental' relationship between entities ("linked to" or "has something to do") which is rather vague. Part-whole relationships are also very much used. As in the previous group a material causal link appears in a number of cases.

Some students were also reticent to give an explanation, but more often they would give a reason for each pair of entities put together. Their use of language seems more sophisticated than the use made by the 8-10 year-olds, and there is quite a lot of incorporation of learned physics in their explanations, not necessarily very helpful in this case.

3.5. Conclusion

The results obtained as a whole in the main study confirmed the results of the pilot study. The 'ontological' space of features and entities is quite stable across a range of age/instructional groups and with the use of different methodologies.

Some fundamental dimensions of thinking about entities in Science seem to be: of being 'dynamic' or 'static', like a 'place' or 'localized', like a 'motion' (effect) or a 'cause' and like an 'immaterial fluid' (continuous) or 'action' (discrete).

The three ways of thinking about things which generated the features presented in the questionnaires of the first study seem also to be present in the way students spontaneously think about these entities and dimensions.

In the next Chapter these results will be discussed in relation to the methodologies used and to the theoretical framework.

Chapter 4: Discussion of the results obtained

4.1. Introduction

The results presented in the last Chapter will be discussed in two different and complementary ways:

1. In relation to the design of the empirical studies, looking into the way the design may interfere with the results;

2. In relation to the theoretical framework developed in Chapter 1, looking into the way in which the data collected and analysed can be interpreted in this frame of reference.

The objective is first to explore the potential and limitations of the design of questionnaires and interviews as well as the techniques used to analyse quantitative and qualitative data. After that it is intended to explore and try to understand the results obtained, in the light of the theoretical framework adopted.

4.2. Discussion of the results in relation to the design of the empirical studies

4.2.1. Discussion of the first study

The outcome of the analysis in the first study was a series of spaces whose dimensionality was chosen in function of some suggested criteria: by the goodness of fit indicated by Kruskal stresses, by the elbow in the plot of stresses against the number of dimensions (figure 3.1), and also by the interpretability of the spaces.

It was in this sense at the same time reasonable and convenient to take four-dimensional solutions for all the groups of individuals and also for the INDSCAL solution in order to be able to compare these results.

The four dimensional spaces which were generated were interpreted taking into account the location of features in this space and also the position of the vectors representing entities in the space. Also the comparison with the other spaces obtained played an important role.

It is difficult to say to what extent the cluster analysis is helpful for this purpose (Appendix I). A more helpful approach was to compare the distribution of features along each dimension in relation to other groups and also with the space obtained in the pilot study (Appendix H and D.2).

The interpretation was also very much guided by the position of entities in these spaces. The overall result seems consistent with the view that these spaces can have similar interpretations and that the four dimensions remain stable across a range of age/instructional levels and a variable selection of entities and features.

It should be remarked also that multidimensional scaling is being used as a descriptive model for representing and understanding the data set, and as such simplicity and interpretability are the key factors to decide the best way to present the results, as long as the goodness-of-fit indicators are not being neglected.

4.2.2. Discussion of the second study

It is remarkable that the spaces obtained in a very different fashion in comparison to the first study could still give rise to spaces which presented a great deal of similarity with the ones obtained in the first study. This lends support to the notion of taking the space as representing a real feature of the reasoning.

One difficulty in the design of the second study is the way in which dimensions are represented as vectors projected in the space of the factors. Also these dimensions are represented as pairs of opposites, dynamic/static for example, the orientation of vectors being chosen conventionally. The given dimensions could be understood as directions determined by the projections of the vectors in the space of factors, the 'size' or magnitude of the vectors informing about their relation to the plane of the factors (a very small size vector could be indicating that the particular dimension is actually nearly orthogonal to the plane of factors, or the plane of the page).

Another difficulty is in the interpretation of the factors. In the first study the features and entities could be used, but now dimensions themselves are being given and used for interpretation. Interpreting factors in terms of the projection of the dimensions on them raises the problem of whether a new label should have been attached to the factors. As the four dimensions obtained in the first study have been given to the subjects it was considered to be more interesting, as it was intended to compare the first and second study, to label the factors with these dimensions. So the factors were interpreted as the one of the four dimensions which was the closest to them.

This resulted in having two directions in the space for these dimensions: the original direction of a dimension, for example place/localized and the direction of the factor interpreted as place/localized. The other dimensions correlating with that factor can be understood to give additional information about the meaning of being like place/localized, for example being imaginary/real.

Another possibility would have been to rotate the factors so that they would correlate as much as possible with one of the four dimensions given. This could have resulted in a better interpretation for the space obtained for undergraduate physicists, as the directions of the four projected dimensions (used to label the factors) are almost orthogonal to one another in the space obtained. This is an important result, showing that these dimensions can be seen to be really independent one from another, or at least not strongly correlated (observe that this was not the case for 16-18 year-olds in the second study).

The fact that a number of dimensions strongly correlate with these four dimensions or factors means that the space can have a large number of possible alternative interpretations for its factors. It also suggests that the spaces obtained in the first study could also been interpreted in various alternative ways: for example dynamic/static could have been immaterial/material, active/passive and so on.

It is very important to notice that alternative interpretations of the four dimensional space (or bi-dimensional for 16-18 year-olds) of factors are possible, but that the four dimensions chosen (or two dimensions) are nearly orthogonal or independent one from another.

Concerning the distribution of individuals' responses in the space, the interpretation of the results is quite a complex task. From the point in the space representing each individual it is difficult to infer the answers of an individual subject. A better approach is to highlight the fact that some individuals have very different opinions about the position of an entity in a given set of dimensions while others seem to generally agree in their answers.

Concerning the qualitative analysis of the written responses obtained, it becomes possible to understand some of the reasons why some dimensions are highly correlated between them in the space of factors: whether by the fact that the subjects explained one dimension with the other, for example saying that being real is being concrete, but also by attributing similar features to them, like being able to see or hold something concrete or real.

4.2.3. Discussion of interviews

The objective of these interviews was to obtain a set of explanations from the subjects about the way in which entities are seen to be similar to other entities without the use of a given set of features.

It was important to allow individuals to give their first reaction about the groups of entities they made, and to accept the answer they considered satisfactory. A more detailed investigation of students' thinking was not the objective of this study, and would require the use of other interview techniques.

Some individuals hesitated quite a lot and the task seemed to be at a very complex level , but by others the task was taken as rather trivial. Even with the short transcripts obtained it was possible to obtain a large number of different explanations of why two entities could be considered similar.

It is important to remember that the 16-18 year-olds interviewed had no previous knowledge of the questionnaire used in the first study, while the 8-10 year-olds were asked during the interview about features which would apply to each entity before grouping these same entities. It is an important result that the answers given in both cases could be classified with the same set of categories.

4.3. Discussion of the results in relation to the theoretical framework

4.3.1. Discussion of the first study

Figure 1.2 seems to summarise the finding of this first study. The characteristics shared between pairs of fundamental categories: space and object being static (related to the permanent or unchanged in the world) and time and cause being dynamic (related to change in the world) and from another perspective time and space being a place (out of the reach of actions) and object and cause being localized (stuff which acts and which is within the reach of actions). Action as change (motion) in space/time or as desire/intention to act (cause); action as discrete (more like the idea of action itself: an object acting on another by contact) and action as continuous (action in space/time: the image of an active immaterial fluid). These were the dimensions found and discussed in the first study.

Entities can be imagined to have different combinations of features associated with these fundamental dimensions: access to an entity is essential in the distinction place/localized for example. In fact for 8-10 year-olds and 13-14 year-olds this dimension is very closely a distinction between what is out of the reach of actions, and what can be manipulated or used in an action (figures 3.2 and 3.3; these ideas previously related to commonsense reasoning of conservation; see paper in the Appendix D.1). These individuals seem to imagine even time and space as being in the reach of actions and this may explain the fact of their scores being quite low on this dimension.

Matter (mass or weight or atom) and space (or maybe vacuum or atmosphere for example) are alike in the sense of being both static, and the other entities, including time (also field, gravity and solar radiation for example) as being dynamic (except light in some groups) . Being static means being accessible to actions and to the senses as 'things' , while being dynamic means being accessible by what they do or by their effects.

Being like motion means being accessible to the senses and to actions and not very active, but still changing or moving (like movement or sound or space). Being like cause means making things happening (like energy or heat for some groups). Being like an immaterial fluid or continuous action means sharing features of a place and a cause or motion (generally light or sound), and being like action itself or discrete action means sharing features of an object and a cause or motion (force and movement generally, but also matter and elementary particles or their properties).

The four dimensional spaces obtained undergo some transformations while remaining interpretable in a similar way. Action/immaterial fluid is replaced by discrete/continuous. For physicists the distinction becomes one between concepts of classical mechanics and quantum mechanics (Figure 3.6.b).

It is possible to conclude from this first study that actions can be seen to be providing features for entities (with a basis in three ways of thinking: what you can do, what it does, what it is made of) which relate to the fundamental categories of thought in figure 1.2 and which generate spaces whose dimensions can be understood in relationship with these fundamental categories of thought.

At the same time this space relates entities and dimensions, categories of thought and features (with basis on actions) in a interpretable way.

4.3.2. Discussion of the second study

The second study provides new spaces which can be related to the ones obtained in the first study.

The space obtained for 16-18 year-olds was a bi-dimensional one. The two factors were interpreted as a distinction place/localized and dynamic/static, the first two dimensions of the previous study (Figure 3.16).

The distinction place/localized can also be understood as imaginary/real for example. The distinction static/dynamic can be understood as material/immaterial, concrete/abstract, object/vacuum, conserved/not conserved, substance/ action and passive/active. All these dimensions can in a way be seen as possible candidates for an interpretation of the first two dimensions of the space obtained in the first study. Cause/effect is in a way somewhat related to both in this space.

The space obtained for physicists was a four dimensional space whose factors were interpreted as being the dimensions of the first study (Figure 3.17). Dynamic/static can be seen as immaterial/material, active/passive and action/substance for example. Place/localized can be discrete/ continuous. Cause/effect can be imaginary/real, abstract/concrete and conserved/not conserved for example.

Actually in this space factor 4 could also be interpreted as cause/effect and factor 3 as conserved/not conserved, but in this case no comparison with the first study would have been possible.

The categorisation of responses (Appendix J) also shows that dimensions which appear as strongly correlated in the space of factors are thought of in similar ways by directly using one dimension to explain another or by the sharing of certain similar features (concerning accessibility for example).

It is remarkable that the same three ways of thinking about things, with a basis in actions, which was used to generate the features to be used in the questionnaire of the first study, appear here as giving the interpretation of the responses given by the subjects when asked to spontaneously describe a set of dimensions (Tables 3.6 and 3.7).

4.3.3. Discussion of interviews

An important aspect has been added to this research with the analysis of interviews (interviews in Appendix G, network of categories in figure 3.22).

Individuals when asked to group similar entities together gave explanations which suggest that, beside looking into shared properties and accessibility, there are also important relationships between them to be considered:

1. A reason to say that two entities are similar is based on a part/whole relationship between them;

2. A reason to say that two entities are similar is that one follows/ causes/creates/ (and so on) the other;

3. A reason to say that two entities are similar is when to have one you need the other (or a condition);

4. Or any other relationship ("reminds me of...").

This suggests that entities are grouped together as similar as long as it is possible to find any relationship between them. In fact most explanations are basically the construction of a coherent sentence in which the grouped entities can participate. For example to explain why force, matter, movement and gravity are grouped together :

> *"...the force which acts upon matter, movement, which causes force, gravity, which influences matter..." (She 16;05)*

The interesting consequence of doing this is that as relationships hold between pairs of entities, and if a large group is made, it will be the case that the first and the last entities in a chain of relationships will not necessarily have a relationship between them. This way of grouping entities seems to be a case of what Vygotsky termed 'complexes' (Vygotsky 1986).

It can be said that in most cases these 16-18 year-old students have heard about concepts like energy, radioactivity and so on, but have only a vague idea of their definitions and relationships, mainly from their own limited experience with the use of these concepts in explaining events. Abstracting and generalising from particular examples is a necessary step to construct what Vygotsky termed 'potential concepts' (Vygotsky 1986).

In a Piagetian perspective it can be said that, in the construction an entity, as long as two entities are considered to participate in an action (of putting one thing inside another or of pushing things for example) they will share a meaning which will cause them to be similar to each other to a certain extent. For example it is possible to see the movement of an object of certain mass in space. This results in subjects giving 'yes' answers to the question 'can you see it?' for space, mass and movement. This will make them similar entities in the ontological space (for example space and movement will be close in dimension motion/cause, movement and mass close in dimension cause/immaterial fluid and space and mass in the dimension static/dynamic).

4.4. Conclusion

The discussion of the results obtained raised a number of important issues. Concerning the design of the empirical work:

1. That the use of multivariate-exploratory statistical methods in exploratory data analysis can be a fruitful way of generating a suitable representation of rather deep ideas, otherwise not easily accessible;

2. That the interpretability of the represented data should guide the choices made by the researcher, together with some statistical indicators;

3. That in the present research items 1 and 2 have give rise to a study in which it was possible to generate a representation of data which had a very natural interpretation in the theoretical framework proposed;

4. That it was possible to find a way of representing this data in a similar interpretable way for different age/instructional groups and with varied sets of input data.

Concerning the theoretical framework:

1. That it was possible to find a way to relate basic ways of thinking about things with a basis in actions : what you can do, what it is made of/looks like and what it can do, to fundamental dimensions of thought about reality as proposed by Piaget (Piaget 1923; see Figure 1.2);

2. That entities can be represented in a space in relation to features with a basis in actions and dimensions related to the fundamental categories of thought;

3. That this space was found to be basically a four dimensional space with dimensions being: place/localized, static/dynamic, cause/motion and action (discrete)/immaterial fluid (continuous);

4. That this space accepts a number of alternative complementary interpretations;

5. That the dimensions obtained in the first study were also found to be associated in similar ways to features and entities when these dimensions were directly presented to and judged by subjects in a second study;

6. That individuals spontaneously group entities in a similar way to the clustering obtained with the use of the ontological features based on actions in the first study;

7. That some of the individuals' reasons why entities are similar to each other in the groups they spontaneously form are based on them being

able to form a sentence in which one entity causes the appearance of the other or in which one is contained by the other;

8. That this last result can be understood in terms of entities sharing some features between them in action.

In the next Chapter some general conclusions and reflections on these results will be presented

Chapter 5: General conclusions

In this Chapter the results obtained and discussed in the last Chapter will be summarised and commented on in relation to the research questions presented in Chapter 1. Some further discussion will relate the present research with past and future research in the area.

Research questions to be answered are:

1. Would it be possible to find a description of people's conceptualisations of entities in Science in terms of the 'meanings' attributed to entities with a basis in actions?

A possible answer to this question is that for the five different age/instructional groups investigated in this research (from 8-10 year-olds to undergraduate physicists) it was possible to obtain a similar data structure, represented by a four dimensional 'ontological' space (obtained with multidimensional scaling), in which features asked about entities with a basis in actions (what you can do to it, what it does and what it is made of/looks like), together with the entities, can be represented and understood with an interpretation of the dimensions of these spaces as:

Dimension 1: static/dynamic
Dimension 2: place/localized
Dimension 3: cause/effect
Dimension 4: action (discrete)/immaterial fluid (continuous)

This space is reasonably stable for a change in the number of features and entities used and across age/instructional groups.

These dimensions can be related to features of entities with a basis in action (you can touch it, you can spread it and so on) and to a diagram relating fundamental categories of thought about reality to action and motion (Figure 1.2).

It was also possible to generate a similar data structure by simply asking individuals from two different age groups (16-18 year-olds and undergraduate physicists) to locate a given set of entities in a given set of dimensions, including the four dimensions of the first study.

A bi-dimensional and a four-dimensional space was obtained (with Principal Components analysis) whose factors could be interpreted as in the first study, with the dimensions used in the first study being nearly orthogonal in the space of factors. At the same time the categorisation of responses obtained by asking individuals to explain the set of dimensions given proved to be interpretable with the use of the three ways of thinking with an origin on actions: what you can do to it, what it is made of and what it does.

Interviewing a number of individuals it was also possible to obtain a similar data structure and to see how the individuals' responses about their way of grouping similar entities is related to actions. The conclusion is that individuals use quite often part-whole relationships and causal relationships holding between entities to establish a similarity relation. This can be understood in terms of entities sharing a 'meaning' when participating in an action, for example of putting something inside something else or of pushing something. In this way entities like 'mass' and 'space' are similar (one contains the other) or energy and force are similar (one causes the other).

2. How would these actions relate to the fundamental categories of thought presented in figure 1.2?

Each of the four dimensions obtained is related to a certain number of features, the ones underlined being present in all the spaces obtained with multidimensional scaling in the first study (using ALSCAL or INDSCAL):

Dimension 1 . *Place:* imaginary, you are inside it, like a place, exist without acting, can't do anything to it , like a field, like a vacuum - *localized* : it appears and disappears, act by contact, localized somewhere, you can destroy it, you can spread it;

A place is that which is out of the reach of actions, as such imaginary, and something you are immersed in, mainly constructed with part-whole relationships. Being localized means you can act on it, it does things and it is somewhere.

Some examples of entities seen as place by the subjects of this study are time and space (also Fundamental Categories in Figure 1.2) and vacuum, atmosphere, field, gravity in this study. Some examples of entities seen as localized are mass and force (related to the categories object and cause) and also matter, weight, atom, heat and energy in this study.

Dimension 2. *Static* : it is at rest, like a solid, concrete, macroscopic, microscopic, substance, like particles, exist without acting, localized somewhere, material, you can touch it, you can see it, it is real, it is like a place - *dynamic* : like a force, destroy things, like a movement, like an action, it causes movement, it is a cause, you can see the effects, it is an effect, like a wave, ;

Something static is mainly understood in terms of its accessibility to the senses while being dynamic is mainly understood in terms of the effects caused.

Some examples of entities seen as static are space and mass (space also a static category and mass related to object also a static category) and also matter, weight and atom in this study. Some examples of entities seen as dynamic are time and force (time is also a dynamic category and force -related to cause- can also be considered to be related to a dynamic category).

Dimension 3. *Motion:* you can see it, you can hear it, you can stop it, like a movement, like a wave, it is an effect, like a place, you are inside it - *cause:* you can feel it, it is a cause, microscopic, like an energy, it transforms things, it acts by itself, it destroys things, act by contact;

Being like a motion is understood in terms of its accessibility to the senses and action. Cause is understood in terms of its activity.

Some examples of motion are movement itself, also a primitive category in figure 1.2, and sound and space (also a derived category from motion). Some examples of causes are energy and heat in this study.

Dimension 4. *Action (or discrete):* can create things, you can create it, you can touch it, you can stop it, it move things, can cause movement, you can destroy it, like an action, concrete, like a solid, like a movement, macroscopic, act by contact, like a force - *immaterial fluid (or continuous):* immaterial, like a gas, act by itself, you can be inside it, act at a distance, like a place, imaginary, multiply by itself, spreads by itself, you can touch through it, like a fluid, it is at rest.

Something like an action or discrete action is understood in terms of all three ways of thinking (what you can do, what it does and what it is made of) and an immaterial fluid or continuous action as well. This dimension is directly related to action itself.

Examples of entities like action (discrete) are force, impulse, mass, atom (active discrete things); examples of immaterial fluids (continuous) are light and sound for most groups of individuals in this research.

3. If such a description is possible what would be the implications for the understanding of commonsense reasoning in Science ?

Concept formation starts very early in childhood and for a number of researches in the area of cognitive sciences it starts even before language acquisition. For Piaget the construction of fundamental categories of thought like space and time starts very early in life. These constructions would be necessary so that the child is able to walk around, return to the same place and organise actions in a space-time frame.

Being in control of actions seems to be the motor for initial concept formation, but with the acquisition of language a further step is necessary. To translate all that is already present in the organisation of motor schemas, and probably also present as images of objects and events in the mind, into language, a total reconstruction of knowledge is necessary, and it is often the case the one knows how to do something without necessarily being able to say it in words (Piaget 1974a and b).

The construction of concepts in Science is far from being an easy task, as the large amount of research in the area of 'alternative conceptions' has shown. In the present research an approach was tried in which actions were taken as point of departure of concept formation to generate questions about entities, and some regularities in the structure of the data collected was found across various age/instructional groups.

Most students do not know how to define or explain most of the concepts in Science, and even for scientists this is sometimes a difficult task. At the same time there is a structured sort of knowledge about many of the entities in terms of the 'sensorimotor experience' of them (seeing, feeling, changing, stopping and so on) and their activity (destroying or moving things for example) or at least that is what this research has tried to show.

The way to use this previous knowledge of entities in the teaching of Science should be addressed when more is known about the way this previous knowledge is constructed and structured from an early age. If this previous knowledge of entities has a basis in actions, a large gap separates the use of these entities in daily explanations and their conceptualisation in Science.

Entities such as 'force' or 'energy' are more clearly present in previous constructions from an early age, and are commonly used in daily explanations, while other entities are introduced in Science whose previous experience with is limited or even non-existent, like 'radioactivity', or 'spin' for example. The way in which entities in both cases will be understood and conceptualised in Science raises important questions. At the moment it is not clear to what extent the use of an entity in daily explanations is helpful or not to conceptualising it in Science.

This research has tried to show that it is possible to find some regularities in the way people think about entities, with a basis in actions. Further research is being done on people's knowledge of events. It is hoped that these studies may be of interest in the understanding of commonsense knowledge of the world and in the development of teaching techniques which would take account of this knowledge in the teaching of Science.

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Appendix A:
The form of the questionnaire for the Pilot Study

The form of the questionnaires, in Portuguese is shown below.

Nós muitas vezes pensamos a respeito de alguns conceitos em Física, mas nem sempre nós os entendemos muito bem. Nós gostaríamos que você procurasse pensar um pouco a respeito deles. Basta tentar imaginar como é que eles são e o que eles podem fazer acontecer.

Nas tabelas abaixo marque com um X aquelas coisas que você puder pensar a respeito da matéria, energia, tempo, espaço, movimento, calor, luz, som e força.

Como é que se pode imaginar que são → Eu imagino que pode ↓	matéria	energia	tempo	espaço	movimento	calor	luz	som	força
parecer um tipo de gás									
se parecer com partículas									
parecer um tipo de fluido									
parecer um tipo de sólido									
ser microscópico									
ser macroscópico									
tem dimensão desconhecida									
↓									

Appendix B:
Table with data obtained in the Pilot Study.

Table with frequencies of 'yes' responses.

feature	*matter*	*energy*	*time*	*space*	*move-ment*	*heat*	*light*	*sound*	*force*
kind of gas	6	5	0	3	1	9	4	2	0
like particles	29	7	0	5	4	8	14	7	7
like a fluid	4	15	3	1	6	7	8	13	3
like a solid	30	2	0	4	1	3	0	0	3
microscopic	21	11	5	5	6	5	5	5	2
macroscopic	26	3	2	8	6	1	10	0	4
unknown dimension	1	18	11	17	9	17	17	12	13
immaterial	2	27	20	10	9	24	19	24	11
real	34	16	12	18	15	16	17	14	21
in mind	0	4	12	3	4	2	1	2	4
like a force	1	32	3	5	23	9	12	4	22
like a place	5	0	4	32	4	3	0	0	1
like waves	1	16	3	5	9	11	15	36	4
everywhere	19	17	21	15	7	11	8	4	7
nowhere	0	0	6	3	0	2	0	0	2
localized	18	13	8	10	11	12	17	17	16
movement	0	4	4	3	16	0	3	6	6
act by contact	17	15	0	1	17	14	8	9	21
act at distance	4	15	10	12	8	21	21	22	12
act by itself	4	16	13	4	10	17	10	5	10
it destroys	11	24	5	4	13	24	4	15	29
it transforms things	15	27	15	6	15	25	9	2	24
it creates	17	15	10	8	12	11	6	5	12
it transfers things	6	15	4	8	33	4	3	5	25
cause movement	7	28	7	9	18	11	10	7	28
reason for everything	12	10	7	2	4	1	3	1	8
act/control	17	14	12	3	18	12	12	19	17
distributes	7	19	8	6	4	23	21	15	8
concentrates	8	12	3	5	1	15	11	6	3
multiplies	5	11	8	3	1	8	11	9	3
exist without acting	24	14	14	16	5	11	15	9	11
appear/disappear	7	14	2	3	11	14	23	22	9
can see it	24	5	0	17	25	1	29	0	4
see through it	10	15	11	13	10	8	26	2	4
can touch it	23	0	0	0	3	1	0	0	2
touch through it	3	6	2	4	2	5	7	3	3
can hear it	2	2	0	0	7	0	0	36	1
hear through it	7	2	1	5	7	3	7	17	0
can feel it	28	31	11	6	25	35	19	10	26
create it	21	19	6	11	21	20	12	22	23
destroy it	30	5	1	11	11	9	8	9	13
transform it	33	31	6	10	14	24	15	15	18
transfer it	11	23	1	7	12	18	14	13	17
concentrate it	7	17	1	0	2	22	14	11	19
disperse it	15	16	0	1	5	23	23	20	12
can stop it	10	16	8	1	34	12	10	21	21
conserve it	24	17	4	15	19	21	10	13	16
move inside it	8	9	20	25	11	5	9	6	6
use/move	13	27	5	10	31	9	5	1	36
use/create	32	19	6	3	9	22	10	3	22
use/destroy	22	27	5	2	7	21	8	7	28
use/ transform	23	29	14	3	16	35	11	2	28
use/conserve	15	12	7	6	4	17	8	0	8
treat/gas	7	1	0	1	6	8	2	0	0
treat/fluid	4	17	2	1	2	9	11	7	2
treat/particles	24	16	0	1	0	4	5	2	1
treat/solid	34	0	0	1	0	1	0	0	1
treat/micro	19	8	1	3	0	3	0	2	0
treat/macro	23	5	1	6	3	3	10	0	6
treat/force	3	30	0	1	22	14	11	8	22
treat/place	1	0	2	38	1	1	0	0	1
treat/real	34	12	12	16	14	14	17	19	14
treat/ imaginary	4	17	22	12	10	12	5	10	15
treat/movement	2	14	9	4	25	5	11	13	18
treat/wave	1	14	1	0	1	20	20	28	4
see effects	10	25	21	2	19	28	26	15	29

Appendix C:

Table with multidimensional scaling results for the pilot study.

Table with coordinates of features and concepts in four dimensions.

Feature	*Dimension:* 1	2	3	4
kind of gas	0.4238	-0.6876	-1.0925	-1.0054
like particles	1.4831	-0.7702	-0.6714	0.1730
like fluid	-1.4827	-0.6885	-0.6460	0.5037
like a solid	1.9435	-0.1349	-0.0549	0.1386
microscopic	1.7129	-0.2759	-0.2709	-0.0318
macroscopic	1.9899	0.0842	-0.2972	0.3825
unknown dimension	-1.9079	1.0026	-0.7683	-0.6054
immaterial	-1.9934	0.4624	-0.8642	-0.5301
real	1.8561	-0.2507	0.2301	0.1280
in the mind	-0.7094	2.5597	0.5699	0.0192
like a force	-1.3017	0.0942	1.3048	-0.0795
like a place	0.8672	2.3112	-0.7428	0.6428
like waves	-1.5550	-0.2379	-1.2023	1.1962
everywhere	1.1526	1.5916	-0.0854	-1.1017
nowhere	-0.0481	2.8041	-0.0456	-0.2772
localized	0.0957	-1.3666	-0.6876	0.7673
it is movement	-0.9689	0.8756	1.1503	1.7911
act by contact	0.0350	-0.9060	1.3334	0.3089
act at a distance	-1.7880	-0.0206	-1.5030	0.1320
act by itself	-1.4393	0.2771	0.4987	-1.2431
destroys things	-0.9657	-0.6076	1.2286	-0.3187
transforms things	-0.2765	0.0345	1.2696	-1.1849
creates things	1.0504	0.2006	1.2757	-0.5876
transfers things	-0.4354	0.5260	1.8350	1.0259
causes movement	-0.9924	0.2803	1.5371	-0.2361
reason for everything	1.1299	0.3495	1.0005	-0.7037
act under control	-0.5047	-0.8067	0.9966	1.2511
distributes	-1.2073	-0.5716	-1.2294	-0.7642
concentrates	-0.4702	-0.5856	-1.1419	-1.1037
multiplies	-1.0423	-0.0778	-1.5675	-0.6977
exists without acting	1.7338	0.7184	-0.7944	-0.6325
appear/disappear	-1.3067	-0.9133	-1.0363	0.7622
can see it	1.2740	0.4653	-0.5300	1.5083
see through it	0.0947	1.1431	-1.5851	-0.7282
can touch it	1.8842	-0.2378	0.1318	0.4043
touch through it	-0.7407	-0.1674	-1.3971	-0.9917
can hear it	-0.9322	-0.0369	-0.8517	2.0430
hear through it	-0.2179	-0.1718	-1.3787	1.9583
can feel it	-0.0407	-0.8765	0.8478	-0.8097
can create it	-0.1922	-1.1291	0.8193	0.9460
can destroy it	1.7454	-0.4198	0.1199	0.7446
can transform it	0.6143	-1.0586	0.1396	-0.5598
can transfer it	-0.9705	-1.0519	0.2539	-0.3223
can concentrate it	-1.1025	-0.9679	-0.0538	-0.7868
can disperse it	-0.6349	-1.2798	-0.9335	-0.1197
can stop it	-0.9991	-0.2663	1.1986	1.4535
can conserve it	1.0262	-0.8992	0.6853	0.3031
can move inside it	0.4022	2.7508	-0.5099	0.3647
use to move	-0.2139	0.3628	1.9154	0.2487
use to create	0.9023	-0.7642	0.6443	-0.7648
use to destroy	0.0283	-0.7455	0.8821	-0.8706
use to transform	-0.0664	-0.3512	1.0201	-1.2097
use to conserve	0.7984	-0.1150	0.0059	-1.5068
treat/gas	1.2956	-0.8978	0.2816	0.1739
treat/fluid	-1.1193	-0.5833	-0.8538	-0.7269
treat/particles	1.3085	-0.6227	-0.2917	-0.4667
treat/solid	1.9233	-0.1807	-0.1630	0.2347
treat/micro	1.6948	-0.2788	-0.2875	-0.1811
treat/macro	1.8435	-0.1997	-0.3124	-0.0266
treat/force	-1.3030	-0.3516	1.1114	-0.0611
treat/place	0.5704	2.3534	-0.8812	0.6125
treat/real	1.7353	-0.3615	-0.6564	0.7730
treat/imaginary	-1.1632	2.0663	0.6885	-0.5882
treat/movement	-1.4234	0.4760	1.1938	1.3048
treat/waves	-1.4618	-0.6524	-1.3868	0.2989
see effect	-1.6375	-0.2210	0.6045	-0.7706
Concept	*1*	*2*	*3*	*4*
matter	2.5491	-1.0230	0.3523	-0.1538
energy	-1.2605	-0.7044	0.9274	-0.7877
time	-0.3968	0.6556	0.2199	-0.4271
space	0.5223	1.0209	-0.3166	0.1676
movement	-0.6399	-0.1841	1.3894	0.6154
heat	-0.9751	-0.9622	0.3344	-0.8957
light	-0.7138	-0.5651	-0.5260	-0.1348
sound	-1.4254	-0.7528	-0.5138	0.7663
force	-0.8115	-0.6001	1.6711	-0.2845

Note: The coordinate c_{ij} of concept i on dimension j is the weighted mean over all features of the fractions f_{ik} of 'yes' responses for the concept i on the feature k, using weights w_{jk} equal to the coordinates on dimension j of feature k.

Appendix D: Published papers.

D.1. Common-sense reasoning about conservation: the role of action (1990).

INT. J. SCI. EDUC., 1990, VOL. 12, NO. 1, 51–66

Common-sense reasoning about conservation: the role of action

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This exploratory study concerns a basic ontology of things that are conserved in the common-sense reasoning of 14–17-year-old students. A questionnaire was given to 84 students in which they were asked to classify a list of different things into several ontologically different categories. They were also asked to explain some of their choices. The results are interpreted with the help of a psychogenetic and sociogenetic approach derived from Piagetian theory. The analysis suggests the possible role of actions in common-sense reasoning about conservation.

Introduction

Recent research in common-sense reasoning has suggested looking for deeper regularities lying behind students' ideas about physical phenomena (Ogborn 1985, Guidoni 1985, diSessa 1988). What common-sense is and how to represent it are both important methodological questions (Bliss and Ogborn 1987). In this paper, we discuss our general theoretical position, and then use this analysis to discuss some preliminary empirical results.

Our aim is to investigate common-sense reasoning about conservation, understood in the widest sense. Our theoretical starting point derives from previous studies in the psychogenesis and sociogenesis of knowledge by Piaget and Garcia (Piaget 1937, Piaget and Garcia 1983). The approach is both *structuralist* and *constructivist*. It is structuralist in looking for organized structures of possibility and impossibility, necessity and contingency, reversibility and irreversibility, etc. It is constructivist in the Piagetian sense of regarding *actions* as providing the most primitive elements of construction (Piaget 1968).

Piaget's first studies of the construction of reality show the child as constructing a basic ontology of things that are conserved, together with the construction of causes (Piaget 1937). Thus, in the sensorimotor period, the child constructs a *knowledge-in-action* of the permanence of objects and of space and time; also of causality.

Piaget's idea is that in the representational period, and later in the operational period, this knowledge-in-action is reconstructed all over again, following the same steps as in previous constructions. An example is the initial conservation of objects as unchanging through displacements, to later reconstructions of similar but more general structures, including the conservation of the object through transformations, and later still to general ideas of invariance. It is the *reconstructive* character of Piagetian theory that supports his fundamental project of genetic epistemology: to understand historical and philosophical problems of knowledge through studying the development of children's thinking. Our proposal, then, is to look to the earliest

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stages of cognitive development as a source for understanding common-sense knowledge about conservation (the psychogenetic approach), and to look for similar structures in scientific ways of reasoning about conservation (the sociogenetic approach).

The psychogenetic approach to conservation

For Piaget, action and movement are the primitives for the first conceptualizations in childhood (Piaget 1973). One might attempt to represent Piaget's final position concerning the development of these conceptualizations as in figure 1. The diagram shows two things: it illustrates Piaget's account of the psychogenesis of cause, object, space and time (and so of the Kantian categories), and at the same time, on a different level, tries to mirror interconnections of the categories that structure physical thinking about reality (for example Piaget and Garcia 1971). The psychogenesis of the four fundamental categories was fully studied by Piaget in his early work (Piaget 1936, 1937, 1946, Piaget and Inhelder 1947; see also Piaget 1926, 1927) where they were subdivided into static (space, object) and dynamic (time, causality) categories.

Piaget sees cause arising out of action as the child tries to make a link between his action and its effect. In this process the object is also constructed, as something permanent through displacements. In sorting out what is changing from what is not changing, the child arrives at a first conservation, that of objects.

More recently, Piaget and Garcia (1987) have drawn attention to a level of logical operations more attached to meaning and to objects than is traditional logical analysis (they call it a 'logic of significations'). Such a logic works with and on objects. In it, the object is firstly *'what you can do to it'*, whether physically or mentally. Physically it can be moved, etc., so that this set of meanings arise from action. Mentally it can be classified, seriated, etc., again a set of meanings related to actions or possible actions. Secondly, the object is *'what it is made of'*. However, finding out what a thing is made of is done by acting on it (squashing, pouring, breaking), so these meanings too have their origin in action. Here Piaget points to the importance of what he terms 'infralogic': the construction of spatial relations of objects, of relations of part and whole, and of proximity and continuity or of inside and outside. We may regard such relations as in a sense underlying traditional logic whilst still being plainly 'logical' in character.

Actions themselves mean *'what they make happen'*; the transformations they produce in objects.

Objects are what actions happen to: their conservation (and so their very existence) appears as a result of the co-ordination of actions, when a group of actions applied to the object leave it still identifiably the same object. Causes are realized in

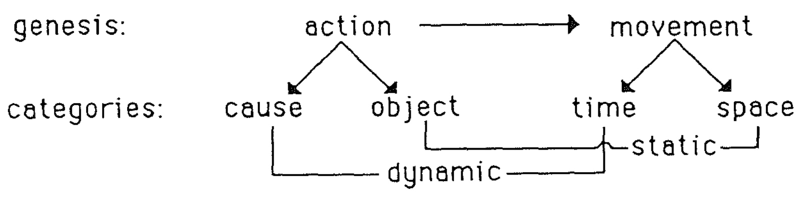

Figure 1. Piaget's account of the development of fundamental categories.

their effects, and are modelled on actions themselves. *Where there's no change there's no cause to be sought.* The first primeval source is the child himself, who can progressively imagine this power possessed by other objects. Going back to figure 1, we can see time and space as being the place (the theatre) for actions to be performed on objects. Thus space, seen as a kind of object, must constitute a *whole*, and its construction requires the infralogic of proximity, inside or outside, etc. Its properties will be the properties of groups of actions performed on objects. Time is to be seen in this way also (Piaget 1937, Piaget and Inhelder 1947).

It should be noted also that conservation, since it concerns what *cannot* be done—the impossible—requires reasoning that goes beyond individual particularities.

The sociogenetic approach to conservation

Many authors try to draw attention to parallels between the content of scientific ideas at a given epoch and the ideas of children (see, for example, Carey and Wiser 1983). We should make it clear that we are *not* making any claim about an isomorphism between the contents of these kinds of knowledge. What Piaget terms a sociogenetic study looks at the way the actual content of science at a given time is related to a certain conception of the world, a frame within which concepts are developed and theories are shaped (Garcia 1987; see also Piaget and Garcia 1983, Garcia 1983). Our interest will be in identifying structural elements in scientific thinking at different times, which are related to conservation. We will look at a number of ideas about the world from the point of view of figure 1, of relations between *space*, *time*, *matter* and *cause*, and of *invariants through transformations*.

We shall consider three different periods: antiquity, the contemporaries of Newton, and the recent pre-Einsteinian period. We shall ask on what grounds entities were seen as conserved, or as candidates for primeval or secondary sources.

The atomism of Democritus conceived an *infinite empty* space that was nevertheless real, thus saying for the first time that a thing might be real without being a body. Objects were constituted of indivisible atoms moving in space. Time was *uncreated*. The Pythagoreans considered space as the place where objects *move*, all things being *in it*, and its surroundings being the infinite void (though they would have identified the air with the void). For both, space differs from matter and is independent of it, but for the Platonists bodies were nothing but space limited by geometrical forms (Jammer 1954, Lindsay 1975).

Heraclitus considered that *all is change*, but also that there is something *invariant* in the universe as a whole, which he took for *fire* (not in the modern sense). Parmenides, on the contrary, treated change as illusion (Lindsay 1975). Aristotle's conception of space is of it as finite, and gives it certain *active* properties through the notion of movement to a natural place (Jammer 1954). In contrast with atomism, which assumes that all atoms are in perpetual motion without the need for an explanation, Aristotle considers that all that moves is moved by something else (Dijksterhuis 1986).

Newton conceived an absolute space, without relation to anything external, always similar and *immovable*. The flowing of absolute time is also not liable to any change. Motion is the translation of a body in absolute space. The causes by which true and relative motions are distinguished are the *forces* impressed upon bodies. For Leibniz, on the contrary, there is no absolute time or space, time being the order of simultaneous things, and space being the order of coexistent things. For him there is no absolute reality outside corporeal things. For Descartes, matter is extension and the conception of an empty space has no meaning. For him the quantity of movement in the Universe is constant, while for Leibniz it is *vis viva* that is conserved (Piaget and Garcia 1971).

Mayer (1814–1878) considered two classes of causes: matter and *force* (force here to be understood as energy). Causes are quantitatively indestructible and qualitatively transformable. According to Mayer causes are transformed into their effects, and these are in turn transformed into further causes and so on, giving origin to secondary sources or causes. He sees the sun as a *primeval source* of physical energy: 'It is the light of the sun which when transformed into heat brings about the motions in our atmosphere' (Lindsay 1975).

The relevance of the elements in figure 1 to the development of scientific thought is perhaps particularly clear in the case of Hertz (1899). In the immediate period before Einsteinian ideas became dominant, we find him stating that all physics has so far rested on four fundamental ideas: space, time, mass and force (in figure 1 read space, time, object and cause). As in figure 1, Hertz claims that mass and time are not connected. Relations between object and space are the basis of statics; between space and time that of kinematics. But Hertz saw force as too dependent on human action to be a fundamental element of reality. So he tried to reduce it, via the concept of action (in the sense of the term used in physics) to a combination of mass and motion, which he did regard as fundamental (see Piaget and Garcia 1971).

With the Einsteinian era, Euclidian space is abandoned and a four dimensional space-time introduces a new unified understanding of space and time. Matter is regarded just as a region of special curvature of space-time, which seems to take us back to Platonic ideas (and also to later Cartesian ones).

Even this short account of ideas suggests something underlying these different views of space, time, cause and matter: *infinite* space and time treated as a *whole* inside which objects are located, actions performed by one object on another; also *finite* space *substantialized*, with actions deriving from certain *properties* of space. Time is seen as being completely independent of the material world. Space and time can also be conceived as having no absolute reality outside corporeal things. Of causes one can say that they are generally assimilated to something that moves other things. They can be a combination of matter and movement or they can have independent existence as *force*. There is a constant search for *invariants*, even if all is changing. There are apparent changes and absolute changes. There is a search for some underlying reality that is *unchangeable*, or quantities that remain constant in the Universe. Often, that which is unchanged is that which is *out of the reach of human actions*.

Design of the questionnaire

A questionnaire was used to make a preliminary investigation of these issues. A questionnaire, rather than an interview, was chosen on several grounds. First, we wanted to ask a rather large number of simple questions, the interest being mainly in the relations between patterns of answers, not in the answers themselves. Second, a common-sense theory of knowledge also contains implicitly the assumption of something that is common to groups of people and that is not too much affected by individual differences. The questionnaire was given to 84 students in secondary school in Italy, half being 14–15 years old, and the other half being 16–17 years old. The questionnaires were answered in approximately one hour.

1. Tick in the box in front of each figure which represents, in your view, something that...
... would last forever

Which things below would last forever ?

diamond		sun		charge		solar system	
iron		oxygen		river		person	
plant		energy		waterfall		car	
wood		force		pendulum		lamp	
food		matter		light		calculator	
electron		star		radioactivity		hammer	
air		space		atom		clock	
heat		water		movement		radio	
time tic tac..		pushed ball		oscillator		tv	

2. Please think of something that...
... would last forever: ....
Can you explain why this thing would last forever?
....
....
(If necessary you can use the same example in each case ; if you wish, you can use the examples shown in the tables)

Figure 2. The format of the questionnaire.

Part of the questionnaire asked whether each of a number of different entities could belong to each of six categories. For each entity, the student was asked to say whether it:

(i) can last for ever;
(ii) can move forever;
(iii) can function forever;
(iv) cannot be created or destroyed;
(v) cannot stop by itself; and
(vi) can produce something without help from outside.

The questionnaire consisted of a series of grids identical to the one shown in figure 2, one for each of the six categories above. In addition, as also shown in figure 2, students were asked to think of something else that would fit each category, and explain why.

The categories were selected in the light of general ways of thinking about conservation: necessary existence (lasting forever), necessary movement (moving forever), necessary source (function forever), indestructibility (not created or destroyed), isolated systems (cannot stop by themselves), and primeval sources (produce something without help).

These six categories can also be understood in terms of the diagram in figure 1: indestructibility (action→object), isolated system (action→movement), primeval source (action→cause), necessary existence (space→object), necessary movement (space/time→movement) and necessary cause (time→cause). The one that is not related to conservation is that of primeval source (creating something out of nothing).

Thirty-six entities were presented. They were selected so as to cover a variety of kinds of things: abstract concepts (force, energy, etc.); microscopic entities (electron, etc.) and cosmic entities (star, sun, etc.); day-to-day machines (television, radio, etc.) and things (wood, iron, etc.); ideal machines (pendulum, etc.); natural cycles (river, etc.) and living things (plant, etc.). Figure 2 shows the complete set chosen.

Analysis of data

The quantitative analysis

The analysis was performed on the overall collection of data, differences between the age groups not being considered at this stage of the research. Before discussing the results of this analysis, a look at the raw data, given in the appendix, is of interest.

Time and electron present a high frequency (about 50% or more) of yes answers in almost all conservative categories, with a marked decrease in the frequency for the last category (primeval source), a pattern also broadly followed by atom, space and movement. Not unlike in pattern (though with lower frequencies) are air, matter and solar system.

Energy presents a high frequency of yes answers not only in most of the conservative categories but also in the last (primeval source). Following nearly the same pattern are light, charge, heat, force and (maybe) oxygen. The sun gets a high frequency of yes answers only in the primeval source category, and following nearly the same pattern are star, person, plant, radioactivity and (maybe) wood.

Diamond has a moderate frequency of yes answers only for the categories *last forever* and *cannot be created or destroyed.* Presenting a low frequency of yes answers in all categories, with an excess in the category *cannot stop own movement* are water, pushed ball, river, waterfall, pendulum and oscillator. Presenting near zero in all categories but *cannot be created or destroyed* and *cannot stop own movement* are car, lamp, calculator, hammer, clock, radio and television. Iron and food only present a moderate frequency of yes answers in *cannot be created or destroyed* (a frequency increased by seven 14–15-year-old students who answered 'no' about creation and destruction for every single entity).

The analysis proceeded in two stages. A factor analysis extracted two factors. Factor 1 loaded strongly on the categories *last forever*, *move forever*, *function forever*, and *cannot stop by themselves*, and moderately on *cannot be created or destroyed.* Factor 2 loaded strongly on *can produce something without help* and moderately on *cannot be created or destroyed.* The factor analysis thus supports the view that the questionnaire, as intended, is looking at two aspects: one to do with permanence and conservation (factor 1), and the other to do with sources of creative or causal power (factor 2). It is interesting that the category *cannot be created or destroyed* belongs almost equally to both aspects. Details of the factor analysis are given in the appendix.

Table 1. Factor scores obtained.

Entities	Factor scores		Entities	Factor scores		Entities	Factor scores	
	Factor 1	*Factor 2*		*Factor 1*	*Factor 2*		*Factor 1*	*Factor 2*
Diamond	−0·330	−0·237	Force	0·159	0·532	Atom	1·870	0·220
Iron	−0·757	−0·341	Matter	0·192	0·532	Movement	1·343	−0·637
Plant	−1·266	0·705	Star	−0·988	1·421	Oscillator	−0·228	−0·903
Wood	−0·996	−0·018	Space	1·163	0·663	Solar system	0·159	0·271
Food	−0·779	−0·599	Water	−0·168	−0·452	Person	−1·316	0·866
Electron	2·526	0·266	Pushed ball	−0·045	−1·121	Car	−0·389	−1·030
Air	0·568	−0·210	Charge	0·305	0·597	Lamp	−0·505	−0·801
Heat	−0·552	0·299	River	−0·082	−0·966	Calculator	−0·44	−0·999
Time	3·065	0·488	Waterfall	−0·111	−0·815	Hammer	−0·413	−1·012
Sun	−1·431	3·557	Pendulum	0·365	−1·038	Clock	−0·592	−0·848
Oxygen	−0·382	0·253	Light	0·485	0·773	Radio	−0·445	−0·930
Energy	0·895	2·072	Radioactivity	−0·436	0·372	Television	−0·445	−0·930

Our interest is in the way the entities are seen as belonging or not belonging to these two factors. For this purpose, it is helpful to examine the factor scores for the entities as shown in table 1. High scores on factor 1 indicate entities seen as conserved in some way. High scores on factor 2 indicate entities seen as sources. To bring out the pattern more clearly, the entities were clustered on the factor scores and were also plotted in the space of the two factor scores. Figures 3 (*a*) and (*b*) show the results. (The cluster analysis used the complete linkage method to avoid having too many very small clusters—see Everitt 1974, Jardine and Sibson 1968.)

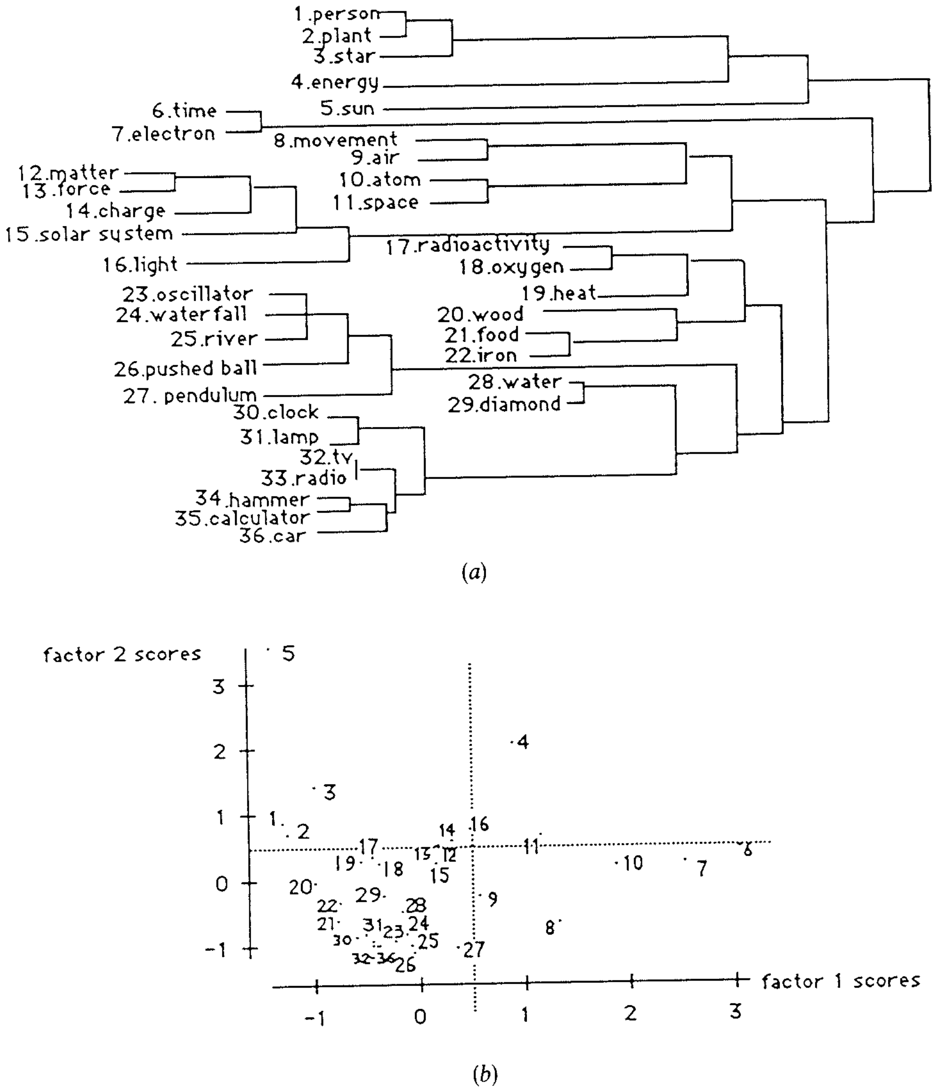

Figure 3. (*a*) Cluster analysis (complete linkage method); (*b*) Plot of factor scores of the entities (the numbers identify the entities).

The qualitative analysis

From the factor analysis and clustering of factor scores it is possible tentatively to identify the following groups, as outlined in figure 4:

(*a*) *possible non-conserved primeval sources* (high on factor 2): person, plant, star, sun (very high) and energy (also high on factor 1);
(*b*) *possible conserved things* (very high on factor 1): time, electron (also positive scores as sources); followed by movement, air, atom and space (atom and space having also positive scores as sources);
(*c*) *moderate sources (possibly secondary) and also moderately conserved things*: matter, force and charge (high scores as sources and positive scores as conserved entities); light (high on both factors) and solar system (positive on both factors);
(*d*) *moderate non-conserved sources* (*possibly secondary*) (positive on factor 2): radioactivity, oxygen and heat:
(*e*) *possible conserved non-sources* (probably related to categories 2 and 5, or conservation of movement): oscillator, waterfall, river, pushed ball and pendulum;
(*f*), (*g*) and (*h*) *non-sources and non-conserved things*: clock, lamp, television, radio, hammer, calculator, car, wood, food, iron, water and diamond.

We will now consider the kinds of explanations students gave for including an entity in a category. It is convenient to begin with the entities found in the first two clusters above.

(*a*) *Primeval sources*
Reasons given for choosing things as 'producing something without help' focus on the entity as a cause, as making something happen:
person—uses his intelligence, produces thinking;
plant—produces fruits/oxygen/flowers without help;
star—produces radiation/light and heat;
sun—nuclear reactions, produces heat/energy/light/electromagnetic waves/life without help;
energy (as producer)—produces work.

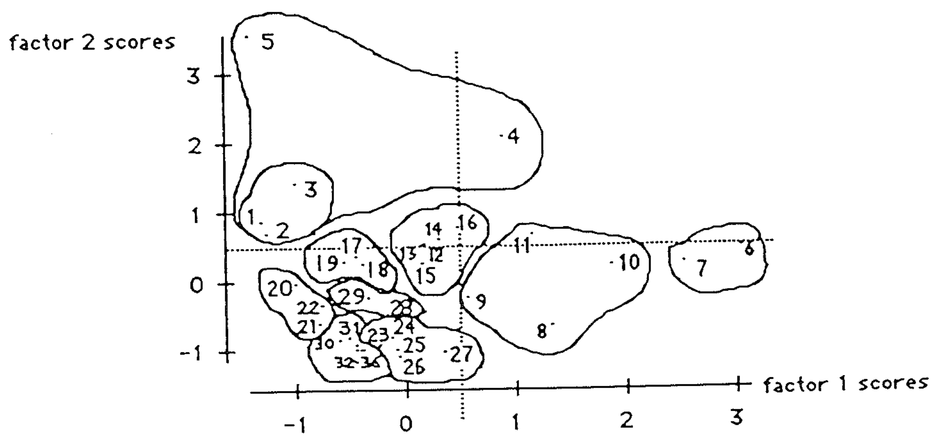

Figure 4. A view of possible clusters.

(b) Conserved entities

Reasons given for choosing objects in the conservative categories have to do with what can or cannot be done to them, or with what they are or are not made of. For conserved entities, the first is mostly about being beyond the reach of action, and the second is about its essential nature or about it as a substantializable entity. Examples of being beyond the reach of action include:

> *time*—no possible external interference, cannot be destroyed, nobody created it, nobody will stop it, untouchable, we cannot intervene, we cannot act on it, it cannot be controlled, it cannot stop or return;
> *electron*—cannot be stopped, there are no obstacles to its movement, elementary indestructible particle;
> *movement*—there always will be something in movement, it cannot stop (*what can be done:* existing atoms, they move and cause movement; something moving only stops by external effect);
> *atom*—nothing is created or destroyed, they cannot stop (*what can be done*: only transforms, changes in form);
> *space*—it cannot be destroyed, nobody created it, in space if something is destroyed at the same time another thing is created, to destroy it, it would have to be filled and there is not sufficient matter to do it, to create it you should eliminate matter which is not possible, whatever happens space lasts forever.

Examples of reasons about essential nature or substantialization include:

> *time*—abstract concept without beginning or end, goes to infinity, like infinity, succession of moments in an empty universe, immaterial, not structured in anything;
> *electron*—like a planet, does not exist at rest;
> *movement*—moves forever by the proper concept of movement;
> *atom*—has internal energy, all particles last;
> *space*—it's infinite.

Reasons that see these conserved entities as causes include:

> *time*—it flows and consumes everything, if it stops nothing changes/the world ends/everything stops, something will always happen, we only see the effects, transformation and oldness, exhausting matter;
> *electron*—neutralizes with the proton of the atom, creates magnetic and electric fields without help, creates centripetal and centrifugal forces with the nucleus, is the basis of everything;
> *movement*—without movement actions could not be made, due to it everything moves;
> *atoms*—matter is formed by them;
> *space*—it can be considered that what moves forever started without anybody or anything to make it (space).

In addition, energy seen as conserved is often substantialized:

> *energy*—when expended is transmitted in another form, it is only transformed, it is conserved, it passes from one body to another, it changes from one form to another, it is not destroyed but is dispersed.

These same forms of reason account for reasons given for objects that were less often seen as conserved or as causes.

What it is made of:
force—it's on its producer and on what stops it;
charge—has its own proper energy;
light—it is what we understand as visible, leaves a trace.

What it makes happen:
radioactivity—produced by elements in matter, produces destruction and death.

What can be done to it (or not):
waterfall—only stops if there's no water, stops by human interference;
river—it's produced alone and cannot be created, to stop it will need an obstacle, stops by human interference;
pushed ball—only friction stops it or it continues by the force of inertia;
pendulum—moves forever, without friction by the principle of inertia a pendulum does not lose energy, without friction the movement is constant;
hammer—gravity makes it fall, does not need energy to function;
car—cannot go without petrol, without braking cannot stop;
Solar system—cannot be stopped, cannot be destroyed, lasts forever if men do not destroy it, there's no specific origin, it was not created;
radioactivity—will always exist, it's not possible to create it or destroy it;
television/radio—can be turned on and off;
charge—needs external interference to stop;
light—the ground stops it, external causes transform it;
water—cannot be destroyed, without external force it cannot change;
diamond—lots of people use it, it isn't consumed.

Discussion of the analysis

In the theoretical discussion, we identified three ways of thinking about things, as objects or causes, in terms of:

(i) what you can do to them;
(ii) what they are made of; and
(iii) what they make happen.

We have shown how the clusters arising from the data and the nature of the reasons students gave can both be looked at as interpretable within this framework.

The same framework is helpful in discussing the kinds of scientific thinking described earlier. Space in the Newtonian view, for example, can be seen as being something always and everywhere the same (what it is made of), and as immovable (what can be done to it); while in the Aristotelian view and also in the Einsteinian conception it may be seen as something active (what it makes happen). Any link between students' ideas and ideas from the history of science thus has to do with their *different* uses of the *same* fundamental ontological resources, and not at all with their having 'the same ideas'.

Our main concern here is to understand conservation. The theoretical analysis, supported in some measure by its ability to give an account of our data, suggests that there are two ways of thinking of something as conserved. The first is if it is *out of the reach of actions*. One reason for something to be out of the reach of actions is when it cannot be thought of as an object to act on, or it cannot be substantialized (in fact, one can also think about a *weak* version of 'being out of the reach of actions', when something is just kept out of the reach of these actions).

The second way is that, being conceived as an object, it is still possible to *identify the entity* throughout all possible imagined actions performed on it. In this case, the conservation is modelled on the first conservation of objects.

The first way can be applied to time and space. They constitute a whole within which actions are performed, and are intrinsically related to certain actions (e.g., the group of displacements). But it is still possible to think about them as objects to act on, by substantializing them.

The second way seems to apply naturally to energy and matter. But they too can be thought of in the other way, as when their conservation is attributed to a general structure of space and time, for example through symmetries. The high scores as conserved things for electrons and atoms, and the explanations given, can be accounted for in both ways. When thought of as objects to act on, they are *indestructible* particles, and do not exist at rest. But they can also be thought of as constituting the proper *inner structure* of matter.

Movement can also be thought about in these ways but will appear mainly in the *weak* version. As one usually thinks about *something* in movement, one may think that in the absence of forces its movement will be conserved.

The entities conceived of as sources can be understood as modelled on *causes*, but they are often substantialized as objects. It might be said that *when you look for a cause you look for an object* (which was generally the case in the history of science, and also in students' common-sense reasoning about causes). However, in any sense a cause is still something like a primeval power, which makes it possible to understand subjects' choices of living things as sources.

The case of energy is particularly interesting in that the pattern of its scores differs from those of other entities. As having a creating power, it is modelled on cause, and as being conserved, it is regarded as like a conserved substance.

Concluding considerations

The work reported above makes some progress in identifying basic ontological categories into which things may fall, so far as conservation and to some extent the power to cause changes are concerned. We now speculate on how one might assemble the elements of an ontology for a somewhat more general account of how common-sense may see the nature of things, using the answers given by students in the questionnaire.

Our thoughts are presented in figure 5 in the form of a network (see Bliss *et al.* 1983). A network organizes categories in relation to one another. Entering a curved bracket (as on the left in figure 5), the thing to be described must be assigned features under every label following the bracket. Entering a vertical bar (as after the feature 'scale'), one choice must be made. A bar with a recursive arrow (see 'nature') indicates that more than one choice may be made. These rules apply at all depths in the network. As a result, a network defines a set of possible combinations of descriptive features. Any one entity will be assigned just one allowed combination.

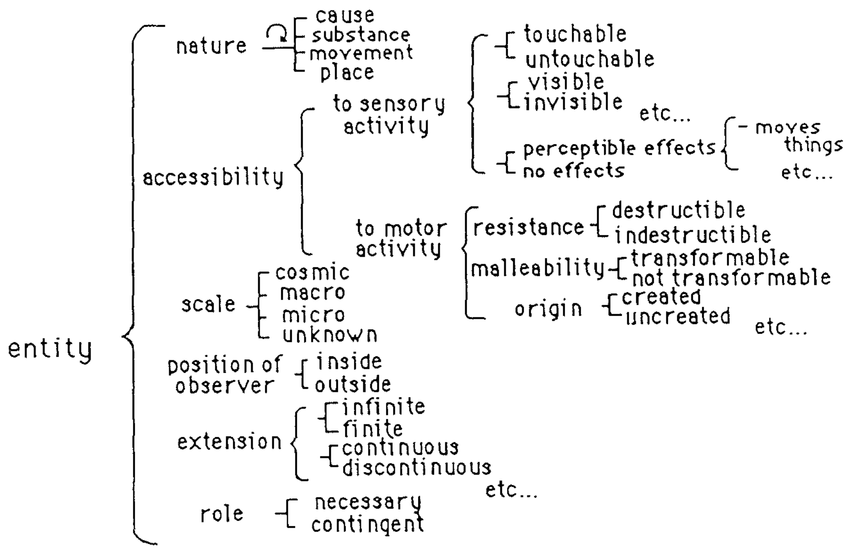

Figure 5. Network for basic ontology.

The network in figure 5 tentatively describes entities in relation to actions. Its categories were based partially on the answers obtained from students. With it, a given way of thinking about an entity can be classified. This is of course not to say that an entity will always be described in the same way: another way of thinking about it will be given by a different selection from the network.

The starting point for the network is to consider the world as consisting of entities that are modelled on the diagram in figure 1 (*nature*), and that can only be thought of through action performed on them (*accessibility*). Observe that *causes* are also accessible through their effects, which are perceived through the senses and modelled on the actions themselves. The *position of the observer* will affect accessibility as will the possible *scale* attributed to the entity (one could think about the distance between the observer and the entity as also being relevant) and its *extension*. The *role* of the entity concerns whether it is fundamental or not.

In its present form, the network can only take account of some of the answers we obtained from students: for example when thinking about time as untouchable, light as visible, electrons as indestructible, energy as transformable, the solar system as uncreated, space as infinite and so on. The nature, position of the observer, scale and role can only be inferred indirectly from the answers. The network will however be the object of further investigation.

It may be interesting also to discuss some possible implications for the representation of common-sense knowledge. Common-sense knowledge can be understood as essentially qualitative in nature (perhaps suitable for expression in Prolog, as has been attempted for common-sense knowledge about movement) (Ogborn 1987). We hope to have suggested some fundamental categories on which such an analysis of common-sense might rest.

We hope to have brought out the essentially qualitative nature of common-sense reasoning about conservation. Our account says that, before being in any way quantified, the attribution of conservation rests either on being the same despite actions, or on being beyond actions (so also being the same despite action). All that is involved is the continuing identity of the object in the course of actions.

Abstract entities can generally be modelled on the conservation of objects. They can be imagined in the form of real objects that have some permanence through change. For example, energy is commonly talked about in ways which imply its *indestructibility* and *substantialization*. Such a vocabulary is strongly reminiscent of Harré's 'robustness principle' for judging things to be real: that 'whatever persists unchanged through change is real' (Harré 1986).

The general problem, addressed here in only a preliminary way, is of the nature of the most primitive building blocks of the construction of physical reality. Our argument is that Piaget is at least correct in seeing action and movement as fundamental, whether or not his account of their place in cognitive development is right. They provide terms in which fundamental ways of thinking about reality, whether taken from children or from the history of science, can be understood. And one may be able to get at them with simple questions requiring only qualitative thinking. However, the discussion is far from complete or conclusive, though we hope that further investigations may show the appropriateness of this kind of analysis.

Acknowledgements

We are grateful to Prof. Dr. Alberto Villani, who helped in the development and application of the questionnaires. The methodology and analysis benefited from parallel work with Gillian Nicholls. This work has financial support from CAPES, a Brazilian government agency, and the ORS Awards Scheme.

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Appendix: Data and details of the analysis.

Table 2. Frequencies yes answers.

	Categories*							Categories*					
Entities	1	2	3	4	5	6	Entities	1	2	3	4	5	6
Diamond	25	2	6	25	12	6	Charge	19	18	17	30	28	26
Iron	4	1	1	22	12	6	River	3	11	2	14	27	9
Plant	1	0	0	21	10	24	Waterfall	3	7	1	15	31	13
Wood	2	0	1	20	10	12	Pendulum	12	17	13	18	23	3
Food	6	0	1	19	9	2	Light	22	24	20	23	33	37
Electron	50	55	40	35	45	27	Radioactivity	12	9	11	20	17	23
Air	24	30	12	25	23	13	Atom	49	40	40	30	33	23
Heat	16	12	10	20	8	17	Movement	35	31	29	16	32	17
Time	71	46	44	50	52	24	Oscillator	8	7	8	13	18	6
Sun	6	13	9	36	14	66	Solar system	14	18	15	34	20	13
Oxygen	17	13	7	22	14	18	Person	0	4	2	18	8	28
Energy	43	25	29	49	32	41	Car	0	2	2	18	20	1
Force	24	13	17	20	28	32	Lamp	0	0	2	18	20	5
Matter	33	17	13	37	15	13	Calculator	3	0	1	18	19	1
Star	5	10	4	26	15	36	Hammer	6	0	2	17	18	1
Space	51	25	30	46	20	12	Clock	1	2	2	18	14	1
Water	12	9	7	14	23	16	Radio	0	0	2	19	20	2
Pushed ball	4	6	3	15	28	6	Television	0	0	2	19	20	2

* Categories: 1. last forever; 2. move forever; 3. function forever; 4. cannot be created or destroyed; 5. cannot stop by themselves; 6. produce something without help.

Factor analysis

Factor extraction method: Principal component analysis
Transformation method: Orthotran/Varimax
Number of factors: 2
Factor scores: Orthogonal solution
Bartlett test and sphericity: DF = 20, Chi Square = 244·9, $P = 0·0001$
Eigenvalues and proportion of orginal variance:

	Magnitude	Variance proportion
Value 1	4·213	0·702
Value 2	0·922	0·154

Table 3. Statistical details.

(*a*) Orthogonal transformation solution–Varimax.

Category	Factor 1	Factor 2
1	0·89	0·32
2	0·9	0·32
3	0·91	0·34
4	0·55	0·65
5	0·87	−0·00
6	0·09	0·92

(*b*) Primary intercorrelations–Orthotran/Varimax.

	Factor 1	Factor 2
Factor	1	
Factor 2	0·21	1

(*c*) Proportionate variance contributions.

	Orthogonal–Direct
Factor 1	0·687
Factor 2	0·313

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Towards an ontology of common-sense reasoning

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This exploratory study concerns a basic ontology present in the common-sense reasoning of secondary students. Two questionnaires were given to 38 students (16–18 years old), in which they were asked to classify a list of different conceptual entities by several ontological features. These features were selected with the help of a network regarding actions (in the Piagetian sense) as providing basic ways of thinking about different entities. The results suggest the form of a fundamental 'ontological space' and locate some scientific concepts in this space.

Introduction

Explanations often follow rather directly from an understanding of the nature of things. Fluids flow; solid things move from place to place; invisible influences cause changes. It is our view that an understanding of people's ideas is usefully approached at this ontological level. That is, if one wants to understand how people think about something, a good start is to ask questions like 'Can you touch it?', 'Can you see it?', 'Can it do anything by itself?', and so on.

The same idea was expressed well by Hertz:

> We form for ourselves images or symbols of external objects; and the form which we give them is such that the necessary consequents of the images in thought are always the images of the necessary consequents in nature of the things pictured (. . .). When from our accumulated previous experience we have once succeeded in deducing images of the desired nature, we can then in a short time develop by means of them, as by means of models, the consequences which in the external world only arise in a comparatively long time (. . .). The images which we here speak of are our conceptions of things (. . .). Various images of the same objects are possible, and these images may differ in various aspects (. . .) to a scientific representation of the images we assign different postulates. We require of this that it should lead us to a clear conception of what properties are to be ascribed to the images for the sake of permissibility, what for correctness, and what for appropriateness. (Hertz 1899)

Such thoughts led Hertz to propose that mechanics should be based wholly on the fundamental categories of matter, time and space, but excluding force which he saw as riddled with conflicting images. We share Hertz's view that scientific reasoning itself operates in this ontological way. Our main concern here, however, is with students' thinking about scientific concepts. The following examples of answers given by students illustrate the level at which we want to tap their ideas:

> *Matter*: it is solid particles that can be imagined or seen; it is like a kind of solid that consequently has real existence; it is something solid that does not move; matter is

related to something that exists; it has a body; it appears in different forms; we can use it to create things.

Energy: reminds me of something that flows in time; like a force; exists in everything; has unknown size; is not completely material; because of it everything happens; we cannot see it; we can see its effects; it is said that it cannot be seen, but I think we can, when it is transformed into light...

Time: like a force that transforms materials; it can act but can also exist without acting; it is immaterial; it is something that we can feel through the effects it causes; we can change things in time; it is imaginary because it is not something concrete; it cannot be stopped; we cannot see or touch it; we live inside it; I cannot touch it, but I know it exists, I feel it; we know nothing about it, but we live inside it; it only exists in our mind because we cannot even imagine how it is.

Space: it is the place where movements happen, in which time flows, where sound flows, where matter exists; it is immaterial; it is what something occupies; it is in everything or everything is in it; it is infinite; it is imaginary, because we cannot really see it; it is strange: it is nothing, but everything is inside it.

Movement: you can only observe it; it is like a wave; it is like a force that needs energy to act; is is immaterial because I cannot touch it; it is used to move things and can be treated as a kind of force.

Heat: it is particles that reach our senses; it is a real force; it is a kind of energy; it can be transferred from one body to another; it is always flowing.

Light: something immaterial; made of particles; it flows like waves; it is matter created by energy; we cannot touch it but we can see it; it is a kind of energy; light from the Sun is also like heat.

Sound: a fluid that cannot be imagined; perceptible to the ears; like waves; it seems as if it doesn't exist; it is an impact between matter; it is a kind of energy.

Force: makes things move; it is something you do; it depends on your will; it is a kind of movement; it can destroy things; it is something that acts on something else, it is an action to modify things.

Our theoretical starting point, discussed more fully in a previous paper (Mariani and Ogborn 1990), derives from a Piagetian structuralist and constructivist view of the construction of reality. Piaget (Piaget 1937, Piaget and Garcia 1987) regards *actions* as providing the basis on which the underlying structure of reality is constructed. Reality is seen in terms of three aspects, all deriving from action: what something is made of, what you can do to it and what it can make happen.

In this paper, we present a study of the basic ontology of nine scientific concepts. We propose the form of an 'ontological space' in which these concepts can be located.

Development of a questionnaire

We have developed a questionnaire in which students are asked basic ontological questions about nine scientific concepts. The concepts selected were:

matter, energy, time, space, movement, heat, light, sound, force.

To have a systematic basis for choosing questions to ask we then needed an analysis of possible ontological features.

Thinking about things through actions

Our starting point for the analysis is to regard entities as basically modelled on the scheme shown in figure 1, which summarizes Piaget's view of the origin of the basic categories of thought. What figure 1 says is that the categories of cause, object, time and space are built out of action and movement. It also says that these categories are

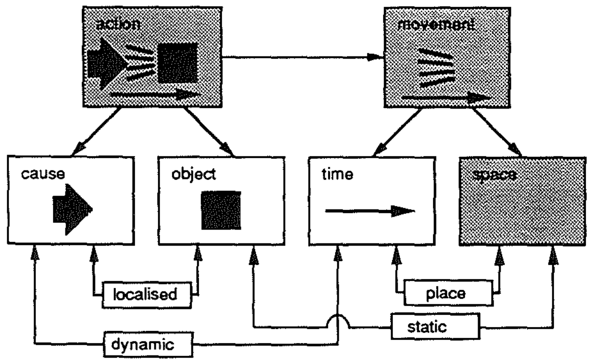


Figure 1. The genesis of fundamental ontological categories.

not dissociated: that a cause expects an object to act upon, that an object can be acted on and move, that time divides causes from effects, and that space contains objects. Each can be remodelled on the others: time as like a moving object, or as like a cause, or space as like a substance, for example.

Common-sense reasoning then draws on these categories in imagining things: invisible entities as like substances which act or can be acted on, causes as like actions and effects as like movements, and so on. Thus these basic resources can be used in many ways. In a previous paper (Mariani and Ogborn 1990) we tried to show that conservation could be understood in this framework. Something can be thought of as conserved in two ways: as being beyond the reach of action, or as being the same despite action. In that paper, we also proposed an analysis of the possible nature of entities, formulated as a systemic network.

The network starts from the three aspects of an entity mentioned above. It says that what an entity is made of can be modelled on cause, substance, movement or place. What you can do to it depends on its accessibility to the senses – on whether it can be touched, seen, or felt, and on its accessibility to motor activity – on whether it can be destroyed, be moved about, etc. Asking about what an entity can do sees it as a cause, looking at the actions it can perform.

Other aspects of the network are scale, position of observer, extension and role. They concern the possibility of acting on an entity. One cannot act on something which is too big or too small. One cannot act on an entity, like space, which surrounds one. Different actions apply to continuous or discontinuous entities: water can be spread out but a stone cannot. An entity which necessarily exists cannot be destroyed.

The questionnaires

The network was then used to guide the selection of items for a questionnaire (Ogborn and Koulaidis 1988) leading to the ontological features listed in table 1, under the three main headings: 'what it is like', 'what it can do' and 'what can be done to it'. For 'what can be done to it', we took from the sensory aspect of accessibility seeing, touching, hearing, feeling and seeing the effects of an entity, together with seeing, hearing, etc., through the entity. Other features of 'what can be done to it' came from the motor aspect: being able to create, destroy, transform, transfer,

Table 1. Ontological features used in the questionnaires.

MAIN FEATURES		
What it is like	*What it can do*	*What can be done to it*
1. Like a kind of gas	18. Acts by contact	33. See it
2. Like particles	19. Acts at distance	34. See through it
3. Like a kind of a fluid	20. Acts by itself	35. Touch it
4. Like a kind of a solid	21. Destroys things	36. Touch through it
5. Microscopic	22. Transforms things	37. Hear it
6. Macroscopic	23. Creates things	38. Hear through it
7. Of unknown dimension	24. Transfers things from one place to another	39. Feel it
8. Immaterial		40. Create it
9. Has real existence	25. Causes movement	41. Destroy it
10. Only exists in our mind	26. It is the reason for everything that happens	42. Transform it
11. Like a kind of force		43. Transfer it
12. Like a kind of place	27. Acts under the control of something else	44. Concentrate it
13. Like a kind of wave		45. Disperse it
14. It is everywhere	28. Distributes by itself	46. Stop it
15. It is nowhere	29. Concentrates by itself	47. Conserve it
16. Can be localized in a certain place	30. Multiplies by itself	48. Move things inside it
	31. Exists without acting	49. Sees its effects
17. It is only movement	32. Appears and disappears	

ADDED FEATURES	
You can treat it as	*You can use it to*
1. A gas	13. Transform things
2. A fluid	14. Conserve things
3. A solid	15. Move things
4. Particles	16. Create things
5. Microscopic	17. Destroy things
6. Macroscopic	
7. A force	
8. A place	
9. Real	
10. Imaginary	
11. Movement	
12. Waves	

concentrate, disperse, stop, and conserve an entity. For 'what it can do', we took the same motor features but now relating to activity of the entity itself, together with others also relating to its perceptible effects: acting by contact, acting at a distance, acting by itself, causing movement, acting under the control of something else, and multiplying by itself.

Features concerning 'what it is like' (its nature) included being like different kinds of substance (gas, fluid, solid, particles), and others concerned with being like cause, movement or place (being immaterial, like a force, like a place, like a wave, being only movement). Other aspects of 'what it is like' concerned scale (microscopic, macroscopic, having unknown dimension) and extension (being everywhere, being nowhere, being localized). Ideas about role were obtained from the features: having real existence, existing only in the mind, being the reason for everything that happens, existing without acting and appearing and disappearing.

Some added features (see table 1) were used to check the effect of using different forms of similar questions. In general these added features were highly correlated with their equivalents (for example, kind of solid and treat as solid; in your mind and treat as imaginary, etc.).

The questionnaire took the form of a grid, with the nine scientific concepts across the top and a list of features down the side. Students were asked to decide, for each concept, whether or not it possessed each feature. Since there were now more than sixty features, the list of features was divided in two, producing two questionnaires each with about 30 features to judge for each of the nine concepts.

The two questionnaires were given to 38 Brazilian secondary school students (16–18 years old), who had studied some science. The students were also asked to write about each entity in the light of the answers they had given.

Analysis of data

The analysis is in two stages. We first show that the responses can be interpreted as lying in a four dimensional 'ontological space', whose dimensions bear a close relationship to the fundamental categories of figure 1. Then we investigate the ontology attributed to the nine scientific concepts, by seeing where they lie in this space.

Ontological space

If frequencies of 'yes' responses to a pair of features, across the nine concepts, correlate highly, we may regard these two features as being 'close' to one another. The matrix of correlations between features was converted into distances (1–correlation coefficient) and subjected to multidimensional scaling, using ALSCAL. The multidimensional scaling was used to find the best arrangement of points in a space of a given number of dimensions, so that distances between the points in this space reproduced as well as possible the ordering of the empirical distances. Multidimensional scaling only determines the space up to rotation of axes, reflection and inversion. It turns out, however, that the dimensions yielded directly by the analysis can be interpreted, in terms related to figure 1.

Goodness of fit is indicated by the value of the stress. A scree plot of the stresses for different numbers of dimensions suggests four dimensions (stresses were: 2 dimensions 0·25; 3 dimensions 0·15; 4 dimensions 0·07; 5 dimensions 0·05).

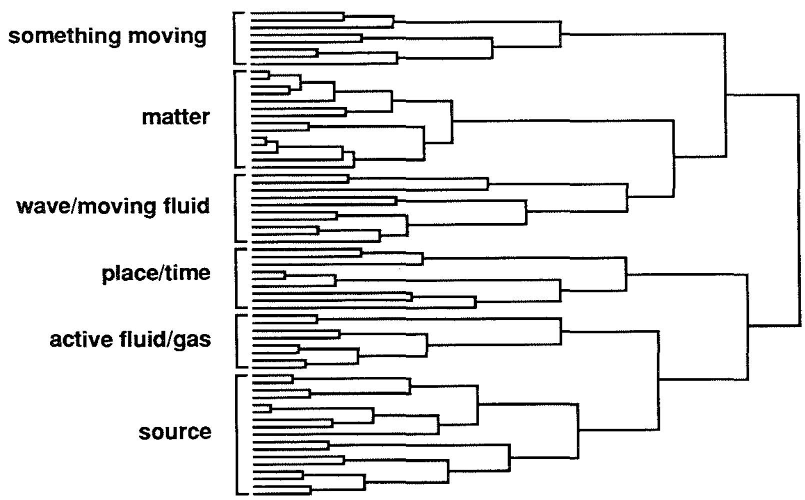
To aid interpretation, clusters were sought amongst the features plotted in the space. When the spatial coordinates of the features were cluster analysed (complete linkage method), six main interpretable clusters were found, as shown in figure 2. These clusters of features appear to be:

1. *Something moving*: features relate to movement of an object
2. *Matter*: features relate to solids, particles, real existence
3. *Moving fluid/wave*: features relate to being a fluid or a wave in motion
4. *Place/time:* features relate to being like place, being everywhere and nowhere, being in your mind
5. *Active fluid/gas*: features relate to being like gas or fluid, multiplying by itself, distributing by itself
6. *Source*: features relate to autonomous active powers

The six clusters were then plotted in the four dimensional space, as shown in figure 3. The four dimensions, together with the interpretations we give them, are described below.

Dimension 1 static – dynamic: The cluster *matter* is high on this dimension, with static features such as *exists without acting* and *it is everywhere* being notably high. The cluster *something moving* is low on this dimension, as are *moving fluid/wave* and *active fluid/gas*. Typical features low on this dimension are dynamic: *can move*, *treat as movement*, and *wave*.

Dimension 2 place-like – localized within a place: The one cluster which is high on this dimension is *place/time*. Clusters which tend to be low are *matter*, *moving fluid/wave* and *source*. Features which fall high on this dimension include *move inside*, *place*, *in mind*, *everywhere*. This dimension appears to have to do with a polarity between



Something moving: treat as movement; it's only movement; you can stop it; use to move; can transfer it; can create it; act by contact.

Matter: treat as solid; kind of solid; can touch it; real; macroscopic; treat as real; can destroy it; can treat as gas; can conserve it; treat as macroscopic; microscopic; treat as microscopic; like particles; treat as particles.

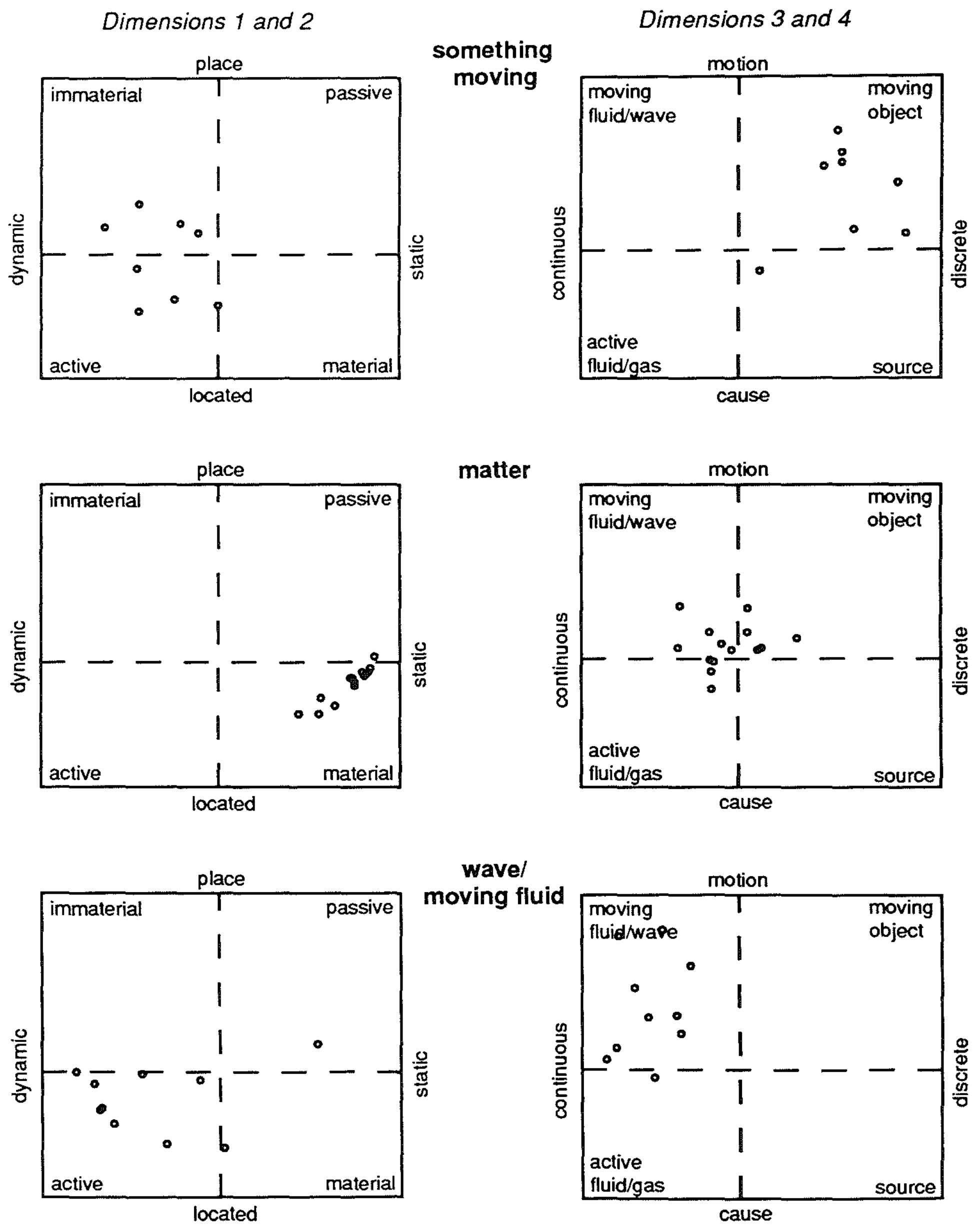
Wave/moving fluid: hear it; hear through it; see it; can disperse; localized; treat as wave; act at distance; appear/disappear; fluid; wave.

Place/time: it's nowhere; it's in your mind; treat as imaginary; treat as place; like a place; can move inside it; exists without acting; it's everywhere; can see through it.

Active fluid/gas: immaterial; unknown dimension; concentrates; kind of gas; treat as fluid; distributes by itself; touch through it; multiplies.

Source: reason for everything; creates things; use to transform; transform things; use to destroy; feel it; use to create; can transform it; use to conserve; can concentrate it; transfer it; see effects; acts by itself; causes movement; like a force; treat as force; destroys things.

Figure 2. Clusters of features.


Dimensions 1 and 2
Dimensions 3 and 4
something moving
matter
wave/ moving fluid
place
located
dynamic
static
immaterial
passive
active
material
motion
cause
continuous
discrete
moving fluid/wave
moving object
active fluid/gas
source

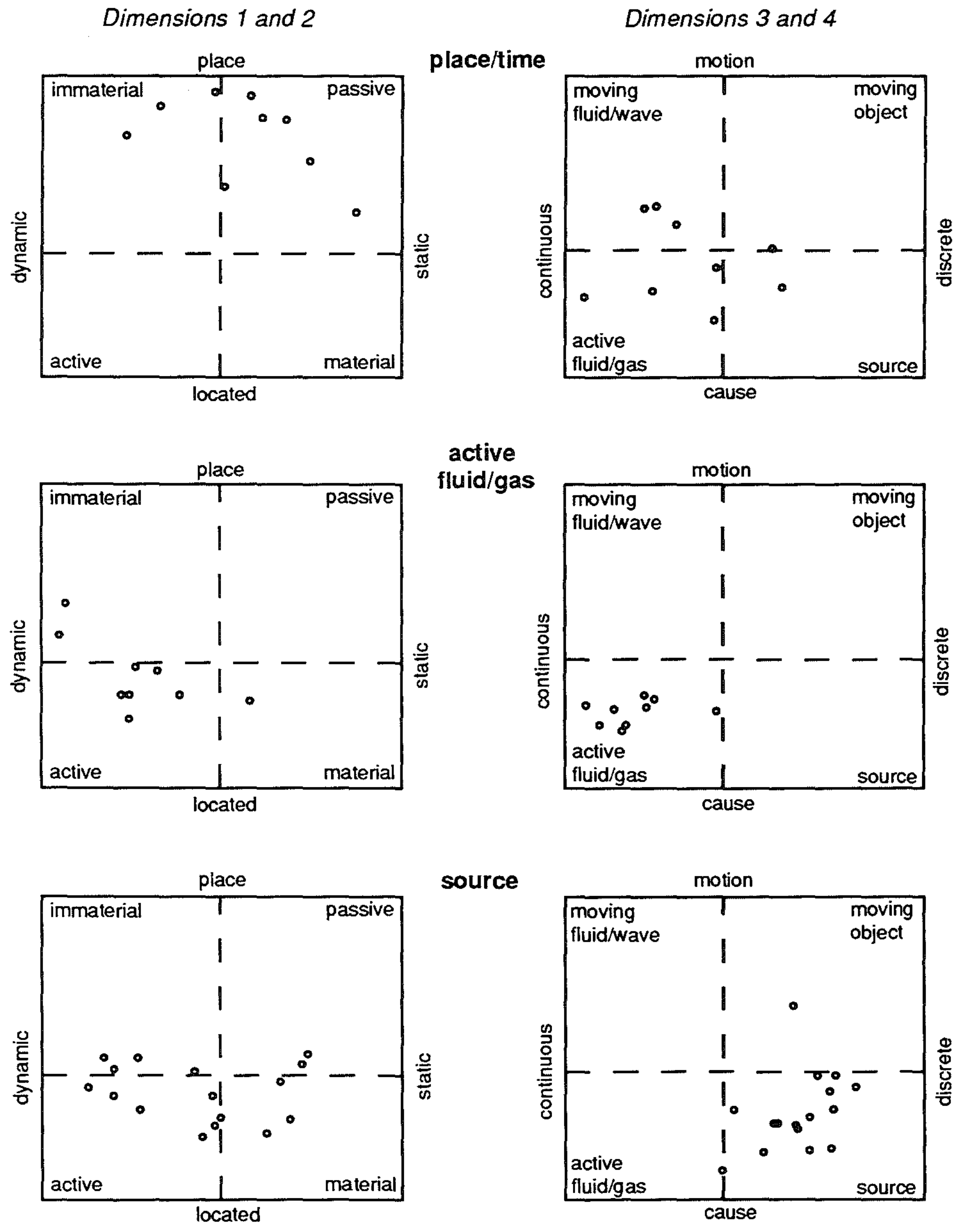


Figure 3. Clusters plotted in 'ontological space'.

being the frame (space or time) in which events happen or objects are found, versus being localized within such a frame.

Dimension 3 discrete – continuous: This dimension distinguishes the clusters *something moving* and *source* from the clusters *moving fluid/wave* and *active fluid/gas*. Features high on this dimension appear to be those concerned with discrete or localized action, like the action of something moving, such as *act under control*, *use to move*, *transfer*, *stop*, *create*, *act by contact* while those which are low seem to have to do with continuity, or spatialized action of something active and *substantial* distributed in space, such as *distributes*, *disperses*, *touch through*, *act at a distance*, *immaterial*, *gas*, *wave*.

Dimension 4 cause – motion (effect): This dimension distinguishes the clusters *something moving* and *moving fluid/wave* from the clusters *source* and *active fluid/gas*. Features to do with movement come high on it, while features to do with causes, such as *act by itself*, *create things*, *see its effects*, and *transform things* come low.

Figure 4 summarizes and adds to this interpretation. It is notable that the first dimension corresponds well to the polarity *static – dynamic* in figure 1, which contrasts the static constructs *space* and *object* with the dynamic constructs *cause* and *time*. The second dimension similarly reflects the alternative polarity *place – localized* in figure 1: *cause* and *object* being localized, and *space* and *time* which are the place (the frame) within which the other two act or exist. The dimension *cause – motion* also reflects fundamental categories in figure 1, distinguishing between the cause and the effect (movement) of an action. The final dimension *discrete – continuous* goes beyond figure 1, but in an obvious way. The construct of an object is the basis for the later construct of a substance, which removes from objects their wholly discrete nature, and replaces it by continuity, itself derivable from space.

Several clusters fall in the diagonal regions of the space, in an interesting way. *Matter* is static and located: clearly modelled on the object. It is here that the feature *real* is to be found. On the first two dimensions all clusters other than *matter* and *space/time* fall in or near the region dynamic and localized: a region which seems to be modelled on activity. It is here, for example, that we find the feature *force*. We have thus added to the diagonals of the sub-space of the first two dimensions the labels

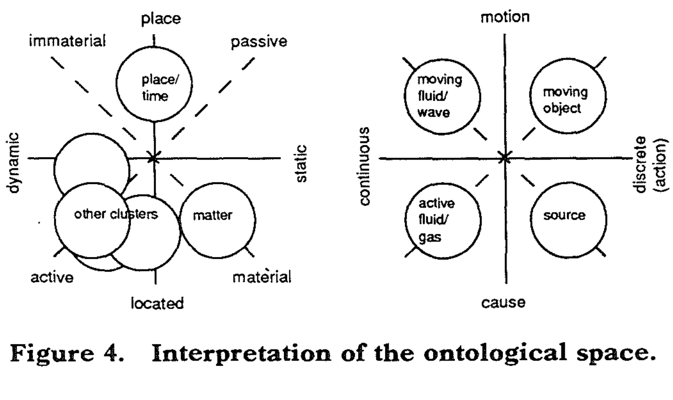


Figure 4. Interpretation of the ontological space.

material–immaterial and *active–passive*. These would be a complementary way of characterizing the space.

The third and fourth dimensions mainly distinguish those clusters which fall in the *active* region. Their fundamental character is to distinguish *cause* and (roughly) *effect* (i.e., motion). The other dimension shows that causes and motions can be seen either as discrete, modelled it would seem on actions, or as continuous, possibly modelled on immaterial substance. This allows both for waves seen as moving throughout a space, and for light which can be seen as filling space with illumination.

Ontology of some scientific concepts

It is now possible to ask where the nine scientific concepts considered fall within this ontology. Figure 5 shows two ways of looking at this. For each concept, those features whose frequencies of 'yes' responses are above the upper quartile for that concept have been selected and plotted in the ontological space. We can therefore see where the features which that concept is most often thought to possess happen to fall. In addition, a location in the space for the concept itself can be found. This has been done by averaging the co-ordinates of all features, weighting each with the fraction of 'yes' responses on the concept, for that feature. Vectors are shown in figure 5 indicating the location of each concept. Figure 6 summarizes these results, showing all the nine vectors together.

Movement is mainly dynamic, but is not necessarily strongly located. However, its features lie well to the discrete pole, so that movement is strongly tied to particular action. Movement, while mainly not a cause, can be a cause.

Forces are active, dynamic and located. They mix features of both cause and motion, the vector for force lying further away from a source and closer to that for movement than one might expect. Force and movement are remarkably close.

Sound, like movement, is dynamic and active, and tends to be located. Unlike movement, it is continuous rather than discrete, modelled rather more on substance than on action. It is less like a cause and more like a motion than even movement itself.

Light resembles sound on the first two dimensions, again being active. But its features are rather more spread out, with some tending to make it like a place rather than being located, and some allowing it to be seen as static not dynamic.

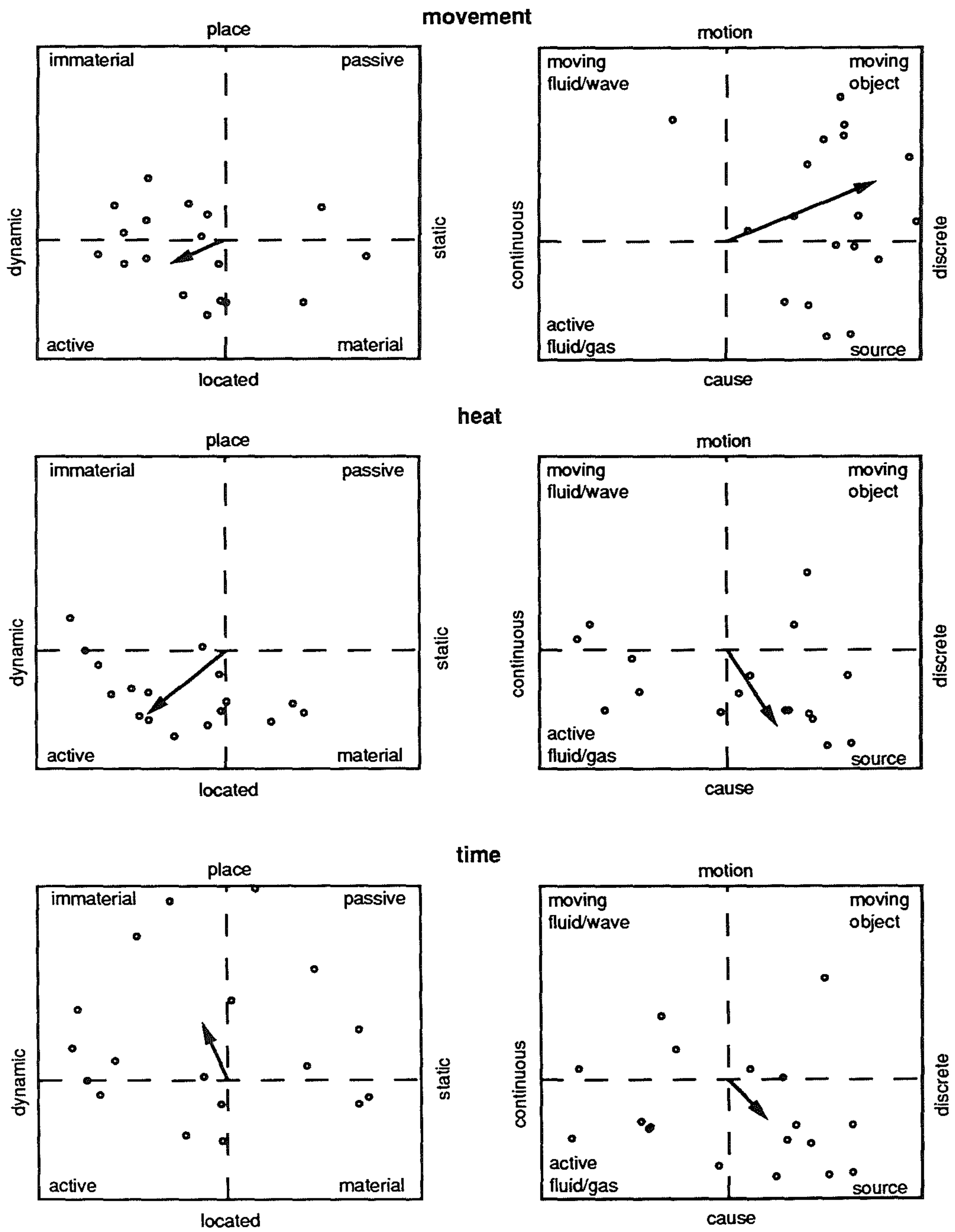
Heat is again mainly active, dynamic and located. However, it is unlike sound or light on the other dimensions, being seen as a source of change or effects. Several features make it causal and discrete, though some exist for which it seems more continuous.

Energy and heat are very similar. Energy is active, dynamic and located, and is essentially seen as a source: discrete and causal.

Matter is static and located, as noted before. On the dimensions to do with activity it has no strong tendency, being able to be seen somewhat as cause and somewhat as motion, and sometimes as discrete but at other times as continuous.

Space is passive: static and a place rather than located. It is continuous rather than discrete.

Time shares with space the property of being a place, but is rather more dynamic in nature. On dimensions to do with activity, it has some features of a source. So time is a place which can effect changes. It is both discrete and continuous.


movement
place
immaterial
passive
dynamic
static
active
material
located
motion
moving fluid/wave
moving object
continuous
discrete
active fluid/gas
source
cause
heat
place
immaterial
passive
dynamic
static
active
material
located
motion
moving fluid/wave
moving object
continuous
discrete
active fluid/gas
source
cause
time
place
immaterial
passive
dynamic
static
active
material
located
motion
moving fluid/wave
moving object
continuous
discrete
active fluid/gas
source
cause

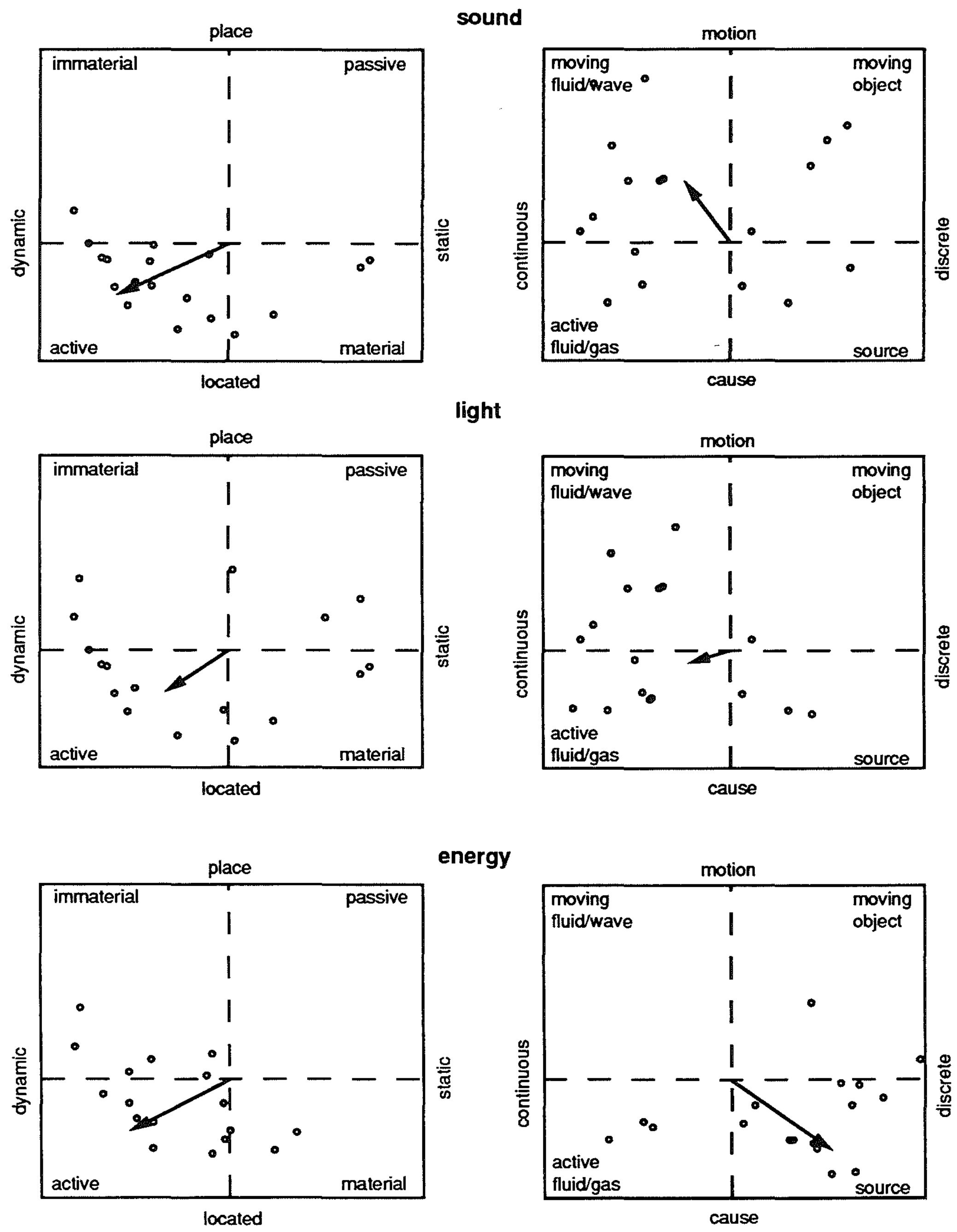


Figure 5. Location of concepts in ontological space.

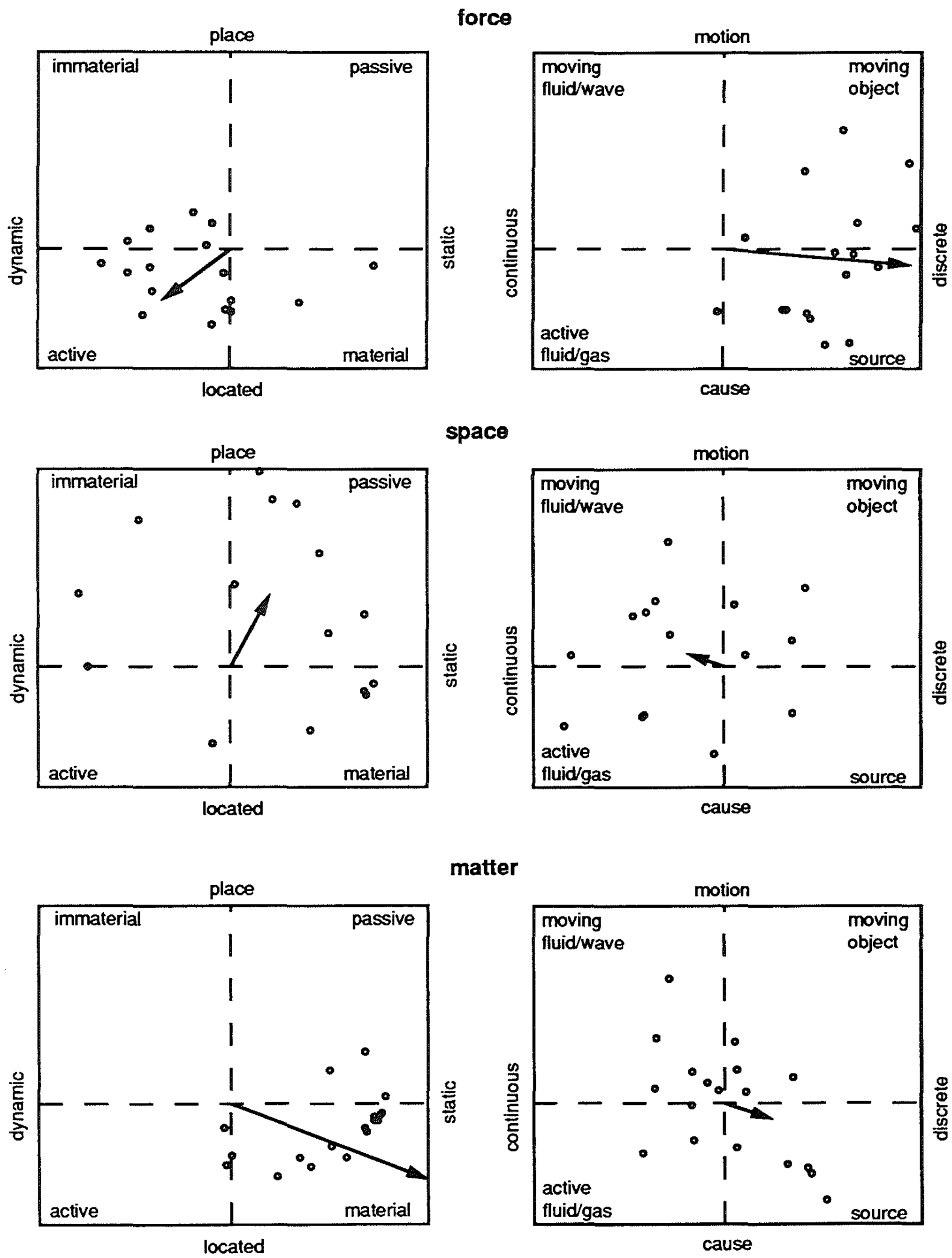


Figure 5. Location of concepts in ontological space (*continued*).

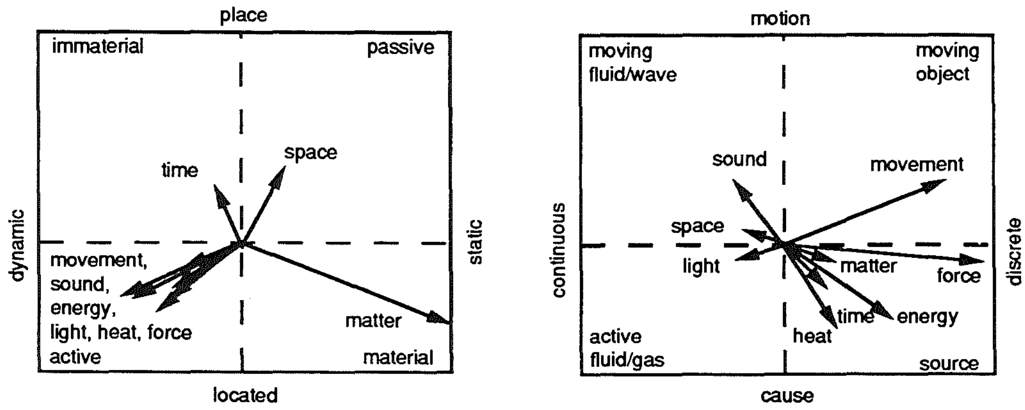


Figure 6. Distribution of concepts over ontological space.

Discussion

The results can be discussed from two points of view. We can speculate about whether they make sense from the point of view of cognitive development. We can also speculate about how similar basic structures of thinking seem to have been variously deployed in the history of scientific thought. Piaget has termed these the psychogenetic and sociogenetic perspectives, respectively.

The psychogenetic perspective

According to Piaget, the child's initial construction of reality has its origin in just two absolutely fundamental things, *action* and *movement* (see, for example, Piaget 1937, 1946, 1973). Out of these, as suggested by figure 1, are built the fundamental ontological categories of *cause*, *object*, *space* and *time*. For Piaget, this involves the progressive ability to represent absent objects, actions and events, through imitation and internalization of imitation, leading ultimately to the possibility of imagining and reflecting upon possible actions on things (Piaget 1937, 1966). Objects are what remain constant despite action and through movement. Space arises out of the co-ordination of actions and movements, and from the infra-logic of part and whole, near and far, together and apart, etc. (Piaget 1937). The construct of cause requires that of time, in the sense of before and after (another aspect of infra-logic). Initially centred on his or her own activity, the child builds a world independent of the self. Thus, progressively, the power to make things happen becomes attributed to other objects, though cause is always liable to be modelled on intentional action, from which it develops. Effects of causes are similarly liable to be modelled on movement. Movement remains attached to objects, its representation being generally that of *something* moving.

Our results seem to be rather consistent with such a picture, as encapsulated in figure 1. The first two dimensions of our ontological space were able to be interpreted as corresponding to two of the main structural features of figure 1: the contrasts between pairs of fundamental categories, on the one hand as being dynamic (related to action and change) versus being static (related to the permanent unchanging furniture of the world), and on the other hand as being localized versus being the place or site for actions to happen or objects to exist. In consequence, the four quadrants defined by these two dimensions correspond well to four categories from figure 1: material object, space, time and action. These categories are related to the two dimensions much as one would expect from the psychogenetic point of view. Thus time is associated with place and with change; space with place and with permanence; object with permanence and with being localized; activity with being localized and with change.

The two further dimensions essentially differentiate the aspect of activity. They distinguish, as they should, cause and effect, with effects seen fundamentally as like movement. They add something more, showing that cause and movement can be seen as discrete, modelled on action, or as more like an active principle in things, modelled somewhat on an immaterial substance. Thus movement, sound, energy, heat, light and force, all seen as simply activity on the first two dimensions, become distinguished. Some entities (energy, force, heat and to some extent matter and time) are seen as sources of change (discrete causes). Other ways of thinking about activity are to see it as movement of an object (discrete movement), as movement of a fluid or wave (continuous movement), or as an active principle of cause inherent in an immaterial substance (continuous cause).

We can also say something about what is real and what is imaginary. Matter is something real because you can touch and see it (the correlation between *it is real* and *you can touch it* is 0·92). And matter derives from the first construction of something which stays the same despite action: the object. The object seems to be the prototype of the real. Space and time being immaterial and 'in the mind', are more imaginary, time particularly so. Whilst matter is *present*, static and located, space and time are everywhere or nowhere; one is inside them. But space is passive whilst time is dynamic and can even be seen as active.

We can understand how other entities are imagined by seeing them as superpositions of basic ontological categories. For example, whilst energy was seen as a source, modelled on discrete action, heat and light had added some of the character of a substance. Force, again a source, had added some of the character of movement. Sound and light both combined aspects of being like a substance with respectively movement and cause.

More generally it seems possible tentatively to suggest that there are two basic substrates from which such entities can be constructed. One is to see them as fundamentally like *activity*, combining the causal properties of action and the visible effect of movement. The other is to imagine them as being in some way like *substance*, combining the permanence of objects and the continuity of space. Substantiality goes with continued existence independent of the self. Activity goes with contingency and change, with what is intended or willed, and so with what could be other than it is.

The sociogenetic perspective

Several of the broad ontological distinctions we find lying behind students' responses have parallels in the history of scientific thought. We have just discussed how it seems to be possible to abstract the properties of a substance or fluid and then to regard entities as behaving as if they were real substances of fluids, without the necessity of regarding them as really material things. In this way space, or cause, can be substantialized. In the quotations below, Mayer and Hertz both detect such a tendency:

> While we vindicate the right of motion to exist as an entity and to represent substantiality, we must unconditionally deny the material nature of heat and electricity. For would it not be too absurd to look to a fluid for the nature of motion and the displacement of mass or to wish to assign in alternation now a material and now an immaterial nature to the same object? Let us speak out the great truth: there are no immaterial materials! (Mayer, quoted in Lindsay 1975)

> At the present time many distinguished physicists tend so much to attribute to energy the properties of a substance (...) so that through all the changes of place and all the transformations of the energy into new forms it retains its identity. (Hertz 1899.)

If cause is seen as action, it is an ontologically independent category, but when cause is substantialized (with the suggestion of its conservation) as 'an active principle in things' it is reduced ontologically to substance (Crombie 1948, Smith 1978).

A yet more fundamental issue is the reality attributed to entities. Even though matter seems to be the paradigm case of the real, we should recall that at various times it has been reduced to something seen as a deeper reality, namely space. This was Plato's conception; it is also that of General Relativity. In current high energy physics, it looks as if a new reduction is in progress, towards seeing matter as *activity*: as the activity of the vacuum. And this has to do with the identification of matter and energy.

Space and time, despite being considered fundamental, are often regarded as imaginary. For example, Leibniz (Piaget and Garcia 1971) did not admit any reality outside corporeal things, and as we have seen, the students in our study tended to agree with him. They saw time as more imaginary than space, perhaps because it seems as if one can in some sense see space.

Force has also been seen differently as fundamental or not. Whilst it is fundamental both for Aristotle and for Newton, Hertz (1899) attempted to reduce it to matter and movement. His reason is interesting: as in our account above, Hertz saw force as modelled on action, and felt that action, as something contingent and dependent only on human will, had too slender a metaphysical basis for a fundamental entity.

Concluding remarks

The world appears to be understood as fundamentally constituted of objects, which are real and have some permanence, and to which one can effect changes by exercising actions, within a spatio-temporal framework. This (which is the import of figure 1) can be understood as being the fundamental result of psychogenetic studies. It is striking how natural an account this perspective seems to provide for dimensions extracted from asking students about the nature of things, while at the same time making connections with ideas about the world developed in the history of Science.

The present work, based on a limited sample of students and a small range of concepts, needs development in several directions. It will be important to refine and select an optimum set of ontological features, to test the stability of the dimensions over a wider range of entities and with different groups of subjects, and to check the validity of the dimensions with interview data. If this can be done, a further step would be to begin to study how different groups of subjects construe entities in similar or different ways, depending on their backgrounds.

Our conjecture is that ontological space provides categories which can be variously superposed in imagining entities. Each dimension of the space carries certain commitments: object or substance to reality and permanence, action or movement to contingency and change. We do not at all suppose that a given entity must be modelled in a certain way, indeed rather the opposite. Thought seems to be capable of combining dimensions very freely, even in ways which seem contradictory. Indeed, there seems to be a permanent tension between substantiality and activity, between what remains the same and what makes things different. The tension is perhaps irreducible, if what remains the same becomes so by being that which action cannot make different.

Acknowledgements

We are grateful to Professor Sonia Dion who helped in the application of the questionnaires. The work received financial support from CAPES, a Brazilian government agency, and the ORS Awards Scheme.

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Appendix E: Design of the questionnaires in the first study.

Contents:

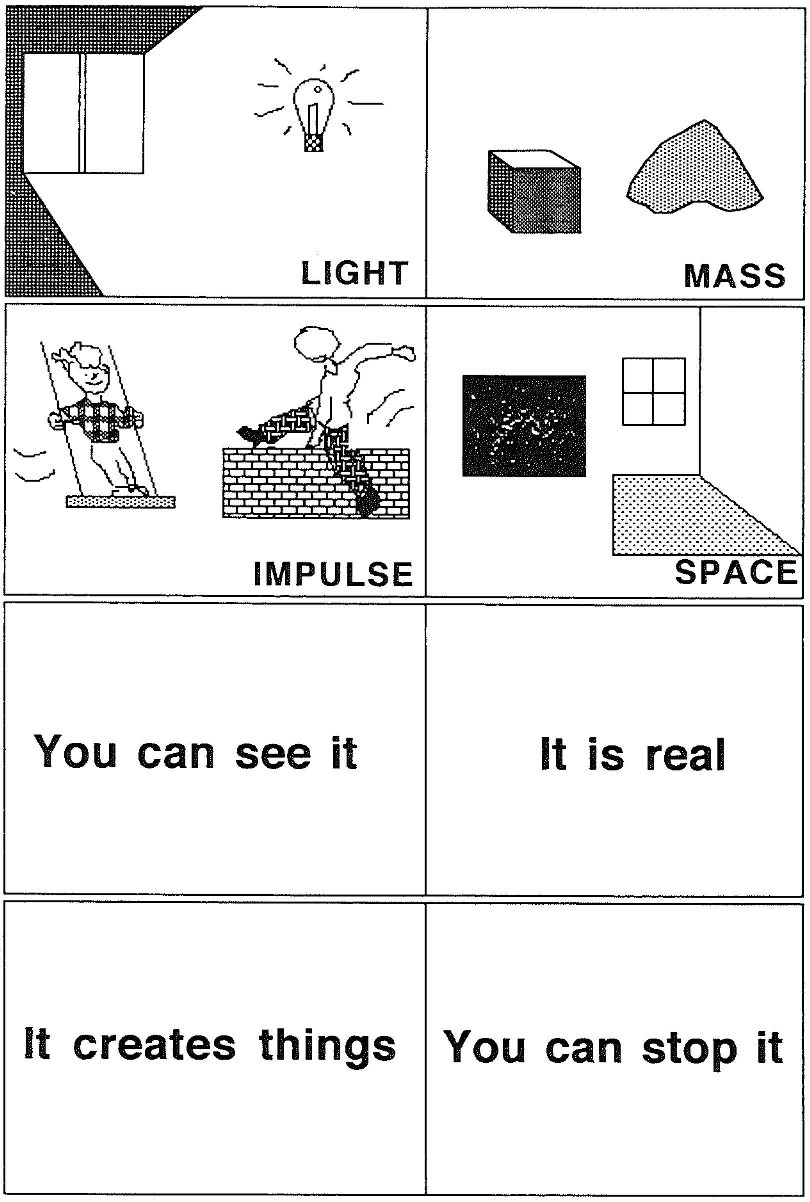

Figure 1. Examples of design of cards to interview 8-10 year-old students.

Name:... Date of birth:....../......../........
School:...Year:.....................................

Please read this page before answering:

With this test we want to know what <u>you</u> think about some concepts you must have heard about at school or elsewhere.

Concepts like *the mass of a body, a movement, a force and so on.*

It is very easy to answer. You only have to tick [✓] in front of the things you can think about these concepts.

For example, if you think you can *see* the mass of a body, you tick in the empty square in front of it:

[✓] see it

But if you think you <u>cannot</u> see it, you leave a blank space:

[ ] see it

So you only tick when the answer is <u>yes</u>.
Read the next page carefully before answering .
Try to answer it quickly giving the first idea that comes to your mind.

You can start now! Thank you!

2. You must have some idea about ***movement*** . Think about ***movement.***
What can you do to it? Can you *see* movement?*Touch* it? And what else?
I think I can: *(Tick in the square in front of each thing :* [✓]*when you think* ***yes)***

[ ] see it	[ ] perceive effects	[ ] conserve it
[ ] touch it	[ ] spread it	[ ] transform it
[ ] hear it	[ ] concentrate it	[ ] destroy it
[ ] feel it	[ ] transfer it	[ ] criate it
[ ] touch through it	[ ] stop it	[ ] can't do anything to it

What does movement look like? *I think it is or it looks like:*

[ ] like a solid	[ ] like movement	[ ] something real
[ ] like a gas	[ ] like a cause	[ ] something immaterial
[ ] like particles	[ ] like an effect	[ ] at rest
[ ] like a force	[ ] like an action	[ ] like a place
[ ] like a fluid	[ ] like a substance	[ ] you are inside it
[ ] like a wave	[ ] something imaginary	[ ] can be localized
[ ] something concrete	[ ] it is nowhere	[ ] microscopic
		[ ] macroscopic

What is it that movement can make happen? *I think it can:*

[ ] act by contact	[ ] destroy things	[ ] spread by itself
[ ] act at a distance	[ ] transform things	[ ] multiply by itself
[ ] act by itself	[ ] criate things	[ ] concentrate by itself
[ ] cause movement	[ ] exist without acting	[ ] appear and disappear

Figure 2. Example of questionnaire given to 13-14 year-old students.

Name..

After answering the first part of this test we would like you to write one or two lines about each concept.

1. *What I can think about mass is...*

2. *What I can think about movement is...*

3. *What I can think about force is...*

4. *What I can think about heat is...*

5. *What I can think about light is...*

6. *What I can think about impulse is...*

7. *What I can think about energy is...*

8. *What I can think about sound is...*

9. *What I can think about time is...*

10. *What I can think about space is...*

Figure 2. Example of questionnaire given to 13-14 year-old students (continued).

Name:.. Date of birth:......./......../........
School:.................................Year:................Profession:.......................

Please read this page before answering:

With this test we want to know what *you* think about some concepts you must have heard about at school or elsewhere.

Concepts like *the mass of a body, a movement, a force and so on.*

It is very easy to answer. You only have to tick ☑ in front of the things you can think about these concepts.

For example, if you think you can *see* the mass of a body, you tick in the empty square in front of it:

☑ see it

But if you think you cannot see it, you leave a blank space:

☐ see it

So you only tick when the answer is yes.
Read the next page carefully before answering .
Try to answer it quickly giving the first idea that comes to your mind.

You can start now! Thank you!

1. You must have some idea about what the ***mass*** of a body is . Think about ***mass.***
What can you do to it?Can you *see* the mass?*Touch* it? And what else?
I think I can: *(Tick in the square in front of each thing : ☑ when you think **yes**)*

☐ see it
☐ touch it
☐ hear it
☐ feel it
☐ touch through it
☐ perceive effects
☐ spread it
☐ concentrate it
☐ transfer it
☐ stop it
☐ conserve it
☐ transform it
☐ destroy it
☐ criate it
☐ can't do anything to it

What does a mass look like? *I think it is or it looks like:*

☐ like a solid
☐ like a gas
☐ like particles
☐ like a force
☐ like a fluid
☐ like a wave
☐ something concrete
☐ like movement
☐ like a cause
☐ like an effect
☐ like an action
☐ like a substance
☐ something imaginary
☐ it is nowhere
☐ something real
☐ something immaterial
☐ at rest
☐ like a place
☐ you are inside it
☐ can be localized
☐ microscopic
☐ macroscopic

What is it that mass can make happen? *I think it can:*

☐ act by contact
☐ act at a distance
☐ act by itself
☐ cause movement
☐ destroy things
☐ transform things
☐ criate things
☐ exist without acting
☐ spread by itself
☐ multiply by itself
☐ concentrate by itself
☐ appear and disappear

Figure 3. Example of questionnaire given to young working adults.

Name..

test 1

After answering the first part of this test we would like you to write one or two lines about each concept.

1. *What I can think about mass is...*

2. *What I can think about movement is...*

3. *What I can think about force is...*

4. *What I can think about heat is...*

5. *What I can think about light is...*

6. *What I can think about impulse is...*

7. *What I can think about gravity is...*

8. *What I can think about sound is...*

Figure 3. Example of questionnaire given to young working adults (continued).

Name:..
Date of birth:........../........../............
School:..
Year:.............................

Please read this page before answering the test:

This questionnaire is not designed to test your knowledge in Science. It is a psychological test and you have to try to answer it with the first idea that comes to your mind.
In the next page you will find a table. Along the horizontal there are some concepts you probably studied or heard about. Along the vertical there are some things to think about these concepts: what you can do or not with then what they look like and things they can do.
You will have to tick the things you think apply to a given concept.
For example suppose one concept to be "mass".
You would find in the table:

What can be done to... / I think one can...	... mass	and so on...
see it		
touch it		
hear it		
feel it		
and so on...		

So, if you thought mass is something you can see you would tick in the appropriate space in the table:

What can be done to... / I think one can...	... mass	and so on...
see it	✔	
touch it		
and so on...		

But if you didn't think you could see mass you would leave a blank space:

What can be done to... / I think one can...	... mass	and so on...
see it		
touch it		
and so on...		

And you would go to the next : touch it. If you thought you could touch mass you would tick in the table. After ticking all the things you could think about mass you would do the same with the next concept in the table and so on , ticking all the things you could think about each concept.
With the table you also have a strip of paper to help you answering along the vertical.

Now you can start! Thank you for your help!

Figure 4. Example of questionnaire given to 16-18 year-old students.

What can be done to ... → / I think one can... ↓	... matter	... energy	... heat	... sound	... light	... gravity
see it						
touch it						
hear it						
feel it						
touch through it						
perceive effects						
transfer it						
conserve it						
criate it						
spread it						
concentrate it						
destroy it						
transform it						
stop it						
you can't do anything to it						
I think it is or it looks like...						
a solid						
a gas						
particles						
a force						
a wave						
a fluid						
movement						
a field						
a substance						
a place						
a vacuum						
an energy						
macroscopic						
microscopic						
an effect						
a cause						
you are inside it						
it is nowhere						
it can be localized						
immaterial						
imaginary						
real						
material						
at rest						
concrete						
like an action						
I think it can ...						
act by contact						
act at a distance						
act by itself						
destroy things						
criate things						
transform things						
transfer things						
cause movement						
exist without acting						
spread by itself						
concentrate by itself						
multiplicate by itself						
appear and disappear						

Figure 4. Example of questionnaire given to 16-18 year-old students (continued).

Name..

test 1

After answering the first part of this test we would like you to write one or two lines about each concept.

1. What I can think about matter is...

2. What I can think about energy is...

3. What I can think about heat is...

4. What I can think about sound is...

5. What I can think about light is...

6. What I can think about gravity is...

Figure 4. Example of questionnaire given to 16-18 year-old students (continued).

Name:..
Date of birth:.........../.........../...........
Course:..
Profession:..

Please read this before answering the test:

In the next page you will find a table. In this table you have some scientific concepts or entities in the horizontal and some things to think about these concepts in the vertical.

We would like you to think intuitively about these concepts.

You will find things to think about these concepts like: if you can see, touch or even conserve each one of these concepts. We would like you to use your intuition to give the first answer that makes sense to you.

This is a psychological test rather than a test of your knowledge in Physics. It was designed to understand the way in which these concepts are constructed in people's minds.

To answer this test you only have to tick ☑ in the table the things you can think about each concept. You should only tick those things that make sense to you at first sight.

Together with the table there is a strip of paper to help you answering it. Please use it along the vertical answering all the questions about a concept before going to the next one.

Thank you for your help!

Figure 5. Example of questionnaire given to undergraduate physicists.

	ENTITIES / CONCEPTS											
accessibility to the senses: ***It is possible to...***	matter	energy	time	space	force	heat	action	photon	wave	spin	gravity	eletricity
see it												
touch it												
hear it												
feel it												
touch through												
perceive effects												
accessibility to actions: ***It is possible to...***	matter	energy	time	space	force	heat	action	photon	wave	spin	gravity	eletricity
transform it												
transfer it												
destroy it												
create it												
conserve it												
stop it												
spread it												
concentrate it												
Identity/ characteristics/ similarities/ analogies: ***It is/ can be / has to be like a...***	matter	energy	time	space	force	heat	action	photon	wave	spin	gravity	eletricity
solid												
gas												
particle/s												
force												
fluid												
place												
field												
vacuum												
movement												
wave												
energy												
property												
relation												
quantity												
substance												
concrete												
discrete												
microscopic												
cause												
imaginary												
immaterial												
effect												
continuous												
material												
real												
macroscopic												
at rest												
action												
state												
invariant												
immutable												
transformation												

Figure 5. Example of questionnaire given to undergraduate physicists (continued).

Location: *It seems that...*	ENTITIES / CONCEPTS											
	matter	energy	time	space	force	action	heat	photon	wave	spin	gravity	eletricity
it is everywhere												
it is nowhere												
we are inside												
it can be localized												
Activity: *In general it can...*												
act by contact												
act at a distance												
cause movement												
transform things												
transfer things												
create things												
act by itself												
destroy things												
spread by itself												
concentrate by itself												
multiply by itself												
act under control												
exist without acting												
appear and disappear												
it is passive												

Figure 5. Example of questionnaire given to undergraduate physicists (continued).

Name... | test 1 |

After answering the first part of this test we would like you to write one or two lines about each concept.

1. *What I can think about matter is...*

2. *What I can think about energy is...*

3. *What I can think about time is...*

4. *What I can think about space is...*

5. *What I can think about force is...*

6. *What I can think about heat is...*

7. *What I can think about action is...*

8. *What I can think about photon is...*

9. *What I can think about wave is...*

10. *What I can think about spin is...*

11. *What I can think about gravity is...*

12. *What I can think about electricity is...*

Figure 5. Example of questionnaire given to undergraduate physicists (continued).

features	8-10	13-14	16-18 Quest. 1	Quest. 2	Quest. 3	Quest. 4	workers Quest. 1	Quest. 2	physicists Quest. 1	Quest. 2
can see it	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
can touch it	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
can hear it	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
can feel it	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
can touch through		✓	✓	✓	✓	✓	✓	✓	✓	✓
can see effects		✓	✓	✓	✓	✓	✓	✓	✓	✓
can transform it		✓	✓	✓	✓	✓	✓	✓	✓	✓
can transfer it		✓	✓	✓	✓	✓	✓	✓	✓	✓
can destroy it	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
can create it	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
can conserve it		✓	✓	✓	✓	✓	✓	✓	✓	✓
can stop it	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
can spread it	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
can concentrate it		✓	✓	✓	✓	✓	✓	✓	✓	✓
can't do anything to it	✓	✓	✓	✓	✓	✓	✓	✓		
like a solid	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
like a gas	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
like a particle		✓	✓	✓	✓	✓	✓	✓	✓	✓
like a force	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
like a fluid	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
like a place	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
like a field			✓	✓	✓	✓			✓	✓
like a vacuum			✓	✓	✓	✓			✓	✓
like a movement	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
like a wave		✓	✓	✓	✓	✓	✓	✓	✓	✓
like an energy			✓	✓	✓	✓			✓	✓
property									✓	✓
relation									✓	✓
quantity									✓	✓
like a substance		✓	✓	✓	✓	✓	✓	✓	✓	✓
concrete	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
discrete									✓	✓
microscopic		✓	✓	✓	✓	✓	✓	✓	✓	✓
like a cause		✓	✓	✓	✓	✓	✓	✓	✓	✓
imaginary	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
immaterial	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
like an effect		✓	✓	✓	✓	✓	✓	✓	✓	✓
continuum									✓	✓
material			✓	✓	✓	✓			✓	✓
real	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
macroscopic		✓	✓	✓	✓	✓	✓	✓	✓	✓
at rest	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
like an action	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
state									✓	✓
invariant									✓	✓
immutable									✓	✓
transformation									✓	✓
everywhere									✓	✓
nowhere	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
can be inside it	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
(localized) somewhere	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
act by contact	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
act at distance	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
cause movement		✓	✓	✓	✓	✓	✓	✓	✓	✓
can move things	✓									
transform things	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
transfer things			✓	✓	✓	✓			✓	✓
create things	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
act by itself	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
destroy things	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
distribute by itself		✓	✓	✓	✓	✓	✓	✓	✓	✓
concentrate by itself		✓	✓	✓	✓	✓	✓	✓	✓	✓
multiply by itself		✓	✓	✓	✓	✓	✓	✓	✓	✓
act under control									✓	✓
exist without acting		✓	✓	✓	✓	✓	✓	✓	✓	✓
appear and disappear	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
passive									✓	✓

Figure 6. Features used for each group.

entities	8-10	13-14	16-18				workers		physicists	
			Quest. 1	Quest. 2	Quest. 3	Quest. 4	Quest. 1	Quest. 2	Quest. 1	Quest. 2
mass	✓	✓		✓			✓			✓
space	✓	✓		✓				✓	✓	
time	✓	✓		✓				✓	✓	
movement	✓	✓			✓		✓			✓
light	✓	✓	✓				✓			✓
energy	✓	✓	✓					✓	✓	
sound	✓	✓	✓				✓			✓
heat	✓	✓	✓				✓		✓	
force	✓	✓		✓			✓		✓	
impulse	✓	✓			✓		✓			
matter			✓					✓	✓	
weight					✓			✓		
temperature					✓			✓		
gravity			✓				✓		✓	
electricity						✓		✓	✓	
atom				✓				✓		
magnetism						✓				✓
radioactivity						✓				
solar radiation						✓				
microwave					✓				✓	
vacuum					✓					
atmosphere				✓						
spin									✓	
quark										✓
field										✓
gamma rays										✓
action									✓	
photon									✓	
wave									✓	
charge										✓
neutrino										✓

Figure 7. Entities used for each group.

Appendix F:

Design of the questionnaires in the second study.

Contents:

Name:..Date of birth:......../......../........
School:..Year:......................................

Please read this page before answering the test:

This is not a questionnaire to test your knowledge in Science but it is rather a psychological test with which we would like to understand how you imagine some basic concepts in your mind.
To answer this test you only have to tick what you can think about some given concepts. Try to answer it quickly given your first idea.
Read carefully the instructions in each page before answering.
You can start now! Thank you!

1. In physics it is common to say that something is **conserved**. We want you to think about this idea.
You will find below a list of different concepts like matter and energy. We would like to know which ones do you think are **conserved** or **not conserved** <u>in your own oppinion.</u>
Tick the appropriate answer:

Tick in this way....						if you think that...
✓	2	3	4	5	6	it is conserved
1	✓	3	4	5	6	it appears more that it is conserved
1	2	✓	4	5	6	neither one nor the other
1	2	3	✓	5	6	it appears more that it is not conserved
1	2	3	4	✓	6	it is not conserved
1	2	3	4	5	✓	I don't know

List of concepts:

1. Think about matter	1	2	3	4	5	6
2. Think about energy	1	2	3	4	5	6
3. Think about time	1	2	3	4	5	6
4. Think about space	1	2	3	4	5	6
5. Think about light	1	2	3	4	5	6
6. Think about force	1	2	3	4	5	6
7. Think about movement	1	2	3	4	5	6
8. Think about sound	1	2	3	4	5	6
9. Think about heat	1	2	3	4	5	6
10. Think about electricity	1	2	3	4	5	6

Figure 1. Example of questionnaire given to 16-18 year-old students.

4. You will find below a list of different concepts like matter and energy. We would like to know which ones do you think are **like a substance or like an action** in your own oppinion.
Tick the appropriate answer:

Tick in this way....	if you think that...
✓ 2 3 4 5 6	it is like a substance
1 ✓ 3 4 5 6	it is more like a substance than like an action
1 2 ✓ 4 5 6	neither one nor the other
1 2 3 ✓ 5 6	it is more like an action than like a substance
1 2 3 4 ✓ 6	it is like an action
1 2 3 4 5 ✓	I don't know

List of concepts:

1. Think about matter	1	2	3	4	5	6
2. Think about energy	1	2	3	4	5	6
3. Think about time	1	2	3	4	5	6
4. Think about space	1	2	3	4	5	6
5. Think about light	1	2	3	4	5	6
6. Think about force	1	2	3	4	5	6
7. Think about movement	1	2	3	4	5	6
8. Think about sound	1	2	3	4	5	6
9. Think about heat	1	2	3	4	5	6
10. Think about electricity	1	2	3	4	5	6

Name:..

test 1

After answering the first part of this test we would like to know what does it mean for you to say that something is...

conserved:

not conserved:

static:

in motion:

active:

passive:

like a substance:

like an action:

like a place:

localized:

Figure 1. Example of questionnaire given to 16-18 year-old students (continued).

Name:..
Date of birth:.........../............./............
Course:..
Profession:..

test 1

The idea of this test is that you locate some entities or concepts in a space with ten dimensions. It is very simple: you only have to give the coordinates of each concept in the dimensions given. The dimensions you will find are related to fundamental categories of thinking about scientific concepts like: being discrete or continuous, imaginary or real, and so on.
Please try to choose the coordinates intuitively. This is a psychological test rather than a test of your knowledge in Physics. You should give the first idea of a coordinate that comes to your mind.
In the next page you will find ten dimensions indicated each one by an axis. You can choose a coordinate for an entity from -5 to 5 in each dimension. For example you have the first dimension:

5 4 3 2 1 0 1 2 3 4 5
1. immaterial |—|—|—|—|—|—|—|—|—|—| material

where: *-5:* immaterial *with absolute certainty*, *-4: certainly* immaterial ,
-3: quite probably immaterial , *-2: probably* immaterial ,
-1: maybe immaterial , *0:* none
1: maybe material , *2: probably* material ,
3: quite probably material , *4: certainly* material ,
5: material *with absolute certainty.*

So the negative side corresponds to something immaterial and the positive side to something material at variable degrees. The zero is neutral.
The same will be true for the other dimensions: negative numbers relate to what is on the left and positive numbers relate to what is on the right at variable degrees as shown above.
You will have to locate some concepts in these dimensions. For example one of the concepts could be "charge". If you thing that a charge is "certainly material"(or number 4) you write this number as the first dimension's coordinate:

dim.: 1 2 3 4 5 6 7 8 9 10
charge (4 , , , , , , , , ,)

The second dimension is:

-5 -4 -3 -2 -1 0 1 2 3 4 5
2. imaginary |—|—|—|—|—|—|—|—|—|—| real

So, if you think that a charge is certainly imaginary (number -4) you write this number as the second dimension's coordinate

dim.: 1 2 3 4 5 6 7 8 9 10
charge (4 ,-4 , , , , , , , ,)

And so on. Complete all the coordinates for each concept.
Thank you for your help!

Figure 2. Example of questionnaire given to undergraduate physicists.

Dimensions:

1. immaterial	-5 -4 -3 -2 -1 0 1 2 3 4 5	material
2. imaginary	-5 -4 -3 -2 -1 0 1 2 3 4 5	real
3. effect	-5 -4 -3 -2 -1 0 1 2 3 4 5	cause
4. passive	-5 -4 -3 -2 -1 0 1 2 3 4 5	active
5. static	-5 -4 -3 -2 -1 0 1 2 3 4 5	dynamic
6. discrete	-5 -4 -3 -2 -1 0 1 2 3 4 5	continuous
7. place	-5 -4 -3 -2 -1 0 1 2 3 4 5	localized
8. abstract	-5 -4 -3 -2 -1 0 1 2 3 4 5	concrete
9. action	-5 -4 -3 -2 -1 0 1 2 3 4 5	substance
10. not conserved	-5 -4 -3 -2 -1 0 1 2 3 4 5	conserved

Concepts:

dim.:	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
mass	(	,	,	,	,	,	,	,	,	,)
charge	(	,	,	,	,	,	,	,	,	,)
sound	(	,	,	,	,	,	,	,	,	,)
heat	(	,	,	,	,	,	,	,	,	,)
gravity	(	,	,	,	,	,	,	,	,	,)
photon	(	,	,	,	,	,	,	,	,	,)
electricity	(	,	,	,	,	,	,	,	,	,)

Figure 2. Example of questionnaire given to undergraduate physicists (continued).

Name..
Course..

After you answered the first part of this test please try to *define* or *explain*, or even *give an example*, of what you understand by saying that something is...

material:	*immaterial:*..
real:	*imaginary:* ....
effect :	*cause:* ....
passive:	*active:* ....
static :	*dynamic:* ....
discrete:	*continuous:* ....
place:	*localized :* ....
abstract :	*concrete :* ....
action:	*substance:* ....
conserved :	*not conserved :* ....

Figure 2. Example of questionnaire given to undergraduate physicists(continued).

Appendix G:

The general structure of the Interviews.

Contents:

A brief description of interviews:

Interviews with 8-10 year-olds:

Duration: 15 minutes.

Method: The same cards used for entities in the first study are now presented to these subjects (Ten cards: mass, force, light, energy, sound, heat, time, space, impulse and movement). They are asked to form groups of entities (presented as cards) they think are similar to each other. After forming these groups they are asked to briefly explain why they have made such groups.

Interviews with 16-18 year-olds:

Duration: 40 minutes (Part 1: 15 minutes; part 2: 25 minutes).

Method:

Part 1: These students are presented with 22 cards which have written on them the same entities used in the first study for 16-18 year-olds: mass, matter, weight, force, light, temperature, heat, solar radiation, radioactivity, sound, time, space, vacuum, atmosphere, impulse, movement, atom, microwave, electricity, magnetism, gravity and energy. They are asked to form groups of similar entities. After that they are asked to explain why they formed such groups.

Part 2: The students are now presented with cards having written on them the 54 features given in the first study for 16-18 year-olds (see Appendix E: figure 6). They are asked to put together similar entities (maintaining or not the same groups formed in Part 1) and the things they could think about them (You can see it, you can hear it, and so on).

Codes used in transcripts:

Example:

2.Mar(12/01/75;15;04;f;2nd;Gusmão)

I: (Same)

S: (Exp. - Part 1)

I: Why did you put time and space together?

S: (...)

I: (Rep.)

S: ...(Conf.) <u>They are equal.</u>

Abreviations/codes used in the interview:

Number. Initials(date of birth; years-old; months-old; sex; grade; school)

I: Interviewer.

S: Subject.

(Same): It means that the same question is asked for each individual. The question can be seen in the first transcript for each group.

(Exp. - Part 1): Pause during which 16-18 year-olds are grouping entities.

(Exp. - Part 2): Pause during which 16-18 year-olds are grouping entities and features.

(Exp.): Pause during which 8-10 year-olds are grouping entities.

(...): Long pause.

(Rep.): The previous sentence in the dialogue is repeated.

... : Pause.

(Conf.): The subject makes an afirmative gest.

<u>Underlined</u>: Relationship / property between entities analysed with network (Figure 3.22, Chapter 3).

In italic: *When the subject changes the position of an entity from one group to another, the temporary (abandoned) position appears in italic in the table with the results for that subject.*

Transcription of interviews with 8-10 year-olds:

1. Car(07/08/80;09;09;m;3rd;Mar.)

I: Now I would like you to put together the things you think are similar to each other...and make groups with them.

S: (...) (Exp.)

Group 1	Group 2	Group 3	Group 4	Group 5
space	energy	impulse	heat	mass
light	force	movement	time	
sound				

Table 1. The result for Car

I:That's it ? (Conf.) Well... Group 1, what is it that space, light and sound have to do with each other ?

S: I think that light... sometimes you have it in space... and sound... It is something which flows and makes the sound... and energy and force, you need energy to have a force...

I: And energy and force make another group ?

S: Yes.

I: And impulse with movement is making another group ?

S: Yes, because you need movement to have an impulse... and heat with time (Group 4) ... Time influences the heat... and mass is alone because there is nothing like it in here...

I: Nothing like it (Conf.) ... All right, thank you.

2. Rod(01/06/79;10;11;m;3rd;Mar.)

I: (Same)

S: (...) (Exp.)

Group 1	Group 2	Group 3	Group 4
time	sound	mass	force
space	light		movement
	heat		impulse
			energy

Table 2. The result for Rod

I: That's it ? (Conf.) What did you think when making group 1?

S: Time is in space...

I: ...and mass is alone ? (Conf.)

S: (...)

I: How about sound, light and heat?

S: Heat has light, and sound has something to do with light...

I: How about force, movement, impulse and energy ?

S: Impulse has energy, energy gives force and movement...

I: All right...Very good, thank you.

3. Jos(03/01/80;10;04;m;3rd;Mar.)

I: (Same)

S: (...) (Exp.)

Group 1	**Group 2**	**Group 3**	**Group 4**
movement	heat	space	energy
sound	impulse	light	force
time			mass

Table 3. The result for Jos

I: That's it ? (Conf.) Why did you do Group 1 ?

S: Because movement and time also have sound... if you move just a bit you make a sound... and time has the sound of a clock.

I: All right... how about Group 2 ?

S: Because after an impulse you will feel the heat.

I: How about space and light ?

S: Because a light has a space...

I: And Group 4 ?

S: Because energy has force and mass has force too.

I: All right... Thank you.

4. Raf(24/01/81;09;04;m;3rd;Mar.)

I: (Same)

S: (...) (Exp.)

Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**
space	movement	energy	sound	mass
time	impulse	heat		
	force	light		

Table 4. The result for Raf

I: That's it? (Conf.) Why did you do Group 1?

S: Because time... is in space (...)

I: ...And why did you do Group 2 ?

S: Because it is action... a movement...you will have force to do it (...)

I: All right... How about Group 3 ?

S: Well... because it lights up... it is energy...

I: And sound and mass are alone ?

S: Yes...

I: They don't look like the others ?

S: No.

I: All right, thank you.

5. Gab(05/06/81;08;11;f;3rd;Mar.)

I: (Same)

S: (...) (Exp.)

Group 1	Group 2	Group 3	Group 4
heat	space	sound	impulse
light	mass	energy	force
time			movement

Table 5. Result for Gab

I: That's it ? (Conf.) Why did you do this one, Group 4 ?

S: Because the force you use to move <u>gives </u>an impulse...

I: How about Group 3 ?

S: Because sound <u>is an</u> energy.

I: How about Group 1 ?

S: Well... heat and light <u>look like</u> each other... and time <u>looks like</u> a light, a heat...

I: And Group 2 ?

S: Because it is something you can... (Obs.: gest of holding something in the air)

I: ...You can hold ?

S: Yes.

I: All right, thank you.

6. Fer(13/12/81;08;05;f;3rd;Anjo)

I: (Same)

S: (...) (Exp.)

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group
energy	mass	light	impulse	time	space	sound
force		heat	movement			

Table 6. Result for Fer

I: That's it ? (Conf.) Can you explain Group 1 for me ?

S: They <u>look like</u> each other...

I: How about Group 3 ?

S: They <u>look like </u>each other...

I: How about Group 4 ?

S: They are <u>similar</u> (...)

I: Al right, Thank you.

7. Mic(27/09/81;08;08;f;3rd;Anjo)

I: (Same)

S: (...) (Exp.)

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
sound	movement	mass	time	space	impulse
force	energy		heat	light	

Table 7. Result for Mic

I: That's it ? (Conf.) Why do you think sound and force are alike ?

S: Because they make a noise...

I: (Rep.) How about Group 2 ?

S: Because movement has energy.

I: (Rep.) How about Group 4 ?

S: Because time is heat.

I: And Group 5 ?

S: Because space gives day and night.

I: All right, thank you.

8. Fab(30/05/80;10;00;m;3rd;Anjo)

I: (Same)

S: (...) (Exp.)

Group 1	Group 2	Group 3	Group 4	Group 5
heat	mass	sound	impulse	movement
light	space	energy		force
time				

Table 8. Result for Fab

I: That's it ? (Conf.) Why did you put mass and space together ?

S: (...) Because mass is fitted inside space.

I: All right. How about Group 1 ?

S: Because as time is changing, light and heat disappear.

I: (Rep.) How about Group 3 ?

S: Because...sound is...the same as energy.

I: (Rep.) How about Group 5 ?

S: Because without force there is no movement.

I: (Rep.) And impulse is alone ?

S: Yes.

I: All right, thank you.

9. Die(14/08/79;10;09;m;3rd;Anjo)

I: (Same)

S: (...) (Exp.)

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
heat	mass	sound	time	energy	impulse
light			space	force	movement

Table 9. Result for Die

I: That's it ? (Conf.) Why did you do Group 1 ?

S: Because they are (...)

I: How about Group 4 ? Any reason ?

S: (...)

I: Just tell what you thought about...

S: Because time is inside space.

I: (Rep.) And how about Group 5 ?

S: Force is strong and energy is also strong...

I: (Rep.) How about Group 6 ?

S: Movement moves things and impulse also moves...

I: (Rep.) How about Group 1 ?

S: Light gives energy and light, and heat also gives light.

I: All right, thank you.

10. Car(22/06/81;08;11;f;3rd;Anjo)

I: (Same)

S: (...) (Exp.)

Group 1	Group 2	Group 3	Group 5	Group 6
impulse	mass	energy	time	sound
space	movement	force	heat	
		light		

Table 10. Result for Car

I: That's it ? (Conf.) Why do you think impulse and space are similar ?

S: (...)

I: They are supposed to be alike...

S: Impulse has movement and space too.

I: (Rep.) All right, how about Group 2 ?

S: Because you apply an energy upon mass,and mass changes its form.

I: (Rep.) How about Group 3 ?

S: Because light can give some energy and force...

I: (Rep.) How about Group 4 ?

S: Because as time goes, also heat goes...

I: (Rep.) All right, thank you.

11. Raf(31/05/80;10;00;f;4th;Anjo)

I: (Same)

S: (...) (Exp.)

Group 1	Group 2	Group 3	Group 4	Group 5
time	space	impulse	sound	heat
light	mass	energy		
		movement		
		force		

Table 11. Result for Raf

I: That's it ? (Conf.) Why is it that light and time are together ?

S: Because time is changing and light is also changing with time.

I: How about Group 2 ?

S: Well...They look alike !

I: ...they look alike ?

S: Yes.

I: How about Group 3 ?

S: Because energy is a kind of force, you need energy to do a force and walk...movement...

I: And the other two don't look like any of the others...?

S: No.

I: All right, thank you.

12. Tia(21/05/80;10;00;m;4th;Anjo)

I: (Same)

S: (...) (Exp.)

Group 1	Group 2	Group 3	Group 4	Group 5
energy	light	mass	impulse	heat
force	space	movement	sound	time

Table 12. Result for Tia

I: That's it ? (Conf.) Why did you do Group 1?

S: Because if you don't have energy you don't have force.

I: (Rep.) How about Group 2?

S: Because light is in space.

I: (Rep.) And Group 3?

S: Because mass gives movement.

I: (Rep.) And Group 4?

S: You have a quick impulse there will be a sound.

I: (Rep.) And why time and heat together?

S: Because as one goes the other disappears...

I: (Rep.) Very good, thank you.

13. Fer(21/08/80;09;09;f;4th;Anjo)

I: (Same)

S: (...) (Exp.)

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
heat	sound	mass	space	force	impulse
light			time	energy	movement

Table 13. Result for Fer

I: That's it ? (Conf.) Why do you think heat and light are alike ?

S: The light of the Sun gives heat.

I: (Rep.) How about Group 4 ?

S: Because time is in space.

I: (Rep.) How about Group 6 ?

S: Because you need movement.

I: (Rep.) How about Group 5 ?

S: Because energy has to have a force.

I: (Rep.) All right, thank you.

14. Ott(19/09/80;09;08;m;4th;Anjo)

I: (Same)

S: (...) (Exp.)

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
energy	movement	heat	impulse	time	mass
force		light	sound	space	

Table 14. Result for Ott

I: That's it ? (Conf.) Why did you do Group 1 ?

S: Because...they are alike.

I: How about Group 3 ?

S: Because...they are alike.

I: How about Group 4 ? Any special reason ?

S: No.

I: Group 5 ?

S: No...

I: And movement and mass don't look like any of the others... ?

S: No...

I: All right, thank you.

15. Gus(04/01/81;09;04;m;4th;Anjo)

I: (Same)

S: (...) (Exp.)

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
mass	time	heat	light	movement	force
space			sound	impulse	energy

Table 15. Result for Gus

I: That's it ? (Conf.) Why did you do Group 5 ?

S: Because both move.

I: (Rep.) How about Group 6 ?

S: Energy gives force.

I: How about Group 4 ?

S: Because... we turn the radio on...

I: (Rep.) How about Group 1 ?

S: Because mass occupies space.

I: (Rep.) And time and heat are different from the rest...?

S: Yes.

I: All right, thank you.

16. Vin(20/01/81;09;04;m;4th;Anjo)

I: (Same)

S: (...) (Exp.)

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
sound	mass	time	space	heat	impulse	movement
						energy
						force
						light

Table 16. Result for Vin

I: That's it ? (Conf.) Why do you think they are similar in Group 7 ?

S: Because of the energy.

I: (Rep.) Is there any other group ?

S: (...)

I: (Rep.)

S: No...

I: Does sound look like any other thing ?

S: No...

I: ...Mass ?

S: Maybe space ?

I:Would you put mass and space together ?

S: No.

I: Time ?

S: No.

I: Impulse ? Heat ?

S: No.

I: All right, thank you.

17. Eli(30/09/80;09;08;m;3rd;Mar.)

I: (Same) (Obs.: twice)

S: (...) (Exp.)

Group 1	Group 2	Group 3	Group 4
light	sound	space	mass
heat	energy	time	movement
			impulse
			force

Table 17. Result for Eli

I: That's it ? (Conf.) What did you think about ...?

S: ...In Group 1 ? I thought that light can also make heat...

I: All right. How about Group 2 ?

S: Because energy can make sound...?

I: All right. How about Group 3 ?

S: Because time can give space.

I: All right. How about Group 4 ?

S: Because...they can make something together.

I: (Rep.) All right, thank you.

18. Let(11/08/79;10;09;f;3rd;Mar.)

I: (Same)

S: (...) (Exp.)

Group 1	***Group 2***	**Group 3**	**Group 4**	***Group 5***	***Group 6***
sound	*mass*	space	impulse	*light*	*time*
mass		light	movement		
		time	force		
			energy		
			heat		
			light		
			time		

Table 18. The result for Let

I: That's it ? (Conf.) Why everything in Group 4 ?

S: ...No... not light (...)

I: All right, you can change it ...

S: (...) (Obs.: changing the position of light from Group 4 to Group 5)

I: Now, why are they similar in Group 4 ?

S: Because... they do something... no, not time...

I: You can change...

S: (...) (Obs.: changing the position of time from Group 4 to Group 6) Because <u>we do</u> them... we jump, we run, we hit...

I: And how about the others ? Are they all different ?

S: No... mass can go with sound (Obs.: changing the position of mass from Group 2 to group 1)... because it is with mass that you <u>make</u> sound.

I: (Rep.)

S: ...and time can go with space... (Obs.: changing the position of time from Group 6 to Group 3)

I: Why ?

S: Because... when it is morning there is ...the Sun... in the night... there is light <u>in</u> space...

I: So, how about light...?

S: ...yes... in space... (Obs.: changing the position of light from Group 5 to Group 3)

I: (Obs.: reading all the groups again)

S: All right now.

I: Thank you.

19. Kat(10/02/81;09;03;f;3rd;Mar.)

I: (Same)

S: (...) (Exp.)

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
light	sound	movement	energy	space	time	mass
heat	force	impulse				

Table 19. Result for Kat

I: That's it ? (Conf.) Why sound and force together?

S: Because they are equal.

I: (Rep.) How about Group 1?

S: Same thing.

I: (Rep.) And Group 3?

S: We do a movement...we walk...they are similar.

I: (Rep.) And the others are different?

S: Yes.

I: All right. Thank you.

20. Jos(29/11/79;10;06;m;3rd;Mar.)

I: (Same)

S: (...) (Exp.)

Group 1	**Group 2**
movement	mass
energy	
sound	
force	
space	
light	
heat	
time	
impulse	

Table 20. Result for Jos

I: That's it ? (Conf.) Why do you think all of them are alike in Group 1?

S: Because they are (...)

I: ...all similar ?

S: Yes.

I: And only mass is different ?

S: Yes.

I: Thank you.

21. Dan(07/09/80;09;08;m;2nd/Mar.)

I: (Same)

S: (...) (Exp.)

Group 1	Group 2	Group 3	Group 4	Group 5
sound	heat	energy	force	impulse
movement	light	space	mass	time

Table 21. Result for Dan

I: That's it ? (Conf.) Why did you do Group 5 ?

S: Because they are nearly equal... We play and afterwards we go to sleep.

I: Why are they similar in Group 3 ?

S: They both are <u>strong</u>.

I: (Rep.) And in Group 4 ?

S: They are the <u>same</u>.

I: (Rep.) How about Group 1 ?

S: Because sound <u>makes a noise</u>...and if you move you also <u>make a noise</u>.

I: And how about Group 2 ?

S: Because light also <u>makes</u> heat...

I: (Rep.) All right, thank you.

Transcription of interviews with 16-18 year-olds:

1. Wen(01/02/72;18;03;m;3rd;Gusmão)

I: I will show you some cards with some concepts or entities written on them which you probably have heard about before. Please look at them (...) (Obs: cards are shown on the table). All right ? (Conf.) Now, I would like you to put together the things which you think are similar to each other, grouping things which share common properties between them, all right ? (Conf.) And afterwards I will ask you to explain why is it that you think they are similar to each other. You can start it now...

S: (...) (Exp. - Part 1).

Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**
force	microwave	vaccuum	time	matter
energy	radioactivity	amosphere		mass
magnetism	temperature	sound		weight
atom	solar radiation	*gravity*		impulse
heat				space
electricity				movement
light				gravity

Table 1a. Result for Wen

S: That's it.
I: Now, could you explain Group 1 to me ? (Obs.: after reading the result in table 5a)
S: Well, magnetism and atom... The atom, we think of something which <u>does</u> a force, <u>gives</u> energy... It is like when we study the atom and the electric current, which <u>gives</u> energy, and that's why I've put atom and electricity together. And... when <u>we think of</u> electricity, <u>we think about</u> light, isn't it ? We have the idea of light... and light <u>transmits</u> heat... and heat <u>has</u> also energy, and this energy <u>has</u> a certain force... I don't know how to explain... I can visualize it but I cannot explain it...and force... you also have magnetic <u>forces</u>, isn't it ? That's why I've put magnetism with force in here... and also the atom with positive and negative charges which attract magnetism ...
I: All right. How about the second group...
S: Solar radiation... we obtain from the Sun and it <u>has</u> a certain temperature... and temperature, it will depend, if it is not too high... It <u>has</u> a radioactivity... and microwave... it <u>has</u> a lot of energy or radioactivity.
I: All right. How about the other group...
S: Atmosphere... you <u>remember of</u> vacuum... and sound... you won't have sound...
I: Why is sound here?
S: Well... it is linked... if you are in the vacuum <u>there is no</u> sound, and gravity <u>is in</u> the vacuum...
I: How about time?
S: Well... I could not put it together with the others... time is something which has to be alone because it cannot go with matter... you can only think of a clock... hours... the time that passes... so it has nothing to do with electricity,... vacuum, heat,...and matter.

I: ...Which is in another group... could you explain this group now (Obs.: Group 5)?
S: All matter occupies a space... it has a certain mass and it has weight because of gravity... but gravity is in another group...
I: Would you like to change it?
S: No... it can stay like that because... well, I think I will change it... because you have movement, and if there is gravity... the weight and gravity, in accordance with them there is more or less movement... and this movement together with gravity... you will have more or less impulse.

I: All right. Now you can choose either to forget about the groups you have already made or not and put together in the same group the similar concepts and the things you can think about them (Obs: reading the 52 cards with the features to be considered). Please use as much cards as you can, putting together in groups the similar concepts and the things you can think about them (Rep.).
S: (...) (Exp. - Part 2).

Groups	Entities	Features
Group 1	mass matter weight gravity space	real, material, can touch throught, feel, concrete, transform, macroscopic, act by contact
Group 2	solar radiation	transform things, cannot act upon it
Group 3	heat atom electricity energy temperature light	cause, cause movement, destroy things, distributes by itself, create things, act by itself, localized, energy, concentrates by itself, solid, movement, tranfer , perceive effects
Group 4	time atmosphere	exists without acting, inside it, vacuum, nowhere, action, imaginary, effect
Group 5	movement	immaterial, hear

Table 1b. Result for Wen

2. Ren(10/12/73;16;05;f;3rd;Gusmão)

I: (Same - Part 1).
S: (...) (Exp. - Part 1).

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
movement	matter	space	gravity	light	sound	temperature	time
impulse	atom	atmosphere	magnetism	energy	microwave		
weight	mass	vacuum	radioactivity	heat			
force			electricity	solar radiation			

Table 2a. Result for Ren

I: Can you explain your first group to me?

S: Movement... force... impulse... force; I've put together everything which has to do with movement, because for them to happen they will need movement. The weight hasn't got very much to do but I've put it here. The second is what we can...(Obs.: gest of holding) hold, isn't it? It has matter, mass... Group 3 is linked to space... space is everywhere... Group 4... They are magnetic forces, aren't they? Group 5... heat... energy... I think they are related. Group 6 is more difficult to explain...I think they have something to do because both emit sonorous waves...Group 7...I think temperature has nothing to do with the rest...I can put it in Group 5 with heat... but temperature... you can have different temperatures... and Group 8, I think time has nothing to do with the others because time is what it is. It is different from the rest.
I: All right. (Same - Part 2).
S: (...) (Exp. - Part 2).

Groups	Entities	Features
Group 1	movement impulse weight force	force, appears and disappears, action, transfer things, stop
Group 2	matter mass atom	particles, substance, concrete, localized, see, touch, exist without acting, real, destroy, solid, concentrate
Group 3	space vacuum atmosphere	field, rest, vacuum, inside it, place
Group 4	gravity magnetism radioactivity electricity	effect, cause movement
Group 5	light solar radiation energy heat	create, material, feel, transform, act by contact, transform things
Group 6	sound microwave	hear, wave, movement, act at distance, touch through
Group 7	temperature	conserve
Group 8	time	nowhere, cannot act upon it, imaginary

Table 2b. Result for Ren

3. Ric(21/06/72;17;11;m;3rd;Gusmão)

I: (Same - Part 1).
S: (...) (Exp. - Part 1).

Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**
atmosphere	microwave	atom	energy	mass
space	sound	radioactivity	electricity	gravity
vacuum	time		magnetism	matter
	light		heat	weight
	solar radiation		temperature	*impulse*
	movement		force	
			impulse	

Table 3a. Result for Ric

I: Can you now explain what you thought about these things...
S: Well... I tried to relate them... Group 1 influences all the others... because all the others are inside it... Group 2 has to do with sound and light... They are phenomena... sound and light... they have movement... Group 3... Well I haven't got a good notion of radioactivity (...)
I: But you think it has something to do with atom?
S: Yes, I think... In Group 4 they all are a kind of force or energy...
I: This is something they have in common...
S: Yes. In Group 5 they are all related to matter.... but impulse...
I: But not impulse? Would you like to change it?
S: ...I'll put it in Group 4.
I: (Obs.: Reading groups again) (Same - Part 2).
S: (...) (Exp. - Part 2).

Groups	Entities	Features
Group 1	atmosphere vacuum space gravity	vacuum, inside it, nowhere, place, cannot act upon it
Group 2	microwave time light solar radiation sound	field, wave, movement, transfer things, act at distance
Group 3	atom radioactivity	particles, concentrate, imaginary
Group 4	energy heat electricity force movement temperature magnetism impulse	act by contact, cause movement, transfer, perceive effects, cause, conserve, effect, touch through, force, energy, transform, feel, destroy things
Group5	mass matter weight	touch, see, real, concrete, material, exist without acting

Table 3b. Result for Ric

4. Hij(17/02/73;17;03;f;3rd;Gusmão)

I: (Same - Part 1).
S: (...) (Exp. - Part 1).

Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**	**Group 6**
matter	light	magnetism	movement	atmosphere	force
mass	heat	solar	time	sound	gravity
atom	energy	radiation		vacuum	weight
	temperature	electricity		space	impulse
	microwave	radioactivity			

Table 4a. Result for Hi

I: Can you now explain to me how you divided them?
S: Well... Group 1... They are related because they are concrete things... Group 2... They are forms of wave which reach us... We can feel them but not by touching or seeing... They are something which surround us... They reach us but we cannot follow them... Group 4... Movement and time are related... because for me without time there is no movement... if there is no movement there is no time... Group 5...They are a kind of a place... if you are in the Earth there is atmosphere; space and vacuum is where there is nothing... no organism; and sound... if there is no atmosphere, space or vacuum, there couldn't be any sound...you'll need one of them...In Group 6 everything is related to force... also gravity is related... In Group 3 they are all forms of energy... magnetism, electricity, radioactivity...
I: All right. (Same - Part 2).
S: (...) (Exp. - Part 2).

Groups	Entities	Features
Group 1	matter mass atom	material, concrete, solid, touch, see
Group 2	magnetism solar radiation electricity radioactivity	see effects, field, energy
Group 3	force impulse gravity weight	force, cause movement
Group 4	atmosphere vacuum sound space	hear, exist without acting, inside it, vacuum
Group 5	movement time	immaterial
Group 6	heat temperature energy light microwave	wave, transfer, feel, transform things, destroy things, act by contact, conserve

Table 4b. Result for Hi

5.Reg(31/07/73;16;10;m;3rd;Gusmão)

I: (Same - Part 1)

S: (...) (Exp. Part. 1) That's it.

Group 1	**Group 2**	**Group 3**
sound	atom	matter
energy	gravity	force
heat	atmosphere	mass
light	vaccuum	time
temperature		space
microwave		movement
electricity		weight
radioactivity		impulse
solar radiation		
magnetism		

Table 5a. Result for Reg

I: Well, what have you thought about when making these groups ? (Obs.: after reading the result in Table 1a)

S: When making the first one I was thinking about what they have in common, in this case - electricity, like temperature and heat... in accordance with they having equalities... In the second group I've put what was left... because they are related...

I: How is it that you think they are related here...? (Obs: reading Group 2)

S: (...) How could I say (...)

I: What did you think about ?

S: I thought that they have something to do with one another... I followed the concepts that our teacher explained... and I've put them together because I think they are related to the atmosphere... with the atoms that make the atmosphere... so I've put them together...

I: All right, and how about Group 3 ?

S: I followed the concept of mass... after mass I've put all the others related to mass...

I: And you think they are similar to each other ?

S: Yes, they are related.

I: (Same - Part 2)

S: (...) (Exp. Part. 2)

Groups	Entities	Features
Group 1	time	
Group 2	matter mass atom	see, touch, hear, feel, touch throught, see effects, transfer, conserve, create, spread, concentrate, destroy, transform, stop, solid, substance, macroscopic, microscopic, effect, inside it, localized, real, material, act by contact, exist without acting
Group 3	energy heat sound light gravity force space atmosphere movement weight temperature impulse vacuum microwave electricity radioactivity solar radiation magnetism	gas, particles, force, wave, fluid, movement, field, place, vaccuum, energy, cause, nowhere, immaterial, imaginary, rest, concrete, action, act at distance, act by itself, destroy things, create things, transform things, transfer things, cause movement, spread by itself, concentrate by itself, multiply by itself, appear and disappear

Table 5b. Result for Reg

6. She(22/12/73;16;05;f;3rd;Gusmão)

I: (Same-Part 1).
S: (...) (Exp. Part. 1).

Group 1	**Group 2**	**Group 3**	**Group 4**
matter	microwave	energy	time
gravity	electricity	heat	
force	radioactivity	sound	
mass	magnetism	light	
space	*temperature*	atmosphere	
atom	*movement*	vaccuum	
weight		solar radiation	
impulse		temperature	
movement		*time*	

Table 6a. Result for She

S: That's it.
I: Well, why did you group them like this? (Obs.: after reading the results in Table 2a)
S: Here (Obs.: Group 3) light has solar radiation, heat... I don't know, I think they are related... atmosphere (...) The vacuum is because light, heat and energy (...) they take a certain time to reach Earth, I mean... light and solar radiation...
I: And how about the time ?
S: Time (...) I don't think (...)
I: If you'd like to change... thinking about similar things...
S: (...) I can't find a place for it...
I: You can consider it separately if you wish...
S: Right... and temperature here (Obs: changing it from Group 2 to Group 3) and movement (...) here (Obs: changing it from Group 2 to Group 1).
I: Is it better now ?
S: Yes, it is better.
I: So, can you explain Group 1 to me?
S: They are related to matter, the atom, the force which acts upon matter, movement, which causes force, gravity, which influences matter, weight by its proper concept... they seen to be related.
I: How about Group 3 ?
S: Well... light gives solar radiation and heat - isn't it ? - and energy... with heat, temperature; and sound with light (...) it is the way they move like... (Obs.: gest imitating waves)
I: And how about time ?
S: Time... it is not possible to relate it to the others... it is different from the rest... the other concepts...
I: All right. (Same-Part 2).
S: (...) (Exp. Part. 2).

Groups	entities	features
Group 1	movement	see, create, stop, effect
Group 2	atom weight mass matter	particle, touch throught
Group 3	impulse force gravity	causes movement
Group 4	space	inside it
Group 5	microwave magnetism radioactivity electricity	destroy things, transform things, like fluid
Group 6	sound	hear
Group 7	heat energy temperature light solar radiation	spread by itself, like wave, feel, see effects, immaterial, like energy, localised

Table 6ba. Result for She

I: How about atmosphere, vaccuum and time ?
S: (...)

Group 8	time	act by itself

Table 6bb. Result for She

I: So, atmosphere and vaccuum can't be grouped ? (Obs.: after reading the result in Table 2ba and Table 2bb)
S: No.
I: All right, thank you.

7. **San(28/03/73;17;02;f;3rd;Gusmão)**

I: (Same - Part 1).
S: (...) (Exp. Part 1).

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
sound	heat	mass	force	electricity	radioactivity	vaccuum	light
	temperature	space	impulse	energy	magnetism	atmosphere	solar radiation
		time	gravity		microwave	atom	
		movement	weight				
		matter					

Table 7a. Results for San

S: That's it.
I: What did you think about when making these groups ? Sound... (Obs.: after reading the results in Table 3a)
S: It is different... Radioactivity, magnetism and microwave are related... well, I think so, but I haven't study them yet... Solar radiation and light, they have something to do... light... vacuum, amosphere and atom...it is difficult to explain...isn't it ?
I: Explain as much as you can...
S: Heat and temperature... one depends on the other, isn't it ? Mass, space, time, movement, matter...
I: Do you think they are alike ?
S: It depends... I grouped them thinking about the formula; force depends on impulse, gravity and weight... electricity, energy (...) Yes, they are similar.
I: All right. (Same - Part 2).
S: (...) (Exp. - Part 2).

Groups	Entities	Features
Group 1	light matter heat solar radiation temperature energy	see, touch, feel, like energy, conserve
Group 2	mass movement force gravity vaccuum weight impulse space time	material, force, exist without acting, cause movement, place
Group 3	sound atmosphere	hear, inside it
Group 4	radioactivity magnetism microwave atom electricity	field, wave, microscopic, act by contact

Table 7b. Result for San

S: That's it.
I: So, these are the groups of things that you think have something to do with one another ?
S: Yes.
I: For example, here you have atmosphere (Obs.: Group 3). Can you hear it? Are you inside it ?
S: I think the sound is in the atmosphere (...) Inside the atmosphere I can hear the sound.
I: All right. And how about Group 2?
S: Mass is related to movement... impulse causes force, gravity and weight (...).
I: How about space ? It is a place...
S: Because it is the place of movement... you need space and time.
I: And Group 1 ?
S: Light is a kind of heat, emits solar radiation, has a certain temperature and it is a kind of energy.
I: How about Group 4 ?
S: Magnetism is a kind of field... the atom is microscopic (...)
I: All right, thank you.

8. Ric(05/09/72;17;08;m;3rd;Gusmão)

I: (Same - Part 1)
S: (...) (Exp. - Part 1)

Group 1	Group 2
energy	mass
heat	force
light	weight
atom	gravity
temperature	movement
	time
	impulse

Table 8a. Result for Ric

S: That's it.
I: Why did you do Group 1 ? (Obs: after reading the results in Table 4a)
S: Because they have a reciprocal relationship. Light is a form of energy, it produces heat... and the atom... they are made of atoms which are small particles... and I would also include temperature (Obs.: including temperature now) because heat has to do with temperature.
I: All right. How about Group 2...?
S: Because... to apply a force you'll have mass... and weight too, which is a kind of force, and to have weight you'll need gravity and also movement, because when you apply a force you'll have movement... and time, because of the dependence with the weight... there is a relation... this because they all: mass, force, gravity and movement, have something to do with time.
I: All right...
S: Matter, I think, is related to all groups... because matter is everything which occupies a place in space...
I: Is it like everything ?
S: Yes.
I: Is there any other group ?
S: Well, impulse, I think, could go on Group 2... (Obs.: including impulse now) It is difficult (...)
I: Can you think of any other group ?
S: No.
I: Then, you'll have just these two groups ?
S: Yes.
I: (Same - Part 2).
S: (...) (Exp. - Part 2).

Groups	Entities	Features
Group 1	vaccuum	vaccuum, at rest, exist without acting
Group 2	space	localized, place, inside it
Group 3	microwave	wave
Group 4	sound	hear
Group 5	atom magnetism radioactivity	movement,act by itself, particles
Group 6	atmosphere	gas
Group 7	mass matter	material, substance, transfer, macroscopic, concrete,create, spread, touch, transform, solid, microscopic, concentrate, see destroy
Group 8	solar radiation time force heatmovement weight electricity impulse gravity temperature energy light	transfer things, action, immaterial, energy, concentrate by itself, destroy things, feel, act at distance, spread itself, force, act by contact, real, see effects, cause movement, multiply itself, create things, transform things, effect, field, conserve

Table 8b. Result for Ric

9. Gla(06/03/72;18;02;m;3rd;Gusmão)

I: (Same - Part 1).
S: (...) (Exp. - Part 1).

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
time	vacuum	weight	force	temperature	atmosphere	atom	sound
		mass	movement	heat	space	radioactivity	microwave
		gravity	impulse	energy		solar radiation	light
		magnetism					electricity

Table 9a. Result for Gla

I: Can you explain how you did the groups?
S: Well... time is something unique, it has nothing to do with the other things... and also vacuum... I think vacuum is another dimension... I don't know... In Group 3 gravity has to do with the mass and the weight of the bodies... magnetism could be gravity acting upon matter... I think so. In Group 4, with force you produce an impulse which gives movement. In Group 5, with energy you can produce heat and temperature, which measures heat. For us, in Group 6, atmosphere is the environment where we live in, and space can be another environment. In Group 7 atom has something to do with radioactivity because radioactivity is obtained from atoms; and solar radiation is radioactivity... In Group 8 they all are waves.
I: All right. (Same - Part 2).
S: (...) (Exp. - Part 2).

Groups	Entities	Features
Group 1	sound	hear, effect, energy
Group 2	time	act by itself, nowhere, inside, fluid, cannot act upon it, vacuum
Group 3	matter mass	concrete, solid, conserve, transfer, exist without acting, material, touch, touch through, concentrate
Group 4	space vacuum atmosphere	gas, concentrates by itself, distributes by itself, place, multiplies by itself
Group 5	atom	destroy, micro, particles
Group 6	movement weight magnetism electricity impulse solar radiation radioactivity energy light microwave heat temperature force gravity	transform things, act by contact, appear and disappear, transfer things, cause movement, see, act at distance, force, cause, field, wave, transform, action, localized, immaterial, imaginary, real, perceive effects, distribute it, destroy things, concentrate, feel, stop

Table 9b. Result for Gla

10. Edi(19/03/72;18;02;m;3rd;Gusmão)

I: (Same - Part 1).
S: (...) (Exp. - Part 1).

Group 1	Group 2	Group 3
energy	force	atmosphere
light	mass	vacuum
electricity	impulse	sound
heat	weight	space
atom	movement	time
radioactivity	magnetism	gravity
solar radiation		matter
temperature		
microwave		

Table 10a. Result for Edi

I: Could you now explain these groups?
S: Well... In Group 1 light is transformed in heat... Solar radiation emits light, energy emits light, when focusing light the temperature increases; radioactivity gives energy and light, electricity...It has to do with radioactivity... Atoms in collision emit light ... and microwave has to do with light...
I: All right. How about Group 2?
S: Force depends on mass and weight... and magnetism is a kind of force... impulse is a kind of force... and also movement, because to move you'll need a force.
I: And how about Group 3?
S: This is more difficult...Vacuum has to do with gravity... Vacuum has space and it also has atmosphere; atmosphere has matter... and it also has time and sound... I think they have more to do with this group than the others.
I: All right. (Same - Part 2).
S: (...) (Exp. - Part 2).

Groups	Entities	Features
Group 1	sound microwave	stop, field, distribute, wave, hear
Group 2	vacuum	immaterial
Group 3	energy impulse magnetism light gravity radioactivity temperature solar radiation heat electricity force movement	conserve, destroy things, perceive effects, feel, create, transfer, cause movement, act by contact, act at distance, transfer things, energy, effect, transform things, force, create things, particles
Group 4	atmosphere	destroy, localized, inside it
Group 5	time	act by itself, exist without acting, cannot act upon it
Group 6	weight mass matter	solid, macroscopic, material, see, touch, real
Group 7	space	rest, transform, place, vacuum
Group 8	atom	microscopic,gas, imaginary, movement, concrete, distributes by itself, concentrates by itself, appear and disappear, multiplies by itself

Table 10b. Result for Edi

11. Val(23/05/74;16;00;m;2nd;Gusmão)

I: (Same - Part 1).
S: (...) (Exp. - Part 1).

Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**	**Group 6**
sound	temperature	atom	energy	atmosphere	magnetism
	time	matter	heat	vacuum	force
	radioactivity	mass	light	gravity	impulse
	microwave	weight	electricity	space	movement
		movement	solar radiation		

Table 11a. Result for Val

I: Could you now explain Group 2 for example...
S: I think they have something to do because temperature is related to time and also radioactivity is related to time... and that's why I've put them together... Group 3 as well... An atom has matter, mass, weight... but maybe movement should not be here... but maybe in Group 6 with force...
I: Do you want to change it?
S: Yes, I want to change.
I: (Obs.: reading groups again) How about Group 4?
S: Here also, energy, heat and light, all the things which belong here, heat, solar radiation... also in Group 5, they all belong to the same...and in Group6 you have a force, you do an impulse, movement; and magnetism is a force which also pulls...
I: How about sound?
S: Well there is no other place to put it in...
I: All right. (Same - Part 2).
S: (...) (Exp. - Part 2).

Groups	Entities	Features
Group 1	time atmosphere mass	conserve, inside it, gas, immaterial, act at distance, macroscopic
Group 2	weight	solid, material
Group 3	movement	stop, destroy, act by contact
Group 4	temperature	create
Group 5	vacuum	cannot act upon it, nowhere, place, vacuum
Group 6	energy electricity force impulse	action, transfer things, cause movement, exist without acting, appears and disappears, transform it, create things, movement, concentrate, transfer, fluid
Group 7	radioactivity solar radiation	perceive effects, effect, cause
Group 8	heat	distribute, feel, energy, rest, destroy things, distribute by itself
Group 9	atom	microscopic, particles
Group 10	matter, light	touch, real, see, substance, concrete, multiplies by itself
Group 11	magnetism	field
Group 12	microwave	transform things, wave
Group 13	sound	hear, concentrates by itself
Group 14	space	touch through, localized

Table 11b. Result for Val

12. Mar(18/08/73;16;09;f;3rd;Gusmão)

I: (Same - Part 1).
S: (...) (Exp. - Part 1).

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
time	atmosphere	sound	atom	movement	energy	radioactivity	force
	vacuum	microwave	matter	space	heat	solar radiation	gravity
			mass		temperature	electricity	weight
					light	magnetism	impulse

Table 12a. Result for Mar

I: Now how did you make these groups? Group 2?
S: Well, because the atmosphere is the opposite of a vacuum, which has nothing in it... no air... and atmosphere is a mixture of gases.
I: And how about Group 3?
S: Well... Sound is with microwave because I think that sound comes in waves... We feel it through waves.
I: And time is alone? Why?
S: It doesn't look like anything.
I: And Group 4?
S: Well, atoms constitute matter, and matter turns into mass.
I: All right, how about Group6?
S: Well, heat is a form of energy, temperature measures heat, and light also has heat.
I: How about Group 5?
S: I've put movement with space because movement happens in a certain space.
I: How about Group 7?
S: Radioactivity...well (...) I think they are more alike...because the Sun has the radiation, magnetic waves... I think they are more similar.
I: And Group 8?
S: Force and gravity...because gravity is a kind of force and also weight is a kind of force; and impulse you have because of a force.
I: All right. (Same - Part 2).
S: (...) (Exp. - Part 2).

Groups	Entities	Features
Group 1	magnetism solar radiation radioactivity electricity	movement, transform things, wave, distributes by itself
Group 2	sound microwave	hear
Group 3	space movement	see
Group 4	impulse	action
Group 5	atom mass atom	concrete, touch, touch through, particles
Group 6	time	perceive effects, immaterial
Group 7	atmosphere, vacuum	exist without acting, inside it
Group 8	energy heat light temperature	energy, feel
Group 9	force gravity weight	cause movement, create, stop, force, field, act by itself, destroy things

Table 12b. Result for Mar

13. Ang(31/08/72;17;09;f;3rd;Gusmão)

I: (Same - Part 1).
S: (...) (Exp. - Part 1).

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
space	atom	microwave	solar radiation	energy	sound	force
atmosphere	matter		electricity	movement	light	mass
vacuum			radioactivity	temperature	time	gravity
			magnetism	heat		weight
			impulse			

Table 13a. Result for Ang

I: Now, how did you make these groups?
S: Well (...) First I thought of space... Vacuum is a place in space, and atmosphere is also in space.
I: How about Group 2?
S: Matter... it is difficult to explain... but it is all you can hold... an atom you can hold too. Microwave I couldn't link to anything else...
I: All right. And Group 5?
S: I think energy is linked to... well, movement is linked to energy, temperature, heat, and heat to energy.
I: How about Group 4?
S: I think electricity is linked to radioactivity, solar radiation and magnetism...
I: And Group 6?
S: Well...how can I explain?...
I: What have you thought about?
S: Well...because I think they are linked...it is like...something is distant from here a number of light-years...
I: All right. How about Group 7?
S: Well, mass is related to gravity... gravity to weight, and weight to force.
I: All right. (Same - Part 2).
S: (...) (Exp. - Part 2).

Groups	Entities	Features
Group 1	temperature	concentrate by itself, effect, act by itself
Group 2	gravity space vacuum atmosphere magnetism	imaginary, place, nowhere, field, vacuum, cannot act upon it, gas
Group 3	microwave	macroscopic, wave
Group 4	weight matter mass atom	particles, touch through, distribute, destroy, solid, see, touch, concrete, micro, material, localized
Group 5	movement force solar radiation	force, transfer things, inside it, transfer, fluid, cause, action
Group 6	time	transform, perceive effects, exist without acting, immaterial
Group 7	impulse	appears and disappears, conserve
Group 8	heat sound energy light	real, stop, substance, rest, feel, hear, create, movement, act at distance, energy, distributes by itself, cause movement, multiplies by itself
Group 9	electricity radioactivity	destroy things, create things, transform things, concentrate, act by contact

Table 13b. Result for Ang

14. Eri(16/03/72;18;02;f;3rd;Gusmão)

I: (Same - Part 1).
S: (...) (Exp. - Part 1).

Group 1	Group 2	Group 3	Group 4
time	matter	force	energy
space	atom	impulse	heat
atmosphere	mass	movement	electricity
vacuum	weight		microwave
sound	*force*		radioactivity
gravity	*impulse*		light
	movement		magnetism
			solar radiation
			temperature

Table 14a. Result for Eri

I: Why did you think the things in Group 1 are similar?
S: I thought that time is in space, atmosphere (...)
I: How about Group 2?
S: (...) Matter... I think they are related... In Group 1, they are a place... and here in Group 2 they are what there is... but... here... (Obs.: looking at the cards with force, impulse and movement)
I: Force, movement and impulse are different?
S: Yes, I think they are.
I: Should they stay in the same group?
S: Maybe there has to be another group, because they are what happen...
I: Can you now explain Group 2?
S: Well (...) an element has matter, mass, and so on.
I: How about Group 3?
S: It is action.
I: And Group 4?
S: It is change... energy...
I: All right. (Same - Part 2).
S: (...) (Exp. - Part 2).

Groups	Entities	Features
Group 1	solar radiation radioactivity	energy, cause, fluid, destroy things, act by contact, act at distance
Group 2	movement	movement, action
Group 3	matter mass weight	concrete, create things, transform, destroy, material, touch, solid, transfer, macroscopic, substance
Group 4	magnetism energy force electricity impulse temperature	create, touch through, conserve, multiply by itself, concentrate by itself, concentrate, force, distribute, cause movement, transfer things
Group 5	sound microwave time heat	vacuum, wave, effect, hear, localized, distributes itself, rest, transform things, act by itself, perceive effects, feel
Group 6	gravity vacuum space atmosphere	exist without acting, imaginary, place, field, inside
Group 7	light	see, appear and disappear, stop, immaterial
Group 8	atom	cannot act upon it, particle, microscopic

Table 14b. Result for Eri

15. Adr(21/07/72;17;10;f;3rd;Gusmão)

I: (Same - Part 1).
S: (...) (Exp. - Part 1).

Group 1	Group 2	Group 3	Group 4	Group 5
light	atom	space	electricity	force
energy	mass	atmosphere	microwave	movement
solar radiation	weight	gravity	sound	time
radioactivity	matter			
Group 6	**Group 7**	**Group 8**	**Group 9**	
temperature	vacuum	impulse	magnetism	
heat				

Table 15a. Result for Adr

I: Can you explain Group 1 to me?
S: Well... that's because of energy... which is light, solar radiation, radioactivity... and atom and its mass, the weight of an atom...
I: How about Group 3?
S: Space... or gravity... well, I don't know... I've put them together... Also in Group 4 (...) they are similar.
I: How about Group 5?
S: Well I don't know to what extent... force and movement... temperature and heat ...they are similar (...)
I: And the others don't look like any of the others...
S: No, I don't think so.
I: All right. (Same - Part 2).
S: (...) (Exp. - Part 2).

Groups	Entities	Features
Group 1	temperature heat	energy, feel
Group 2	force movement time	movement, action, force, act by contact, cause movement
Group 3	impulse	transfer things
Group 4	microwave electricity sound	real,wave, immaterial, hear
Group 5	magnetism	fluid
Group 6	mass atom weight matter	imaginary, micro, particles, solid
Group 7	radioactivity solar radiation energy light	perceive effects, act at distance, see, destroy things
Group 8	space atmosphere gravity	localized, place, inside, field, cannot act upon it
Group 9	vacuum	vacuum

Table 15b. Result for Adr

16. Ros(02/11/72;17;06;f;2nd;Gusmão)

I: (Same - Part 1).
S: (...) (Exp. - Part 1).

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
time	microwave	atom	heat	energy	gravity
atmosphere	radioactivity	magnetism	temperature	electricity	force
space	solar radiation	sound	vacuum		weight
	light				mass
					matter
					impulse
					movement

Table 16a. Result for Ros

I: Can you now explain how did you do Group 1?
S: Because time influences in space... well at least that is what I've learned in the first year... when solving problems in Physics... you have to use space and time... and atmosphere... well...it must have something to do, but I can't explain...
I: All right. How about Group 2?
S: I think that... I never studied these before... but I think they look alike...
I: How about Group 3?
S: Magnetism, I think, It has something to do with atom... and sound... something to do with magnetism...?
I: All right. How about Group 4?
S: You also have problems to solve about heat and temperature... and vacuum... well, in some problems, if you have vacuum it is one thing... that's it.
I: But you thinkit has to be here in this group, not alone...
S: Well... yes, I would leave it in here.
I: How about Group 5?
S: I think they have something to do, they are linked.
I: And Group 6?
S: Well... movement has to do with impulse... matter and mass are linked; weight and force... force and gravity... gravity influences the force... well, all of them are linked... when you are solving a problem you will use all of them.
: All right. (Same - Part 2).
S: (...) (Exp. - Part 2).

Groups	Entities	Features
Group 1	microwave radioactivity solar radiation light	destroy things, field, fluid, transform things, effect, wave
Group 2	time space	movement, exist without acting, inside it
Group 3	sound magnetism	immaterial, act by itself, act at distance
Group 4	atmosphere gravity vacuum	gas, rest, cannot act upon it, vacuum, imaginary
Group 5	matter mass atom	macroscopic, microscopic, touch, see, immaterial, real, particles, solid, concrete
Group 6	energy electricity	perceive effects, create, destroy, energy, act by contact
Group 7	heat tempeature	conserve, appears and disappears, distribute by itself, create things, localized, feel
Group 8	impulse movement force weight	cause movement, force, cause, action

Table 16b. Result for Ros

17. Wil(21/02/73;17;03;m;2nd;Gusmão)

I: (Same - Part 1).
S: (...) (Exp. - Part 1).

Group 1	Group 2	Group 3	Group 4	Group 5
matter	heat	impulse	sound	time
mass	electricity	weight	temperature	
atom	radioactivity	gravity	light	
	microwave	force		
	solar radiation			
	energy			
	magnetism			

Group 6	Group 7	Group 8	Group 9
vacuum	space	atmosphere	movement

Table 17a. Result for Wil

I: So, how did you do Group 1?
S: Well... I think in Group 1... It refers to matter... The atom and mass are a part of matter.
I: And Group 2?
S: In Group 2...well (...) I think it is the concept of energy.
I: (Rep.)
S: Yes.
I: How about Group 3?
S: Group 3... the force... They are a part of force...
I: And Group 4?
S: Group 4 (...) I can't explain.
I: Do they have something to do?
S: Yes...
I: All right. (Same - Part 2).
S: (...) (Exp. - Part 2).

Groups	Entities	Features
Group 1	atmosphere	gas, microscopic, particles
Group 2	space	place, cannot act upon it, exist without acting
Group 3	movement	movement
Group 4	temperature	
Group 5	vacuum	vacuum, concentrate by itself, immaterial, rest
Group 6	sound	hear, act at distance, distributes by itself
Group 7	mass matter atom	macroscopic, real, material, concentrate, transfer, concrete, feel, touch, see, conserve, touch through, distribute, fluid, solid, substance, localized
Group 8	radioactivity electricity heat light microwave solar radiation energy magnetism	energy, act by contact, destroy things, perceive effects, wave, transform things, transform
Group 9	time	create, stop, act by itself, inside it, nowhere, imaginary, create things
Group 10	force weight impulse gravity	force, effect, appears and disappears, cause movement, destroy, cause, action, transfer things

Table 17b. Result for Wil

18. Mar(21/04/74;16;01;m;2nd;Gusmão)

I: (Same - Part 1).
S: (...) (Exp. - Part 1).

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
space	time	vacuum	atom	movement	force	gravity	temperature
sound	energy	radioactivity	matter	microwave	weight	atmosphere	
	heat	solar	magnetism	impulse	mass		
	electricity	radiation					
	light						

Table 18a. Result for Mar

I: Can you explain Group 1 to me?
S: I thought about space... something moves in this space... and I related sound which is a noise coming from various places... and sound moves in space.
I: How about Group 2?
S: Well... time... It is necessary... It is related. For example, electricity takes a certain time to go from one place to another... so, time is related.
I: How about Group 3?
S: In vacuum radiation moves. Everybody says that there is nothing in the vacuum, but for me radiation exists inside the vacuum.
I: All right. And Group 4?
S: Matter is made of atoms... then, as magnetism is related to the poles...it means that magnetic poles exist in the matter and the atom.
I: All right. How about Group 5?
S: Movement is a part of (...) I don't know.
I: And Group 6?
S: Well... the force... To find a force you look for a mass, and mass has weight. Then, if you do not have mass or weight... you won't find a force of reaction which depends on the mass.
I: How about Group 7?
S: Gravity exists in the Earth or atmosphere. I think that it is the atmosphere that makes the force downwards of gravity, to pressure the Earth.
I: And Group 5 again?
S: Well... movement is a way of moving... and microwave and impulse... if you give an impulse it is a kind of a movement you are doing, it is a force on that person.
I: And temperature is alone...
S: Yes.
I: All right. (Same - Part 2).
S: (...) (Exp. - Part 2).

Groups	Entities	Features
Group 1	mass weight	force, concrete
Group 2	radioactivity solar radiation	destroy things, act by contact, effect, perceive effects
Group 3	vacuum	exist without acting, cannot actupon it, vacuum, nowhere, rest, transform things
Group 4	force impulse heat time temperature	inside it, cause, feel, material, cause movement
Group 5	space atmosphere matter atom	imaginary, field, particles, place, macroscopic, microscopic
Group 6	sound microwave	hear, appear and disappear
Group 7	electricity	transfer, fluid, localised, transfer things
Group 8	energy magnetism	create things, conserve, wave, energy
Group 9	movement	action, create, movement
Group 10	light	distribute
Group 11	gravity	touch through

Table 18b. Result for Mar

Appendix H:

Tables with results.

Contents:

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Tables with the coordinates of entities in the four-dimensional spaces obtained:

Figure with the distribution of 'yes' frequencies:

Tables for the second study:

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Tables for 16-18 year-olds:

Tables for undergraduate physicists:

Tables with the coordinates in the space of factors obtained:

Tables with the coordinates of individuals in the space of factors obtained:

Tables obtained for 16-18 year-olds:

Tables obtained for undergraduate physicists:

Tables for interviews:

Tables for the first study:

Tables with raw data:

features	light	sound	movement	force	mass	time	impulse	heat	energy	space
can see it	23	2	22	14	23	8	17	4	4	23
can touch it	4	10	8	7	22	0	7	5	4	8
can hear it	0	23	19	13	3	5	12	1	7	1
can feel it	11	12	18	18	23	13	17	21	22	10
can create it	9	17	23	22	17	2	22	17	20	15
destroy it	12	11	9	8	19	0	6	6	11	8
spread it	7	10	12	8	22	2	9	13	10	6
can stop it	10	15	15	12	8	1	14	6	9	3
can't do	2	2	1	1	0	10	3	2	0	2
like a solid	5	2	2	3	13	0	0	1	1	4
like a gas	6	2	2	3	1	5	1	9	1	4
like a fluid	2	1	1	0	2	0	1	3	2	6
like a force	15	16	16	23	4	9	20	11	18	4
action	3	14	23	23	6	6	21	7	13	6
like a place	6	2	6	4	2	6	2	4	0	20
movement	5	8	23	16	1	7	16	2	10	1
at rest	14	6	0	1	16	4	0	6	5	21
can be inside	3	6	12	3	1	15	5	8	5	22
nowhere	5	1	1	2	2	3	2	1	2	1
somewhere	21	22	22	19	23	18	16	21	19	21
imaginary	0	2	1	3	1	4	1	2	3	3
real	22	22	22	22	23	22	23	23	23	23
concrete	10	10	9	10	17	8	7	8	11	11
immaterial	22	16	13	9	1	20	8	14	11	12
act contact	13	5	13	17	8	4	6	14	14	3
act distance	12	10	13	9	4	10	6	14	8	7
act by itself	13	6	7	11	7	15	7	15	13	9
app. dis.	17	13	9	7	2	3	8	15	10	4
transform things	6	7	13	11	11	9	8	13	10	5
move things	1	2	19	15	8	4	17	3	10	2
create things	3	6	10	9	15	5	8	5	9	7
destroy things	5	7	12	18	3	7	10	14	14	2

Table 1. Frequencies of 'yes' answers for 8-10 year-olds.

features	mass	movement	force	heat	light	impulse	energy	sound	time	space
can see it	28	17	4	5	33	9	10	0	7	21
can touch it	29	2	4	3	1	4	3	3	0	2
can hear it	3	9	2	0	0	1	8	33	1	1
can feel it	23	17	29	33	20	32	29	23	20	13
touch through	3	1	3	7	11	2	7	7	2	6
see effects	9	27	29	24	24	25	25	26	17	11
spread it	22	6	22	19	18	9	15	15	3	16
concentrate	14	4	19	18	17	12	14	13	2	12
transfer it	17	5	14	12	18	8	11	9	2	10
can stop it	18	24	21	7	12	17	7	13	5	2
conserve it	21	14	8	19	13	10	15	10	2	14
transform it	24	15	17	9	6	10	14	14	3	17
destroy it	21	9	8	3	8	4	4	3	0	6
can create it	8	17	14	9	8	6	10	9	2	10
can't do	2	3	0	6	4	3	4	5	17	8
like a solid	23	2	1	0	1	2	0	0	0	5
like a gas	7	2	0	9	3	0	5	0	2	3
particles	17	4	5	2	10	2	13	6	0	4
like a force	3	25	25	5	2	26	15	10	1	3
like a fluid	4	3	1	5	8	1	6	7	1	3
like a wave	0	7	4	9	6	9	8	20	1	2
concrete	24	1	4	1	2	4	1	3	1	5
movement	0	18	7	0	2	14	3	3	1	1
cause	2	7	11	7	5	12	9	7	11	2
effect	1	14	14	15	16	9	15	16	10	5
action	3	22	18	6	4	17	10	4	8	0
substance	14	0	1	4	1	2	4	4	0	2
imaginary	1	4	7	14	13	5	9	14	20	13
nowhere	0	1	3	3	0	2	1	0	4	0
real	24	24	20	20	24	20	22	18	18	18
immaterial	0	6	8	17	14	10	11	10	10	5
at rest	6	0	1	5	12	0	3	2	4	11
place	2	0	0	1	0	2	1	2	2	16
can be inside	7	8	5	6	8	2	6	6	12	14
somewhere	22	14	13	16	21	13	16	12	6	14
microscopic	15	1	2	2	3	1	1	2	0	1
macroscopic	19	6	4	3	8	4	3	2	2	5
act contact	13	17	18	18	9	22	13	14	3	3
act distance	8	7	7	12	15	5	10	14	3	3
act by itself	4	6	4	16	11	3	12	7	20	5
cause mov.	7	24	27	4	3	26	15	12	5	4
destroy things	8	20	22	15	2	14	10	8	8	0
transform things	20	21	21	26	16	16	23	13	12	8
create things	11	10	13	8	3	6	11	5	6	6
exist without acting	24	6	4	8	10	24	10	11	17	20
spread itself	4	3	3	16	12	3	9	13	9	7
multiply by itself	4	1	4	8	5	3	5	6	9	4
concentrate by itself	4	1	5	8	8	3	7	4	5	7
app. dis.	2	5	9	16	14	6	6	9	3	3

Table 2. Frequencies of 'yes' answers for 13-14 year-olds.

features	mass	movement	force	heat	light	impulse	gravity	sound
can see it	24	19	7	5	29	8	1	1
can touch it	25	3	4	5	3	5	0	0
can hear it	1	17	1	0	0	0	2	29
can feel it	21	15	26	31	14	26	25	8
touch through	6	3	2	6	7	3	4	2
see effects	19	29	29	27	25	27	26	24
can spread it	16	5	16	17	15	10	4	14
concentrate	7	3	16	14	14	4	5	9
transfer it	9	8	20	15	14	7	5	16
can stop it	7	20	15	7	11	17	4	16
conserve it	14	12	13	17	14	7	8	15
transform it	14	6	13	10	8	11	8	10
destroy it	11	5	14	11	6	7	6	7
can create it	5	15	17	11	7	15	4	16
can't do	8	4	2	5	5	3	8	4
like a solid	21	1	4	0	0	1	0	0
like a gas	4	0	0	11	6	0	3	1
particles	9	4	2	10	10	6	3	10
like a force	9	24	18	6	12	28	22	7
like a fluid	1	6	3	6	6	1	4	8
like a wave	2	11	3	2	6	7	6	18
concrete	17	0	8	3	3	0	1	1
movement	1	10	5	1	0	19	6	5
cause	1	11	12	13	7	8	10	12
effect	2	11	13	12	14	12	9	14
action	4	25	23	11	10	21	15	7
substance	11	0	0	3	1	0	0	0
imaginary	1	7	11	15	8	7	13	12
nowhere	0	3	3	3	1	2	0	1
real	19	15	19	18	20	14	11	13
immaterial	0	10	12	9	12	8	11	11
at rest	5	0	3	8	6	3	9	6
like a place	1	2	0	1	1	1	1	0
can be inside	5	7	5	4	7	2	13	5
somewhere	14	13	13	16	20	5	6	13
microscopic	6	4	3	5	5	1	0	1
macroscopic	12	6	6	4	10	1	0	1
act contact	17	16	23	14	16	17	8	11
act distance	4	15	10	10	16	6	11	15
act by itself	2	6	3	10	10	4	17	8
cause movement	17	23	24	10	9	24	19	7
destroy things	8	16	26	21	4	18	9	9
transform things	14	15	21	24	13	13	9	7
create things	10	9	13	11	9	9	5	6
exist without acting	16	10	6	13	13	3	14	11
spread itself	5	2	7	15	12	7	9	13
multiply by itself	4	2	4	9	5	4	6	9
concentrate by itself	5	0	3	6	6	3	6	4
app. dis.	2	16	14	18	18	11	4	16

Table 3. Frequencies of 'yes' answers for young working adults.

features	matter	space	energy	time	eletricity	weight	temperature	atom
can see it	29	18	12	5	11	13	8	13
can touch it	24	2	9	0	6	16	2	5
can hear it	8	1	2	2	4	3	0	0
can feel it	15	10	19	16	23	28	29	2
touch through	2	5	4	1	2	5	3	3
see effects	19	14	27	20	27	11	28	17
can spread it	8	7	13	3	18	17	5	6
concentrate	6	3	12	1	15	14	4	9
transfer it	10	6	18	2	20	8	3	5
can stop it	4	0	7	2	9	3	1	0
conserve it	15	10	14	1	14	19	10	5
transform it	22	4	19	7	14	8	8	13
destroy it	15	4	7	1	10	6	2	10
can create it	18	12	19	6	19	8	7	6
can't do	1	8	2	11	2	2	8	7
like a solid	19	2	3	1	1	13	2	5
like a gas	3	5	1	3	0	3	5	2
particles	15	2	5	2	6	3	9	27
like a force	6	4	24	5	27	16	7	7
like a fluid	1	2	3	5	4	1	3	0
like a wave	2	1	6	3	6	0	3	1
concrete	15	4	4	0	2	16	4	9
movement	1	3	6	8	2	0	1	5
cause	3	3	7	2	10	6	10	4
effect	1	2	5	4	12	2	9	1
action	3	0	10	11	7	6	4	4
substance	4	1	5	3	4	6	2	4
imaginary	1	16	8	16	4	2	8	8
nowhere	0	1	0	0	0	0	0	0
real	16	14	18	16	22	20	16	19
immaterial	2	10	5	6	8	3	7	1
at rest	6	9	0	4	4	4	4	3
like a place	2	13	0	2	1	0	2	0
can be inside	6	26	5	15	2	3	9	1
somewhere	14	13	10	5	12	14	8	10
microscopic	11	2	2	2	2	0	3	16
macroscopic	9	6	4	1	3	7	3	2
act contact	12	2	16	2	20	11	10	18
act distance	4	5	10	6	12	2	8	5
act by itself	5	3	7	16	6	1	17	6
cause movement	14	16	19	11	21	·16	8	14
destroy things	10	2	18	14	21	11	11	5
transform things	19	2	18	15	11	11	13	14
create things	15	3	11	12	9	6	5	9
exist without acting	10	20	8	14	7	4	10	19
spread itself	4	5	11	7	6	2	16	10
multiply by itself	4	1	7	9	6	4	13	8
concentrate by itself	3	9	7	5	4	6	7	7
app./dis.	3	7	12	3	7	1	7	1

Table 3. Frequencies of 'yes' answers for young working adults (continued).

features	matter	energy	heat	sound	light	gravity	force	mass	time	space	atom
can see it	48	7	2	0	41	1	9	39	5	17	14
can touch it	48	4	10	0	2	1	6	39	0	3	10
can hear it	0	8	1	50	1	1	5	1	3	1	0
can feel it	41	30	43	21	14	29	36	36	27	10	5
touch through	16	17	13	13	12	10	13	10	2	7	3
see effects	21	42	47	33	39	36	43	10	39	24	25
transfer it	26	35	22	21	22	2	23	15	3	4	16
conserve it	38	28	34	17	21	9	20	28	6	10	17
can create it	32	30	33	38	26	3	34	16	3	12	10
can spread it	37	29	31	27	22	2	26	29	6	7	21
concentrate	24	32	24	17	19	6	18	22	4	6	13
destroy it	38	13	12	11	10	7	18	22	4	7	18
transform it	37	29	19	17	8	4	30	28	6	13	20
can stop it	18	19	10	34	20	6	28	5	6	0	4
can't do	1	12	13	12	17	34	1	3	38	23	8
like a solid	33	0	1	0	1	4	2	40	0	7	15
like a gas	5	10	15	1	4	11	0	4	3	7	3
particles	27	21	17	7	11	7	4	22	3	9	40
like a force	7	40	14	15	17	30	27	0	8	1	3
like a wave	0	18	17	44	18	8	5	0	5	8	1
like a fluid	3	8	13	12	6	6	4	0	11	6	2
movement	3	18	9	8	8	9	22	0	15	2	6
like a field	4	25	12	10	12	27	13	2	2	21	7
substance	33	4	1	0	1	3	3	26	0	1	15
like a place	3	1	3	5	5	13	0	2	5	33	1
vacuum	1	1	7	9	4	20	2	1	11	18	3
energy	6	39	40	13	35	15	33	3	6	2	10
macroscopic	30	11	9	6	13	7	3	24	1	9	2
microscopic	16	16	7	8	3	8	7	10	4	3	32
effect	8	30	40	37	34	27	29	3	15	4	6
cause	16	17	19	15	18	14	20	11	14	4	4
can be inside	15	15	14	7	15	25	4	3	34	39	3
nowhere	0	2	1	2	1	2	4	0	8	2	0
localized	46	12	28	28	30	18	16	35	5	17	22
immaterial	1	31	31	35	29	30	22	1	30	17	11
imaginary	2	23	13	16	13	26	11	4	22	11	14
real	45	31	37	34	37	31	28	36	20	24	26
material	39	3	2	0	4	3	5	34	0	6	15
at rest	11	8	13	10	15	18	2	10	5	13	0
concrete	44	8	9	7	7	7	3	33	1	6	17
action	4	34	30	22	20	23	36	0	14	1	4
act contact	23	24	17	18	12	11	43	10	3	2	19
act distance	6	22	31	29	34	23	6	3	12	10	2
act by itself	14	19	30	16	21	35	2	6	40	13	17
destroy things	17	31	36	11	8	10	31	6	13	4	13
create things	29	22	22	10	17	3	17	11	9	7	28
transform things	26	33	34	8	19	13	31	10	20	4	20
transfer things	14	23	13	8	9	12	21	3	6	12	4
cause movement	15	40	17	12	9	26	44	8	14	7	11
exist without acting	21	13	17	7	11	18	3	19	16	25	9
spread itself	7	27	33	24	22	26	4	6	8	10	17
concentrate by itself	7	12	19	8	12	18	5	11	6	6	15
multiply by itself	5	12	21	12	16	14	2	6	7	3	16
app./dis.	5	25	31	31	31	10	19	1	2	2	3

Table 4. Frequencies of 'yes' answers for 16-18 year-olds.

features	atm.	mov.	weight	temp.	impulse	vacuum	microw.	eletric.	radioac.	solar rad.	magn.
see it	9	42	15	5	18	5	7	13	5	20	15
touch it	2	6	18	3	6	0	4	6	0	0	6
hear it	3	14	0	0	4	4	7	6	3	1	0
feel it	21	35	39	49	39	18	26	26	22	40	20
tou. thr.	8	5	9	2	7	4	8	11	11	10	14
see effe.	38	39	27	38	42	25	36	47	43	40	40
transfer	2	16	21	24	17	4	8	29	13	13	18
conser.	13	26	31	37	5	17	10	20	11	11	18
create it	0	34	12	12	28	13	16	25	24	4	17
spread it	2	12	28	15	8	7	7	30	16	15	10
concen.	4	7	15	14	6	8	9	23	21	17	18
destroy	16	13	10	2	9	9	8	8	10	1	8
transfo.	10	25	14	16	11	6	14	19	14	15	13
stop it	2	38	2	5	26	4	7	23	9	5	14
can't do	15	1	5	4	2	19	10	9	16	21	12
solid	3	4	31	2	2	1	3	0	1	3	6
gas	35	3	5	12	1	15	3	2	13	7	1
particle	11	7	14	16	4	10	25	16	23	13	11
force	5	39	25	6	39	10	16	37	20	21	38
wave	6	6	0	17	5	7	43	24	26	18	25
fluid	10	2	1	6	3	9	15	8	14	15	9
movem.	6	15	1	4	23	3	12	12	4	14	5
field	22	3	2	8	1	28	14	21	17	9	33
substa.	7	2	11	4	2	3	3	3	7	2	2
place	18	0	2	1	1	17	1	1	2	4	2
vacuum	18	1	2	2	5	35	5	2	7	4	6
energy	5	27	4	33	24	6	30	45	34	42	27
macro	9	11	15	2	5	1	2	8	4	6	3
micro	3	9	4	5	4	7	18	7	14	4	9
effect	13	41	16	29	26	17	18	26	27	28	24
cause	4	21	19	22	26	15	10	15	22	11	11
inside	43	26	4	20	5	10	4	2	2	18	6
nowhere	0	2	0	1	6	4	4	3	2	4	5
localiz.	11	23	22	18	14	25	19	30	28	27	20
imater.	19	14	6	30	19	26	17	19	27	25	22
imagin.	20	13	3	10	11	20	14	8	13	14	20
real	25	33	33	25	21	15	18	26	21	23	23
material	2	7	24	1	3	2	5	4	1	5	4
at rest	13	1	10	7	0	29	3	6	6	11	9
concrete	5	11	31	6	7	3	6	12	11	10	9
action	4	38	3	12	29	6	16	24	22	18	20
act con.	4	34	13	17	26	2	22	30	19	9	28
act distance	17	10	5	9	9	6	10	20	25	33	20
act itse.	25	10	7	18	6	12	8	8	15	33	22
destroy things	8	17	18	24	15	4	14	19	44	24	7
create things	6	17	5	17	8	3	16	17	18	11	10
transfo. things	12	22	16	30	8	7	26	18	29	25	10
transfer things	5	28	5	10	16	4	6	14	7	4	17
cause movem.	18	26	17	12	35	10	18	28	12	16	31
exist wit. act	11	5	14	12	6	25	7	5	11	11	7
spread itself	20	8	3	19	2	7	6	15	13	30	10
concen. itself	9	3	11	13	1	13	6	7	11	9	8
multip.	4	5	1	8	1	4	6	7	12	7	6
ap. dis.	5	23	6	20	13	11	11	20	7	18	3

Table 6. Data from 16-18 year old (Entities abreviated: atmosphere, movement, temperature, microwave, electricity, radioactivity, solar radiation, magnetism)

Table 4. Frequencies of 'yes' answers for 16-18 year-olds (continued).

features	matter	energy	time	space	force	action	heat	photon
can see it	31	7	0	19	0	11	5	12
can touch it	31	2	0	2	0	2	5	2
can hear it	6	14	0	0	2	3	0	0
can feel it	26	23	16	11	24	17	28	10
can touch through	14	7	1	8	3	2	6	5
can see effects	24	31	26	13	31	28	30	29
can transform it	26	30	5	15	19	17	23	14
can transfer it	29	28	2	5	24	19	32	18
can destroy it	14	4	0	2	3	10	4	14
can create it	9	17	0	8	11	14	11	16
can conserve it	25	28	2	11	12	12	19	9
can stop it	23	3	3	2	19	18	3	7
can spread it	28	28	1	3	18	14	28	17
can concentrate it	31	30	1	3	24	13	24	21
like a solid	31	5	0	5	2	2	1	4
like a gas	30	4	0	4	2	2	5	0
like a particle	31	7	0	4	2	2	5	23
like a force	5	16	1	2	27	17	5	1
like a fluid	29	13	6	3	4	4	11	4
like a place	7	0	2	27	1	1	0	1
like a field	4	20	3	11	21	12	1	7
like a vacuum	3	6	3	12	3	1	0	3
like a movement	10	22	15	10	19	19	18	13
like a wave	8	26	4	2	5	5	12	20
like an energy	19	31	4	2	21	14	27	26
property	13	11	6	6	8	5	13	4
relation	2	10	10	1	11	7	6	1
quantity	23	20	9	8	12	7	15	8
substance	28	7	1	1	0	1	2	4
concrete	27	3	3	8	2	2	4	5
discrete	23	18	6	4	4	4	1	21
microscopic	25	9	4	11	6	5	10	21
cause	8	18	5	4	23	17	16	9
imaginary	3	7	15	10	5	2	1	5
immaterial	1	23	25	16	16	15	12	14
effect	9	16	4	4	21	21	24	11
continuum	20	16	23	21	10	9	12	0
material	27	3	2	3	0	2	0	5
real	29	20	16	19	17	16	16	13
macroscopic	28	6	4	11	5	6	7	0
at rest	13	4	1	14	0	0	1	0
action	2	16	6	1	25	26	3	7
state	7	17	3	5	2	5	14	2
invariant	12	11	4	6	3	4	2	4
immutable	9	4	3	6	2	2	3	2
transformation	19	22	10	9	15	17	17	8
everywhere	15	21	18	25	6	4	9	8
nowhere	1	2	11	0	3	5	2	1
can be inside it	5	7	10	16	2	2	6	0
localized	24	14	1	13	17	13	19	19
act by contact	22	10	1	2	19	15	23	21
act at distance	15	17	1	3	19	11	15	7
cause movement	12	27	0	2	19	23	17	21
transform things	11	25	9	2	19	21	23	17
transfer things	9	21	3	2	19	21	12	11
create things	0	11	2	4	5	6	2	1
act by itself	3	7	21	5	8	6	6	11
destroy things	4	16	2	1	14	9	14	4
distribute by itself	25	24	3	5	13	10	24	10
concentrate by itself	25	24	2	3	13	10	19	12
multiply by itself	2	4	1	2	9	1	6	4
act under control	13	4	1	2	9	1	4	6
exist without acting	20	17	24	20	7	3	12	11
appear and disappear	5	8	0	2	11	9	8	12
passive	20	2	13	16	1	1	3	3

Table 5. Frequencies of 'yes' answers for undergraduate physicists.

features	wave	spin	gravity	electricity	mass	charge	movement	field
can see it	18	0	1	9	23	0	22	0
can touch it	8	0	0	4	20	1	1	0
can hear it	16	0	0	4	1	0	5	1
can feel it	21	0	22	25	22	16	16	20
can touch through	12	3	6	7	8	1	1	2
can see effects	30	23	32	31	21	30	23	30
can transform it	24	5	4	25	17	5	24	16
can transfer it	18	4	1	27	23	22	25	6
can destroy it	15	1	0	4	8	3	14	10
can create it	21	3	1	15	5	3	20	12
can conserve it	9	16	5	17	24	29	24	14
can stop it	7	2	0	6	16	7	25	3
can spread it	18	2	4	25	25	27	13	14
can concentrate it	14	2	3	18	25	26	8	16
like a solid	2	2	3	2	22	4	1	0
like a gas	2	2	2	2	20	3	2	0
like a particle	6	3	5	12	21	16	5	5
like a force	5	6	22	13	5	8	9	14
like a fluid	10	1	5	13	17	7	6	6
like a place	3	2	3	3	3	2	3	3
like a field	13	5	23	21	2	11	5	28
like a vacuum	1	1	4	3	1	2	2	6
like a movement	24	16	5	15	6	8	29	9
like a wave	28	0	6	13	2	10	14	14
like an energy	28	12	15	22	14	11	16	21
property	4	20	14	10	18	18	10	13
relation	1	2	6	4	4	5	6	12
quantity	3	4	6	8	27	24	14	7
substance	2	0	0	1	19	5	0	0
concrete	2	1	2	6	21	10	7	3
discrete	4	16	2	6	11	22	1	3
microscopic	7	22	2	14	18	18	7	7
cause	8	6	21	18	9	16	9	16
imaginary	4	9	7	3	1	8	3	13
immaterial	22	14	13	12	3	13	10	15
effect	13	9	11	16	6	8	29	21
continuum	18	3	15	10	14	3	10	17
material	3	1	0	4	22	6	2	2
real	16	9	15	18	27	15	17	13
macroscopic	10	1	7	8	17	4	11	6
at rest	1	1	5	2	9	3	1	3
action	11	5	16	12	5	6	16	15
state	6	16	4	1	8	6	16	9
invariant	3	3	8	1	8	10	4	2
immutable	1	5	6	1	4	6	1	2
transformation	8	2	3	15	11	7	19	11
everywhere	11	2	17	4	12	10	17	21
nowhere	1	4	1	3	3	2	8	2
can be inside it	4	1	12	1	5	1	7	13
localized	15	11	8	17	25	20	12	12
act by contact	16	2	3	20	16	11	10	3
act at distance	8	9	28	19	16	23	1	24
cause movement	22	6	29	26	17	22	19	24
transform things	18	1	12	20	3	7	9	8
transfer things	10	1	19	19	7	7	17	13
create things	1	0	0	2	1	5	3	6
act by itself	8	9	10	6	11	9	7	14
destroy things	10	0	6	10	5	6	7	7
distribute by itself	16	0	5	23	18	24	11	16
concentrate by itself	15	0	4	19	21	20	10	19
multiply by itself	5	0	1	7	0	0	5	2
act under control	5	5	4	5	5	1	6	4
exist without acting	12	14	15	12	12	13	6	16
appear and disappear	8	4	2	7	2	3	9	11
passive	1	4	9	2	15	5	5	4

Table 5. Frequencies of 'yes' answers for undergraduate physicists (continued).

features	sound	light	quark	neutrino	magnetism	gamma rays	microwave
can see it	0	29	0	1	1	0	1
can touch it	3	3	0	0	1	0	1
can hear it	31	0	0	0	0	0	0
can feel it	18	16	2	3	11	5	7
can touch through	3	3	0	0	3	1	2
can see effects	26	26	18	21	32	30	31
can transform it	19	14	5	7	13	11	12
can transfer it	11	12	7	8	10	8	8
can destroy it	15	12	3	5	9	9	10
can create it	22	16	4	7	11	19	21
can conserve it	6	8	12	11	15	7	9
can stop it	14	7	3	7	2	9	6
can spread it	15	23	7	7	12	18	17
can concentrate it	14	22	7	8	16	20	21
like a solid	1	2	5	4	0	3	1
like a gas	3	2	0	0	0	0	1
like a particle	7	21	29	29	2	16	15
like a force	6	3	4	3	18	4	1
like a fluid	5	5	2	2	5	2	2
like a place	3	2	2	2	2	2	2
like a field	5	17	3	2	28	11	14
like a vacuum	0	5	1	1	3	4	2
like a movement	21	16	7	11	12	13	13
like a wave	31	29	4	8	13	24	31
like an energy	25	25	13	13	25	23	24
property	3	5	7	4	15	6	4
relation	1	3	2	4	8	4	3
quantity	7	8	8	5	7	7	7
substance	1	1	5	3	1	3	1
concrete	8	8	6	6	4	4	5
discrete	2	14	16	15	3	11	9
microscopic	3	13	23	26	9	12	10
cause	6	10	8	9	15	10	10
imaginary	2	2	7	4	8	2	2
immaterial	7	9	2	3	11	7	10
effect	26	18	5	7	1	12	16
continuum	10	7	1	0	9	7	7
material	4	5	10	8	1	4	3
real	18	16	13	14	14	15	16
macroscopic	8	6	1	0	9	4	5
at rest	0	1	0	0	2	0	0
action	11	9	4	3	10	8	10
state	2	3	4	2	3	1	1
invariant	1	5	5	4	4	4	2
immutable	0	1	5	2	3	2	0
transformation	12	10	4	7	13	12	11
everywhere	11	11	10	8	11	5	7
nowhere	4	2	4	2	2	1	2
can be inside it	5	4	1	1	6	2	4
localized	17	17	12	15	15	19	18
act by contact	14	9	19	9	5	11	10
act at distance	10	9	7	6	26	9	7
cause movement	15	12	8	8	22	9	12
transform things	5	11	9	8	8	18	17
transfer things	15	1	3	7	14	8	10
create things	2	3	3	3	5	4	3
act by itself	5	13	6	6	12	6	7
destroy things	5	8	6	6	9	15	11
distribute by itself	16	17	6	7	13	15	18
concentrate by itself	14	15	4	7	14	13	15
multiply by itself	2	3	0	0	3	2	2
act under control	10	3	1	1	4	2	5
exist without acting	6	8	11	15	10	9	7
appear and disappear	11	7	1	5	4	6	5
passive	2	3	5	4	4	2	2

Table 5. Frequencies of 'yes' answers for undergraduate physicists (continued).

Tables with the coordinates of features in the four-dimensional spaces obtained:

Table with the coordinates of features in the four-dimensional space obtained for the 8-10 year-old group.

features dim 1	place/ localized	features dim 2	static dynamic	features dim 3	motion /cause	features dim 4	action/ imm. fluid
imaginary	1.6527	*rest*	2.0964	*see*	1.4459	*create things*	1.6156
inside	1.5296	fluid	1.8110	nowhere	1.0772	*create*	1.5851
place	1.1150	*solid*	1.7547	*hear*	.9350	*touch*	1.4096
can't do	1.0966	*concrete*	1.7036	*stop*	.8844	spread	1.4033
action	.7608	*somewhere*	1.3045	immaterial	.7468	*stop*	1.2147
hear	.7056	*touch*	1.3030	*movement*	.7213	*move things*	1.2104
create things	.6949	destroy	1.1660	*place*	.7114	*destroy*	1.2027
move things	.6876	*see*	1.1482	somewhere	.4477	feel	1.1747
real	.6225	*real*	1.1474	*inside*	.4043	*action*	0.9733
movement	.5430	*place*	1.1416	destroy	.3421	*concrete*	0.9008
create	.3819	spread	.8802	action	.2870	hear	0.8078
fluid	.3145	create things	.6076	force	.2710	transform things	0.6904
touch	.2304	inside	.5173	move things	.2490	*solid*	0.687
see	.1834	gas	.1131	touch	.2104	*movement*	0.6051
destroy things	.0469	nowhere	.0208	solid	.2079	*act contact*	0.3231
concrete	-.0296	feel	-0.1636	rest	.1989	*force*	0.2793
rest	-.1355	imaginary	-0.3144	can't do	.1355	somewhere	0.269
feel	-.1376	act itself	-.3297	app./dis.	.0914	real	0.2143
transform things	-.1678	can't do	-0.4920	act distance	.0409	destroy things	0.1858
force	-.1965	create	-0.5138	concrete	-.0478	see	0.1692
immaterial	-.3978	immaterial	-0.6849	create	-0.1113	app./dis.	-0.6745
solid	-.4019	app./dis.	-.8278	create things	-.1433	*rest*	-0.7602
act itself	-.4880	transform things	-.8977	fluid	-.3502	*fluid*	-0.8353
stop	-.4975	act contact	-.9007	spread	-.4187	*imaginary*	-1.2194
spread	-.5846	stop	-1.0444	gas	-.6557	*place*	-1.2863
gas	-.6508	move things	-1.1148	act contact	-.6769	act distance	-1.3179
destroy	-.8035	act distance	-1.1408	*destroy things*	-.8256	nowhere	-1.3264
actdistance	-.9021	hear	-1.3936	imaginary	-.8923	*inside*	-1.5102
somewhere	-.9711	action	-1.5042	*act itself*	-1.1874	*act itself*	-1.8124
act contact	-1.1783	movement	-1.5976	*transform things*	-1.2260	*gas*	-1.9884
nowhere	-1.2796	*destroy things*	-1.7790	*feel*	-1.3735	can't do	-2.0724
app./dis.	-1.6497	*force*	-2.0163	real	-1.4996	*immaterial*	-2.1177

Table 1.Features in the four-dimensional space obtained for 8-10 year-olds. The features are shown in the decreasing order for each dimension. In italic are the features which broadly guided the distinction made in each dimension (place/localized, etc.) and which are in most cases shared with other groups. Underlined are those which are shared with all the other groups (including the study of all the five groups together) in characterizing these same dimensions.

Table with the coordinates of features in the four-dimensional space obtained for the 13-14 year-old group.

features dim 1	place localized	features dim 2	static dynamic	features dim 3	motion cause	features dim 4	action/ imm. fluid
can't do	1.8639	*solid*	1.8483	*hear*	1.8908	*stop*	1.9496
exist witho. act	1.8219	*macro*	1.8301	*create*	1.2140	*causemov.*	1.8628
place	1.5955	*concrete*	1.7427	gas	1.1867	*force*	1.7746
inside	1.5953	*see*	1.6910	*place*	1.1850	*action*	1.6161
nowhere	1.3307	*micro*	1.6591	*wave*	1.0851	*movement*	1.6021
cause	.9542	*touch*	1.6180	*inside*	.9651	*create things*	1.5803
movement	.8006	destroy	1.6163	*movement*	.9492	*destroy things*	1.52
action	.7743	*substance*	1.5916	*see*	.8571	*act contact*	1.4977
imaginary	.7185	*particles*	1.4823	fluid	.7453	*create*	1.3809
act itself	.7027	transform	1.3336	transform	.5413	transform	1.204
solid	.6830	conserve	1.2979	*effect*	.4714	real	1.0748
concrete	.6083	*somewhere*	1.2645	touch through	.4112	*destroy*	0.8994
cause mov.	.5492	*exist witho. act*	1.2373	see effects	.3159	transform things	0.8615
multiply itself	.5489	*rest*	1.1308	cause mov.	.3054	*touch*	0.6139
create things	.5456	transfer	1.0249	*stop*	.3041	see effects	0.5813
force	.4224	spread	.9394	force	.3024	*concrete*	0.4862
touch	.4027	*real*	.8644	act distance	.2958	*macro*	0.4603
destroy things	.3758	gas	.8148	rest	.2952	*solid*	0.4544
macro	.2663	*place*	.6954	imaginary	.2908	cause	0.4419
transform	.2207	inside	.5046	real	.2104	feel	0.4255
micro	.2096	concentrate	.1420	solid	.2066	micro	0.3735
see	.2083	fluid	.1385	spread itself	.0757	particles	0.2279
destroy	.1279	create things	.0794	destroy	.0755	substance	0.2155
substance	.0117	concent. itself	.0132	particles	.0697	conserve	0.1595
rest	.0086	touch through	-.0263	can't do	.0482	somewhere	0.0515
stop	-.0226	stop	-.1907	somewhere	.0001	hear	-0.0012
hear	-.0525	create	-0.3071	action	-.0397	wave	-0.1163
gas	-.1516	actdistance	-.3494	conserve	-.1079	concentrate	-0.1572
feel	-.2623	transform things	-0.5247	macro	-.1088	spread	-0.1688
create	-.3835	can't do	-.6799	exist witho. act	-.1487	transfer	-0.1703
concent. itself	-.4096	spread itself	-0.7243	concrete	-.2352	nowhere	-0.1857
see effects	-.4541	multiply itself	-0.7601	immaterial	-.2632	effect	-0.3387
immaterial	-.4815	hear	-0.8168	app./dis.	-.2644	exist witho. act	-0.3554
act contact	-.5197	act contact	-0.8647	transfer	-.3187	see	-0.3641
spread itself	-.5674	app/dis.	-1.0487	*act contact*	-.3844	*act distance*	-0.5116
real	-.6382	act itself	-1.0615	*cause*	-.4188	app./dis.	-0.7826
effect	-.6458	*movement*	-1.0848	concent. itself	-.4359	*gas*	-0.8389
particles	-.6746	*causemov.*	-1.1066	*micro*	-.4478	*place*	-1.0829
transform things	-.7521	feel	-1.1345	*destroy things*	-.4579	*fluid*	-1.1153
wave	-.7761	imaginary	-1.1714	spread	-.4633	*immaterial*	-1.1159
conserve	-.8200	*force*	-1.2215	concentrate	-.5137	*inside*	-1.5615
somewhere	-.9996	*destroy things*	-1.3065	touch	-.5272	*touch through*	-1.5652
touch through	-1.0539	*action*	-1.3684	substance	-.5275	can't do	-1.6904
spread	-1.1225	*wave*	-1.4505	*act itself*	-.7298	*act itself*	-1.7174
transfer	-1.1367	nowhere	-1.5866	create things	-.8017	rest	-1.7836
fluid	-1.2013	immaterial	-1.7447	multiply itself	-.8144	*spread itself*	-1.8546
app./dis.	-1.2545	*effect*	-1.9232	*transform things*	-1.0123	*multiply itself*	-1.86
concentrate	-1.4339	*see effects*	-1.9978	nowhere	-1.1403	concent. itself	-1.8857
actdistance	-1.5326	*cause*	-2.1098	*feel*	-1.3495	imaginary	-2.0921

Table 2. Features in the four-dimensional space obtained for 13-14 year-olds. The features are shown in the decreasing order for each dimension. In italic are the features which broadly guided the distinction made in each dimension (place/localized, etc.) and which are in most cases shared with other groups. Underlined are those which are shared with all the other groups (including the study of all the five groups together) in characterizing these same dimensions.

Table with the coordinates of features in the four-dimensional space obtained for the young working adults group.

features dim 1	place /localized	features dim 2	static /dynamic	features dim 3	motion /cause	Features dim 4	action/ imm. fluid
can't do	2.4182	*concrete*	2.2710	somewhere	1.3217	*movement*	1.6986
inside	2.2248	*solid*	2.2214	*place*	1.1732	*cause movem.*	1.5994
exist witho. act	2.1539	*substance*	2.1601	conserve	1.1029	hear	1.4779
concentr. itself	2.0407	*touch*	2.0895	touch through	1.0463	place	1.0243
rest	1.9570	*see*	1.7360	macro	1.0183	inside	0.9368
imaginary	1.8013	*micro*	1.6821	*hear*	0.9458	*create*	0.8851
place	1.7776	*macro*	1.6258	nowhere	0.8938	wave	0.8829
act itself	1.7475	*particles*	1.4056	*see*	0.8328	*micro*	0.829
gas	1.5194	*real*	1.3458	rest	0.7605	*force*	0.7786
spread itself	1.1529	transform	1.1943	spread	0.7314	see	0.766
multiply itself	1.0909	destroy	1.1082	immaterial	0.6895	*action*	0.6708
touch through	.8967	concentr. itself	.9558	*inside*	0.6649	*solid*	0.6085
fluid	.7070	touch through	.9106	transfer	0.6520	exist witho. act	0.5467
immaterial	.5639	exist witho. act	.8896	app. dis.	0.5800	*create things*	0.5443
particles	.4995	*somewhere*	.8284	act distance	0.5022	can't do	0.5079
micro	.3163	gas	.6614	*stop*	0.4937	*stop*	0.4642
hear	.0749	create things	.6611	fluid	0.4045	*touch*	0.3804
act distance	.0499	conserve	.6199	concentrate	0.3877	transform	0.3667
substance	.0030	spread	.4854	*create*	0.3719	*particles*	0.2804
wave	-.0431	*rest*	.3927	*wave*	0.2472	*macro*	0.1459
somewhere	-.0997	concentrate	.3391	*effect*	0.1279	*concrete*	0.1066
see	-.1117	*place*	.3172	gas	0.0944	destroy	0.0947
movement	-.1351	transform things	.2893	cause movem.	0.0631	imaginary	0.058
app. /dis.	-.2627	can't do	.1412	exist witho. act	0.0378	nowhere	-0.0006
concrete	-.2788	act contact	.1346	destroy	0.0277	*immaterial*	-0.0359
macro	-.3025	inside	-.1670	concrete	0.0120	act contact	-0.0939
solid	-.3086	*cause movem.*	-.2022	*cause*	-0.0097	substance	-0.1744
effect	-.3144	transfer	-.2942	solid	-0.0111	see effects	-0.1759
cause	-.4244	multiply itself	-.3979	touch	-0.0121	*act distance*	-0.1821
nowhere	-0.4746	create	-.4099	real	-0.1032	*act itself*	-0.1871
see effects	-.5203	feel	-0.4273	concentr. itself	-0.1653	destroy things	-0.1923
feel	-.6064	spread itself	-.6632	imaginary	-0.1908	*fluid*	-0.403
touch	-.6457	hear	-0.9212	force	-0.2192	app. /dis.	-0.4408
action	-.7823	act itself	-.9772	*act contact*	-0.4071	*rest*	-0.4512
conserve	-.8585	*destroy things*	-.9869	action	-0.4204	effect	-0.5713
real	-.8845	*force*	-1.0695	substance	-0.4655	transfer	-0.5847
concentrate	-.8892	nowhere	-1.2586	*destroy things*	-0.6930	transform things	-0.5904
transform things	-.9432	*movement*	-1.2704	*see effects*	-0.7081	somewhere	-0.6602
spread	-1.0171	stop	-1.2751	can't do	-0.7537	cause	-0.678
stop	-1.1180	imaginary	-1.3513	*feel*	-0.7922	concentr. itself	-0.6892
create things	-1.1571	app./dis.	-1.3946	spread itself	-0.8961	conserve	-0.7418
transform	-1.1900	*see effects*	-1.5823	*micro*	-0.9329	*multiply itself*	-0.7445
transfer	-1.2285	act distance	-1.6339	movement	-0.9379	real	-0.9168
destroy	-1.2449	*action*	-1.6342	transform	-0.9497	*touch through*	-0.9426
cause movem.	-1.2946	*cause*	-1.6369	create things	-1.0712	spread	-1.0319
destroy things	-1.3683	fluid	-1.6519	*transform things*	-1.1374	*spread itself*	-1.132
create	-1.4222	*effect*	-1.7333	*act itself*	-1.1887	*gas*	-1.2193
force	-1.4705	*wave*	-1.7466	*particles*	-1.4207	concentrate	-1.3175
act contact	-1.5986	immaterial	-1.7806	multiply itself	-1.6974	feel	-1.4963

Table 3. Features in the four-dimensional space obtained for young working adults. The features are shown in the decreasing order for each dimension. In italic are the features which broadly guided the distinction made in each dimension (place/localized, etc.) and which are in most cases shared with other groups. Underlined are those which are shared with all the other groups (including the study of all the five groups together) in characterizing these same dimensions.

Table with the coordinate of features in the four-dimensional space obtained for the 16-18 year-old group.

features dim 1	place localized	features dim 2	static dynamic	features dim 3	motion cause	dim 4 features	action imm. fluid
can't do	2.5177	solid	2.2481	hear	1.6959	nowhere	1.646
vacuum	2.4163	substance	2.0842	feel	1.1160	inside	1.278
place	2.1813	material	2.0397	app. dis.	0.9004	transfer things	1.2227
act itself	2.0861	exist witho. act	2.0173	cause	0.8438	movement	1.165
imaginary	2.0567	concrete	1.8503	real	0.8236	cause movem.	1.1336
gas	1.9436	touch	1.8454	rest	0.7493	see	1.1201
inside	1.9081	macro	1.7139	act distance	0.6870	place	1.0165
field	1.7991	destroy	1.5407	localized	0.6499	force	0.9243
fluid	1.7616	see	1.4051	touch through	0.6400	stop	0.8438
rest	1.7568	particles	1.3267	effect	0.5762	feel	0.8348
immaterial	1.5813	localized	1.3000	macro	0.5554	vacuum	0.8188
exist witho. act	1.2771	rest	1.2074	spread itself	0.4363	cause	0.6873
concentr. itself	1.0865	place	1.1749	conserve	0.4191	destroy	0.5227
nowhere	1.0835	real	0.9993	create	0.4053	act contact	0.4564
spread itself	1.0799	conserve	0.9713	stop	0.3832	solid	0.428
actdistance	1.0179	gas	0.9197	inside	0.3356	material	0.4138
multiply itself	0.6649	concentr. itself	0.8810	immaterial	0.2710	exist witho. act	0.3513
wave	0.6034	vacuum	0.6578	spread	0.2681	imaginary	0.3422
see effects	0.5384	inside	0.6561	place	0.1956	can't do	0.3394
hear	0.1686	micro	0.6510	gas	0.1413	hear	0.3317
effect	0.1350	transform	0.5792	vacuum	0.1258	action	0.3309
movement	-0.1017	spread	0.5471	see	0.1089	macro	0.2902
app./dis.	-0.1377	create things	0.1672	exist witho. act	0.0720	touch	0.2695
energy	-0.2498	concentrate	0.0983	transfer	0.0570	transform	0.2277
action	-0.2559	can't do	0.0363	act itself	-0.0139	create	0.1713
force	-0.3943	act itself	-0.0288	wave	-0.0150	substance	0.153
micro	-0.4868	feel	-0.0692	action	-0.0217	field	0.1171
cause movem.	-0.4935	touch through	-0.0815	concrete	-0.0328	concrete	0.0961
particles	-0.5155	multiply itself	-0.1798	concentr. itself	-0.0394	see effects	-0.0324
destroy things	-0.5845	field	-0.2104	solid	-0.0914	rest	-0.1861
transform things	-0.7051	spread itself	-0.3787	fluid	-0.1239	effect	-0.2232
touch through	-0.7481	transfer	-0.3986	multiply itself	-0.1286	real	-0.2442
transfer things	-0.7748	transform things	-0.6104	touch	-0.1484	immaterial	-0.2487
solid	-0.8164	create	-0.6341	see effects	-0.1516	act itself	-0.2923
cause	-0.8592	hear	-0.8215	concentrate	-0.1819	transfer	-0.3952
macro	-0.8793	transfer things	-0.9473	can't do	-0.1864	gas	-0.4627
localized	-0.9011	imaginary	-0.9495	material	-0.1927	micro	-0.4781
substance	-0.9333	act distance	-0.9902	transfer things	-0.2695	energy	-0.4851
real	-0.9721	destroy things	-0.9939	transform	-0.2999	app.'dis.	-0.5064
feel	-1.0362	act contact	-0.9986	force	-0.3335	conserve	-0.5423

features dim 1	place localised	features dim 2	static /dynamic	features dim 3	motion cause	dim 4 features	action/ imm. fluid
material	-1.0393	fluid	-1.0148	destroy	-0.3372	*touch through*	-0.6624
concentrate	-1.0469	*cause*	-1.1173	*energy*	-0.3744	*spread*	-0.6744
stop	-1.0764	stop	-1.1458	movement	-0.3992	localized	-0.6777
destroy	-1.0779	*cause movem.*	-1.2688	substance	-0.4203	*fluid*	-0.682
see	-1.1278	app./dis.	-1.2994	*act contact*	-0.4655	create things	-0.7376
touch	-1.1939	nowhere	-1.3665	*destroy things*	-0.5637	*act distance*	-0.7809
concrete	-1.2027	immaterial	-1.4173	imaginary	-0.5819	transform things	-0.9238
create things	-1.2426	*wave*	-1.5211	nowhere	-0.7113	destroy things	-0.9433
conserve	-1.2445	*force*	-1.6039	create things	-0.7646	concentrate	-0.9693
create	-1.4096	*energy*	-1.6409	cause movem.	-0.7997	wave	-1.0566
spread	-1.4733	*effect*	-1.7048	*transform things*	-0.8007	particles	-1.1157
act contact	-1.4945	*movement*	-1.7448	field	-1.0675	*spread itself*	-1.254
transfer	-1.5065	*action*	-1.8186	*particles*	-1.1250	concentr. itself	-1.3936
transform	-1.6830	*see effects*	-1.9617	*micro*	-1.8151	*multiply itself*	-1.564

Table 4. Features in the four-dimensional space obtained for 16-18 year-olds. The features are shown in the decreasing order for each dimension. In italic are the features which broadly guided the distinction made in each dimension (place/localized, etc.) and which are in most cases shared with other groups. Underlined are those which are shared with all the other groups (including the study of all the five groups together) in characterizing these same dimensions.

Table with the coordinates of features in the four-dimensional space obtained for the undergraduate physicists group.

features dim 1	place /localized	features dim 2	static /dynamic	features dim 3	motion cause	features dim 4	discrete/ * continuous
imaginary	2.7910	*passive*	2.1401	*hear*	1.7651	nowhere	1.8275
actitself	2.1636	immutable	1.9217	*movement*	1.4842	*discrete*	1.6621
vacuum	2.1340	*material*	1.8970	*place*	1.4573	*micro*	1.6299
inside	2.1190	*micro*	1.8425	nowhere	1.2613	*particle*	1.6187
immaterial	1.9860	*rest*	1.8055	destroy	1.2167	act itself	1.6147
exist witho. act	1.8786	*solid*	1.8039	*see*	1.1435	wave	1.4573
everywhere	1.7614	*concrete*	1.7883	*stop*	1.1333	*destroy things*	1.1599
relation	1.6835	*substance*	1.6678	*create*	1.1043	imaginary	0.8644
nowhere	1.4290	gas	1.5724	act control	0.9176	*create things*	0.8503
field	1.3830	*exist witho. act*	1.5397	*inside*	0.9022	*destroy*	0.8444
place	1.3500	*touch*	1.5009	continuum	0.8849	*create*	0.5575
continuum	1.2563	invariant	1.4997	everywhere	0.8730	app. dis.	0.41
transfer	1.1763	*place*	1.4918	*effect*	0.8600	transform things	0.3609
create things	1.0800	*particle*	1.4840	*wave*	0.7291	*movement*	0.3444
immutable	.9610	discrete	1.4258	transform	0.6940	see effects	0.3236
force	.9240	*real*	1.1672	vacuum	0.6419	material	0.3002
property	.8862	*see*	1.1448	macro	0.5613	exist witho. act	0.2884
state	.8862	*macro*	1.1413	app. dis.	0.5606	energy	0.2708
passive	.8831	quantity	1.0964	immaterial	0.5498	*act contact*	0.2453
rest	.6957	fluid	.9899	transforma.	0.4647	hear	0.2435
act distance	.6308	touch through	.9475	touch through	0.4583	immaterial	0.2232
action	.5482	property	.9036	real	0.4456	concentrate	0.1459
invariant	.4672	conserve	.7058	passive	0.4243	localized	0.109
cause	.3819	everywhere	.6107	multiply itself	0.4180	vacuum	0.1043
see effects	.1120	*localized*	.5733	state	0.3446	see	0.0861
feel	-.0320	vacuum	.3493	rest	0.2252	*concrete*	0.0847
transfer things	-.0725	continuum	.3481	touch	0.1614	field	0.036
cause movem.	-.1797	imaginary	.2608	concrete	0.1267	substance	0.0091
movement	-.2697	inside	.2319	action	0.1227	invariant	0.0036
quantity	-.2847	act control	.2129	gas	-0.0019	distribute itself	0.0031
discrete	-.3020	state	.1268	material	-0.0098	spread	-0.016
touch through	-.3066	stop	.1049	solid	-0.0440	passive	-0.0708
macro	-.3749	act contact	-.1155	*feel*	-0.0549	stop	-0.0709
multiply itself	-.3863	concent. itself	-.1488	exist witho. act	-0.1153	solid	-0.0848
conserve	-.4409	concentrate	-.1670	*act itself*	-0.1274	immutable	-0.0956
effect	-.5038	spread	-.2032	imaginary	-0.1277	relation	-0.1114
transforma.	-.5053	distribute itself	-.2786	fluid	-0.1711	action	-0.1162
hear	-.5180	transfer	-.2914	transfer things	-0.1719	*place*	-0.1227
micro	-.5557	act itself	-.2983	*act contact*	-0.1842	effect	-0.1447
transform things	-.5698	destroy	-.3542	substance	-0.2564	touch	-0.1976
solid	-.5794	act distance	-.4012	transfer	-0.2938	quantity	-0.2017
destroy things	-.5860	feel	-.4265	*energy*	-0.3510	concent. itself	-0.2048
gas	-.5939	nowhere	-.4349	*particle*	-0.3963	everywhere	-0.2552

features dim 1	place /localised	features dim 2	static /dynamic	features dim 3	motion /cause	features dim 4	discrete/ * continuous
real	-.6011	transform	-.5965	*transform things*	-0.4543	conserve	-0.3163
fluid	-.6022	hear	-.7975	localized	-0.4917	cause	-0.3766
substance	-.6277	transforma.	-.8078	concent. itself	-0.6327	*gas*	-0.3877
see	-.6499	relation	-1.3049	*destroy things*	-0.6648	property	-0.4657
concrete	-.6840	create things	-1.3608	spread	-0.6989	transfer	-0.4731
material	-.7184	*cause movem.*	-1.3829	*micro*	-0.7067	cause mov.	-0.5049
app. /dis.	-.7490	immaterial	-1.4046	distribute itself	-0.7156	*act distance*	-0.5215
transform	-.7553	*wave*	-1.4055	relation	-0.7431	*multiply itself*	-0.5346
wave	-.7756	*cause*	-1.4361	create things	-0.7516	*fluid*	-0.5643
touch	-.8176	*force*	-1.4401	field	-0.7802	*rest*	-0.5712
act control	-1.0176	create	-1.5251	immutable	-0.8039	act control	-0.6053
create	-1.0375	*energy*	-1.5575	quantity	-0.8073	*inside*	-0.6117
concent. itself	-1.0557	field	-1.5753	concentrate	-0.8154	real	-0.6176
distribute itself	-1.1019	*movement*	-1.6450	invariant	-0.8545	transform	-0.6807
particle	-1.1265	multiply itself	-1.6642	force	-0.8850	transfer things	-0.6926
energy	-1.1300	transfer things	-1.7814	discrete	-0.8991	transforma.	-0.7373
concentrate	-1.2075	app. /dis.	-1.8185	cause move.	-0.9733	macro	-0.766
spread	-1.2994	*destroy things*	-1.8288	*see effects*	-1.0045	force	-0.8848
stop	-1.3054	transform things	-1.8338	conserve	-1.1042	*continuum*	-0.9837
destroy	-1.3574	*effect*	-1.8684	*cause*	-1.4822	*touch through*	-0.9987
localized	-1.6448	*seeffects*	-1.9485	property	-1.6358	feel	-1.2026
act contact	-1.8899	*action*	-2.1934	act distance	-1.7206	state	-1.4899

Table 5. Features in the four-dimensional space obtained for undergraduate physicists. The features are shown in the decreasing order for each dimension. In italic are the features which broadly guided the distinction made in each dimension (place/localized, etc.) and which are in most cases shared with other groups. Underlined are those which are shared with all the other groups (including the study of all the five groups together) in characterizing these same dimensions.

** Discrete/continuous replacing action/immaterial fluid in this group*

Table with the coordinates of features in the four-dimensional space obtained for all groups (INDSCAL) using all entities.

all entities features	dim 1 place /localized	all entities features	dim 2 static /dynamic	all entities features	dim 3 motion /cause	all entities features	dim 4 action imm. fluid
imaginary	2.1840	*rest*	1.5612	*place*	1.9662	*create things*	1.8187
nowhere	1.8457	*solid*	1.5529	*hear*	1.8031	*destroy*	1.0536
act itself	1.7936	*concrete*	1.4908	*see*	1.6100	*movement*	0.9886
inside	1.4341	*touch*	1.2794	*inside*	1.5603	*force*	0.9803
immaterial	1.4011	gas	1.1536	*create*	.8929	*touch*	0.9243
place	.9030	*place*	1.0652	*movement*	.7359	*concrete*	0.87
movement	.6875	*see*	1.0374	*stop*	.7052	*action*	0.8669
action	.6178	*real*	0.9748	rest	.6485	*solid*	0.8592
force	.5530	inside	0.9085	destroy	.5545	*stop*	0.6523
rest	.2717	destroy	0.5836	solid	.4480	real	0.6346
create things	.2154	*somewhere*	0.5443	concrete	.4007	*destroy things*	0.629
gas	.0989	act itself	0.4358	imaginary	.2506	nowhere	0.6204
feel	.0549	spread	0.2159	touch	.2419	*create*	0.6094
destroy things	.0516	create things	0.1390	fluid	.1660	feel	0.5931
act distance	-.0686	imaginary	0.1259	somewhere	.1326	*act contact*	0.5396
fluid	-.0787	feel	0.0886	action	.0540	transform things	0.5384
transform things	-.2357	fluid	-0.0094	force	-.0530	see	0.4298
hear	-.2440	nowhere	-0.2041	immaterial	-.2868	*spread*	-0.028
app. /dis.	-.2982	transform things	-0.4316	nowhere	-.4545	hear	-0.4957
see	-.6463	act distance	-0.7282	create things	-.5004	somewhere	-0.6538
stop	-.7204	immaterial	-0.8588	act distance	-.5034	*place*	-0.7873
solid	-.8523	act contact	-0.9113	spread	-.6031	*inside*	-0.797
real	-.8601	create	-1.0675	app. /dis.	-.6414	*imaginary*	-0.9232
concrete	-.8678	hear	-1.1103	real	-.8772	*act itself*	-0.9716
create	-.8760	app. /dis.	-1.1133	gas	-.9317	app. /dis.	-1.225
act contact	-1.0325	*destroy things*	-1.1883	*act contact*	-.9857	*rest*	-1.2863
touch	-1.0978	stop	-1.1896	*act itself*	-1.0601	*immaterial*	-1.3962
destroy	-1.1661	*movement*	-1.4152	*destroy things*	-1.4070	*gas*	-1.4079
spread	-1.5214	*action*	-1.4633	*transform things*	-1.8793	*act distance*	-1.7104
somewhere	-1.5466	*force*	-1.4660	*feel*	-1.9867	*fluid*	-1.9256

Table 6. Features in the four-dimensional space obtained for all groups with all entities. The features are shown in the decreasing order for each dimension. In italic are the features which broadly guided the distinction made in each dimension (place/localized, etc.) and which are in most cases shared with individual groups. Underlined are those which are shared with all the individual groups in characterizing these same dimensions.

Table with the coordinates of features in the four-dimensional space obtainedfor all groups (INDSCAL) using only common entities.

common entities features	dim 1 place /localized	common entities features	dim 2 static /dynamic	common entities features	dim 3 motion /cause	common entities features	dim 4 action/ imm. fluid
imaginary	2.1678	*rest*	1.7169	*place*	1.7884	*create things*	1.5717
inside	1.9590	*solid*	1.3982	*hear*	1.6487	*touch*	1.4871
nowhere	1.8812	*concrete*	1.3918	*see*	1.6024	*solid*	1.4173
act itself	1.7872	*touch*	1.2744	*inside*	1.4917	*concrete*	1.3423
place	1.3513	*see*	1.2705	*create*	1.1323	*destroy*	1.2082
immaterial	1.2487	gas	1.1398	*stop*	1.0411	feel	0.9576
rest	0.6797	*real*	1.0998	*movement*	1.0133	transform things	0.7395
movement	0.2461	*somewhere*	1.0877	destroy	0.6791	real	0.6756
gas	0.2445	*place*	0.9718	solid	0.6677	*force*	0.6069
create things	0.1595	spread	0.5701	concrete	0.6289	*destroy things*	0.6032
see	-0.0205	inside	0.5673	touch	0.3481	*act contact*	0.5362
fluid	-0.0379	destroy	0.5636	force	0.3476	spread	0.431
transform things	-0.1095	fluid	0.4424	rest	0.2503	*action*	0.4101
destroy things	-0.1597	act itself	-0.0029	action	0.2084	see	0.4091
solid	-0.1683	feel	-0.1900	somewhere	0.0937	nowhere	0.3667
action	-0.2086	act distance	-0.2726	imaginary	-0.1038	*movement*	0.3106
concrete	-0.2613	imaginary	-0.3688	nowhere	-0.1730	*stop*	0.0675
feel	-0.2676	create things	-0.4957	immaterial	-0.5343	create	-0.0751
force	-0.3286	app./dis.	-0.6534	app. /dis.	-0.6028	somewhere	-0.3831
touch	-0.4244	nowhere	-0.7278	act distance	-0.6508	*inside*	-0.7208
hear	-0.5403	act contact	-0.7464	*act contact*	-0.6739	*place*	-0.7778
real	-0.5786	hear	-0.7763	fluid	-0.7129	*gas*	-0.8516
act distance	-0.7070	transform things	-0.7915	create things	-0.7237	*act itself*	-0.8754
app. /dis.	-0.8792	immaterial	-0.8159	real	-0.8571	*imaginary*	-0.8815
create	-1.0543	stop	-0.9053	spread	-0.9242	*rest*	-0.9798
stop	-1.0687	create	-0.9200	*destroy things*	-1.0503	hear	-1.1316
destroy	-1.1419	*destroy things*	-1.2405	*act itself*	-1.2582	app. /dis.	-1.3777
act contact	-1.1922	*force*	-1.4704	*gas*	-1.3688	*immaterial*	-1.5423
spread	-1.2638	*action*	-1.5303	*transform things*	-1.5524	*act distance*	-1.7075
somewhere	-1.3124	*movement*	-1.5864	*feel*	-1.7552	*fluid*	-1.8365

Table 7. Features in the four-dimensional space obtained for all groups with only common entities. The features are shown in the decreasing order for each dimension. In italic are the features which broadly guided the distinction made in each dimension (place/localized, etc.) and which are in most cases shared with the individual groups. Underlined are those which are shared with all the individual groups in characterizing these same dimensions.

Tables with the coordinates of entities in the four-dimensional spaces obtained:

Table 1. Entities in space for 8-10 year-olds.

entities	static/dynamic	place/localised	motion/cause	action/ imm. fluid
light	0.53507	-1.1411	0.07298	-0.31672
sound	-0.70102	-0.30504	0.04276	1.1920
movement	-1.4946	0.20963	0.25610	2.0460
force	-1.6942	-0.06808	-0.32749	1.9338
mass	2.3018	-0.43568	-0.42180	2.6781
time	-0.22921	0.21113	-0.41385	-1.0699
impulse	-1.3701	0.23834	0.01595	1.9325
heat	-0.31647	-0.80482	-1.1189	0.20068
energy	-0.91367	-0.41451	-0.80374	1.4577
space	2.1042	0.46394	0.16234	-0.38250

Table 2. Entities in space for 13-14 year-olds.

entities	static/dynamic	place/localised	motion/cause	action/ imm. fluid
mass	2.4257	-0.27139	-0.25141	1.1355
movement	-1.0129	-0.16253	0.32472	1.9678
force	-1.1382	-0.55429	-0.25372	1.8034
heat	-0.93658	-0.92875	-0.42977	-0.08919
light	0.06916	-1.0017	0.04022	-0.37778
impulse	-1.0616	-0.06232	-0.16705	1.5967
energy	-0.71534	-0.66699	-0.10727	0.59242
sound	-1.0830	-0.70119	0.37571	0.29727
time	-0.93521	0.43674	-0.20752	-0.54385
space	0.77523	0.01635	0.23502	-0.40537

Table 3. Entities in space for young working adults.

entities	static/dynamic	place/localised	motion/cause	action/ imm. fluid
mass	1.7286	-0.97065	-0.09072	0.12917
movement	-1.3920	-1.3583	0.47604	-0.02378
force	-0.91364	-2.0008	-0.33654	0.25542
heat	-0.56846	-0.73581	-1.0012	0.38908
light	-0.23431	-0.55090	-0.53098	-0.17642
impulse	-1.2471	-1.5764	0.17805	0.52804
gravity	-1.1757	-0.03857	-0.12849	0.44323
sound	-1.4068	-0.54351	-0.10236	-0.13708
matter	1.6095	-1.1943	0.20382	0.21086
space	0.21060	0.73990	0.15731	-0.44488
energy	-0.35491	-1.4825	-0.20283	0.37537
time	-0.60989	0.34646	0.00523	0.62980
electricity	-0.56365	-1.7593	-0.33738	0.17084
weight	0.92783	-1.2415	-0.44585	-0.04848
temperature	-0.46009	0.04978	-0.60015	0.63504
atom	0.95608	-0.27308	0.04834	0.70932

Table 4. Entities in space for 16-18 year-olds.

entities	static/dynamic	place/localised	motion/cause	action/ imm. fluid
matter	2.27349	-2.74364	0.08311	0.05989
energy	-1.69614	-0.76159	-0.11873	-0.36139
heat	-1.23938	-0.33454	0.31492	-0.85309
sound	-1.57208	-0.18815	0.75228	-0.43575
light	-0.87533	-0.23401	0.40829	-0.41335
gravity	-0.81279	1.37272	0.12297	0.04181
force	-1.76345	-1.62466	-0.06229	0.21448
mass	2.25645	-1.93282	0.16106	-0.00429
time	-0.82984	1.16184	0.07189	0.19683
space	0.55125	0.97808	0.13234	0.27095
atom	0.65868	-0.85829	-0.50300	-0.54930
atmosphere	0.05836	1.28967	0.11586	0.07186
movement	-1.30830	-1.46764	0.27328	0.52630
weight	0.82592	-1.40347	0.22009	0.00763
temperature	-0.87424	-0.39996	0.21965	-0.47763
impulse	-1.58232	-0.97480	0.14103	0.58418
vacuum	-0.00607	1.16443	0.16744	0.03146
microwave	-1.06720	-0.28999	-0.22039	-0.33685
electricity	-1.47228	-1.05318	0.02727	-0.27639
radioactivity	-1.19122	-0.21329	-0.12365	-0.68614
solar radiation	-1.10483	0.30671	0.19921	-0.41239
magnetism	-1.17123	-0.14983	-0.14925	0.00484

Table 5. Entities in space for undergraduate physicists.

entities	static/dynamic	place/localised	motion/cause	discrete/ continuous
matter	2.2510	-1.7677	-0.37710	-0.24310
energy	-1.8368	-0.26134	-0.72755	-0.17863
time	-0.23122	1.3258	0.15831	0.10884
space	0.87169	0.95418	0.46762	-0.25594
force	-2.3010	-0.27982	-0.68278	-0.32564
action	-1.9526	-0.40988	-0.26760	-0.20370
heat	-1.3755	-0.82732	-0.63983	-0.35493
photon	-0.81915	-0.96825	-0.40779	0.65521
wave	-1.5684	-0.70561	0.23346	0.03645
spin	-0.06067	0.40460	-0.42837	0.21112
gravity	-1.1330	0.93264	-0.78264	-0.44778
electricity	-1.5401	-0.73812	-0.71302	-0.16996
mass	1.5246	-1.1157	-0.65667	-0.25744
charge	-0.12615	-0.33107	-1.3746	0.18366
movement	-1.3525	-0.48440	0.41595	-0.23451
field	-1.6201	0.56691	-0.57866	-0.17315
sound	-1.6054	-1.0604	0.47403	0.09006
light	-0.83234	-0.82559	-0.16612	0.50919
quark	0.30883	-0.36777	-0.58071	0.58775
neutrino	0.03597	-0.48603	-0.45666	0.62489
magnetism	-1.3850	0.20594	-0.84842	-0.09411
gamma rays	-1.1578	-0.83097	-0.43028	0.50398
microwave	-1.3792	-0.85975	-0.29186	0.47073

Table 6. All entities in common space.

entities	static/dynamic	place/localised	motion/cause	action/ imm. fluid
1.light 8-10	0.21823	-0.74831	-0.36509	-0.29179
2.sound 8-10	-1.0072	-1.0067	0.05349	0.34118
3.movement 8-10	-1.4367	-1.0100	0.23453	1.17020
4.force 8-10	-1.5227	-0.85311	-0.58377	1.45310
5.mass 8-10	1.6769	-2.4685	-0.29225	1.55080
6.time 8-10	0.11312	0.57851	-0.58524	-0.47666
7.impulse 8-10	-1.3087	-0.81572	-0.08170	1.33550
8.heat 8-10	-0.36148	-0.76056	-1.6009	-0.21536
9.energy 8-10	-0.99463	-0.78936	-1.1447	0.90946
10.space 8-10	1.69900	-0.33994	1.0721	-0.54552
11.mass 13-14	1.4267	-2.1437	-0.32082	1.26870
12.movement 13-14	-1.3882	-0.51948	-0.54061	1.22270
13.force 13-14	-1.2463	-0.64777	-1.3999	1.17050
14.heat 13-14	-0.39651	-0.14350	-1.9118	-0.26965
15.light 13-14	0.31302	-0.60436	-0.46485	-0.47671
16.impulse 13-14	-1.1064	-0.40947	-1.1618	1.08250
17.energy 13-14	-0.47697	-0.29349	-1.2435	0.24224
18.sound 13-14	-0.88472	-0.32687	-0.43014	-0.23437
19.time 13-14	0.09594	0.83648	-0.77941	-0.19332
20.space 13-14	0.92800	-0.23310	0.35766	-0.17684
21.mass workers	1.09360	-1.6644	-0.45740	1.31360
22.movem. workers	-1.69130	-0.26099	-0.27854	0.54273
23.force workers	-1.23860	-0.67965	-1.4402	1.08000
24.heat workers	-0.40178	-0.39633	-1.8318	0.06968
25.light workers	-0.13868	-0.64741	-0.60362	-0.20084
26.impulse workers	-1.59880	-0.17928	-0.98338	1.21930
27.gravity workers	-0.58639	0.77636	-0.87708	-0.09004
28.sound workers	-1.15170	-0.36318	-0.01128	-0.47978
29.matter workers	0.92503	-1.5201	-0.01814	1.28540
30.space workers	0.72521	0.33735	0.66819	-0.57943
31.energy workers	-0.86461	-0.62121	-1.0234	0.87625
32.time workers	-0.21257	0.75486	-0.74023	0.01393
33.electric. workers	-0.88814	-0.89143	-1.0928	0.79476
34.weight workers	0.51661	-1.2367	-0.81158	1.09720
35.temper. workers	0.026650	0.13551	-1.1989	-0.03681
36.atom workers	0.23133	-0.66854	-0.45452	0.68001
37.matter 16-18	1.61170	-2.3809	-0.33326	1.68870
38.energy 16-18	-1.40510	0.10711	-1.2099	0.38056
39.heat 16-18	-0.74959	-0.23221	-1.7469	-0.16705
40.sound 16-18	-1.39610	-0.46770	-0.02807	-0.52269
41.light 16-18	-0.33203	-0.36124	-0.27280	-0.32869
42.gravity 16-18	-0.14060	1.0334	-0.66839	-0.66081
43.force 16-18	-1.61300	-0.69150	-1.1537	1.19700
44.mass 16-18	1.72650	-1.8793	-0.13193	1.11270
45.time 16-18	-0.19027	1.3226	-0.62946	-0.48964
46.space 16-18	0.89895	0.41930	0.63677	-0.61579
47.atom 16-18	0.39492	-0.64560	-0.55217	0.69608
48.atmosph. 16-18	0.79387	0.83050	-0.16340	-0.99283
49.movement 16-18	-1.12160	-0.55546	-0.18234	1.05080
50.weight 16-18	0.73615	-1.1468	-0.81094	0.85633
51.temperat. 16-18	-0.28743	0.12018	-1.5074	-0.08801
52.impulse 16-18	-1.27130	-0.16992	-0.49240	0.90706
53.vacuum 16-18	0.30355	0.38967	-0.03636	-0.84462
54.microwave16-18	-0.64901	-0.13217	-0.80128	0.26483
55.electricity 16-18	-1.08660	-0.75376	-0.83870	0.53045
56.radioactiv.16-18	-0.86397	-0.20955	-1.2981	0.05427
57.solar radia.16-18	-0.35962	0.41606	-1.1509	-0.50974
58.magneti. 16-18	-0.52497	0.08590	-0.53064	0.17738
59.matter physic.	1.78370	-2.4297	-0.14268	0.16674
60.energy physic.	-1.18210	-0.28508	-1.0612	0.14146
61.time physicists	-0.21222	1.3841	-0.66017	-0.32924
62.space physicists	0.96446	0.35230	0.82782	-0.46986
63.force physicists	-1.79760	-0.25308	-1.3506	0.53849
64.action physic.	-1.38500	-0.40799	-0.76851	0.79591
65.heat physicists	-0.61434	-0.89787	-1.5415	0.08397
66.photon physic.	-0.48356	-0.85185	-0.63304	0.21322
67.wave physicists	-0.89554	-0.67610	-0.29323	0.27883
68.spin physicists	-0.39701	0.45958	-0.09997	-0.31168
69.gravity physic.	-0.55173	0.58076	-0.89290	-0.41704
70.electricity phys.	-0.84158	-0.81277	-1.1381	0.16192
71.mass physicists	1.34500	-1.6858	-0.42500	0.08236
72.charge physic.	-0.22447	-0.51592	-0.96128	-0.29865
73.movement phys.	-0.91429	-0.48086	0.19784	0.90340
74.field physicists	-0.70526	0.39294	-0.70384	-0.38860
75.sound physicists	-1.09190	-0.86623	0.15922	0.33923
76.light physicists	-0.07757	-0.85010	-0.27340	0.39921
77.quark physicists	-0.21094	-0.32980	-0.53939	0.26124
78.neutrino phys.	-0.23545	-0.44342	-0.35406	0.24559
79.magnetism phy.	-0.70388	0.05081	-0.63989	-0.1412
80.gamma rays	-0.72401	-0.81279	-0.70296	0.43750
81.microwave phys.	-0.58094	-0.68444	-0.62042	0.37300

Table 7. Common entities in common space.

entities	static/dynamic	place/localised	motion/cause	action/ imm. fluid
light 8-10	0.58207	-0.73637	-0.26947	-0.21679
sound 8-10	-0.62736	-1.4394	0.25909	-0.01421
movement 8-10	-1.1628	-1.4902	0.64918	0.59413
force 8-10	-1.3723	-1.4657	-0.07525	0.97922
mass 8-10	1.8484	-1.7974	-0.13174	2.0805
time 8-10	0.06558	0.56189	-0.58186	-0.44551
heat 8-10	-0.14206	-0.9934	-1.4629	-0.07752
energy 8-10	-0.87933	-1.2644	-0.79221	0.69581
space 8-10	1.8465	0.33699	0.88669	-0.30178
mass 13-14	1.5619	-1.4937	-0.09856	1.8345
movement 13-14	-1.3266	-1.03	-0.12319	0.78364
force 13-14	-1.2315	-1.1568	-1.0199	1.0086
heat 13-14	-0.40482	-0.3433	-1.8738	-0.06475
light 13-14	0.56966	-0.48877	-0.5613	-0.3258
energy 13-14	-0.47111	-0.53401	-1.1549	0.26368
sound 13-14	-0.6953	-0.67535	-0.42248	-0.41839
time 13-14	-0.15657	0.81759	-0.80962	-0.13645
space 13-14	0.95317	0.1568	0.23681	0.01931
mass workers	1.1414	-1.167	-0.20055	1.7956
movement workers	-1.4918	-0.93463	0.01393	0.02927
force workers	-1.2134	-1.1766	-1.06	0.94763
heat workers	-0.4081	-0.63781	-1.7518	0.265
light workers	0.12883	-0.74805	-0.60529	-0.15293
sound workers	-0.8378	-0.7973	-0.0573	-0.83321
space workers	0.7188	0.64975	0.53589	-0.48736
energy workers	-0.82654	-0.96253	-0.72373	0.76757
time workers	-0.47212	0.62448	-0.75143	-0.02866
mass 16-18	1.8277	-1.1457	0.02252	1.7155
energy 16-18	-1.4189	-0.50534	-1.0264	0.12358
heat 16-18	-0.68722	-0.62356	-1.7023	-0.12609
sound 16-18	-0.98545	-1.0265	-0.04979	-0.98092
light 16-18	-0.07502	-0.53269	-0.28453	-0.45637
force 16-18	-1.5523	-1.2661	-0.74999	0.86813
time 16-18	-0.48351	1.2079	-0.70719	-0.52238
space 16-18	0.8473	0.79262	0.47619	-0.48464
movement 16-18	-1.014	-0.98234	0.20747	0.65459
mass physicists	1.6832	-1.198	-0.47982	0.66122
energy physicists	-1.0682	-0.70807	-1.013	-0.02426
heat physicists	-0.43205	-1.066	-1.4267	0.2434
sound physicists	-0.80444	-1.2676	0.32374	-0.05241
light physicists	0.10295	-0.80576	-0.17619	0.40182
force physicists	-1.6583	-1.0511	-1.0189	0.23207
time physicists	-0.52497	1.2898	-0.71289	-0.40545
space physicists	0.94948	0.75602	0.69282	-0.38059
movement physic.	-0.79941	-0.74715	0.48215	0.48013

Figure with the distribution of 'yes' frequencies:

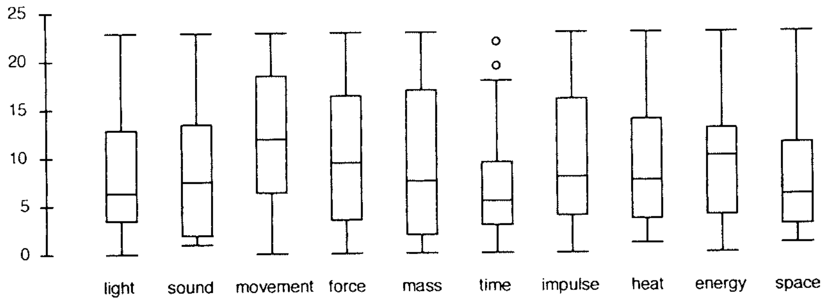


Figure 1. Distribution of frequencies of 'yes' answers for 8-10 year-olds.

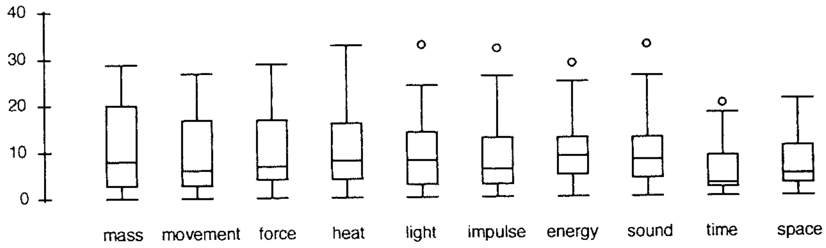


Figure 2. Distribution of frequencies of 'yes' answers for 13-14 year-olds.

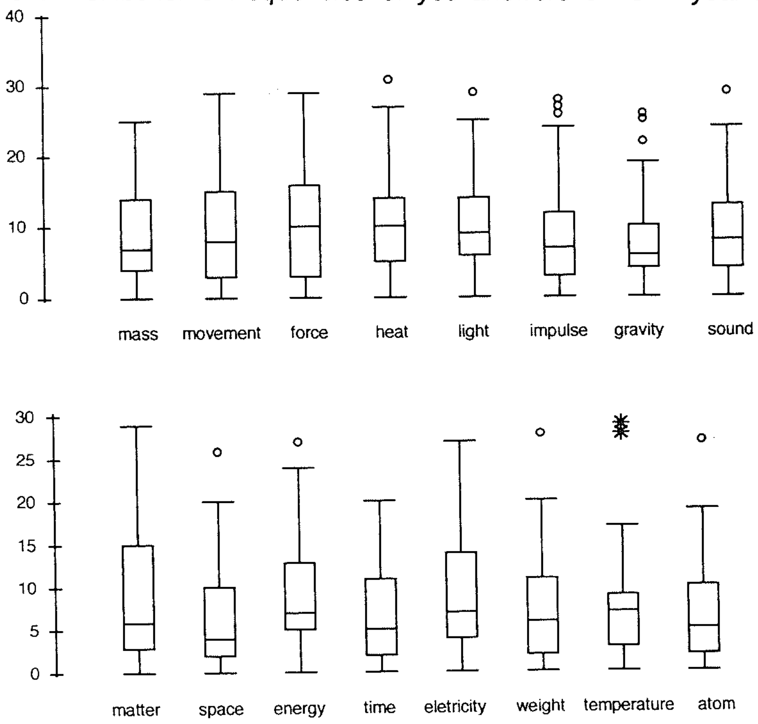


Figure 3. Distribution of frequencies of 'yes' answers for young working adults.

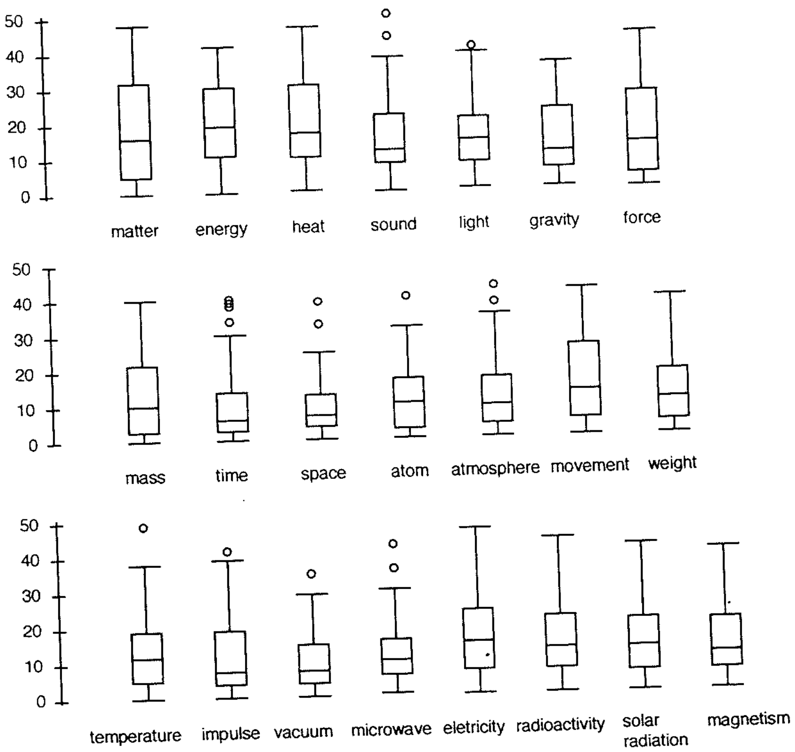


Figure 4. Distribution of frequencies of 'yes' answers for 16-18 year-olds.

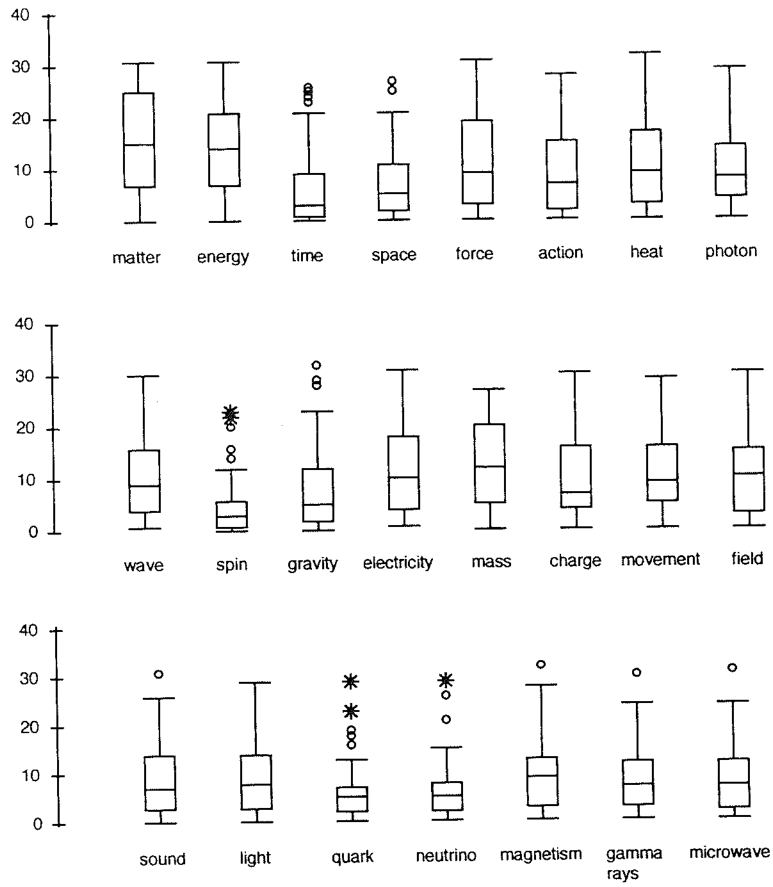


Figure 5. Distribution of frequencies of 'yes' answers for undergraduate physicists.

Tables for the second study:

Tables with raw data:

Tables for 16-18 year-olds:

students	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Luc(f;16;11)	2	1	1	1	4	1	1	1	1	3
2.Luc(f;17;06)	3	5	2	5	5	1	1	1	1	1
3.Lui(m;17;02)	5	5	5	1	4	5	1	1	1	1
4.Mar(f;17;10)	3	3	5	1	1	3	1	1	1	1
5.Mar(m;17;04)	1	4	3	3	5	2	1	1	1	1
6.Lil(f;16;11)	2	2	2	3	3	3	1	1	1	1
7.Mar(m;18;11)	2	1	1	*	5	5	1	1	1	1
8.Luc(f;16;09)	1	3	3	1	3	3	1	1	1	1
9.Luc(f;17;04)	1	5	5	3	5	5	1	1	1	1
10.Pri(f;17;01)	1	2	3	1	5	1	1	1	1	1
11.Mar(m;16;07)	5	4	5	1	1	2	1	1	1	1
12.Rei(m;18;10)	2	3	4	1	5	1	1	1	1	1
13.Luc(f;16;08)	1	2	5	1	5	1	1	1	1	1
14.Reg(m;16;00)	1	5	5	1	5	5	1	1	1	1
15.Lin(f;17;01)	1	1	1	1	1	2	1	1	1	1
16.Reg(f;16;10)	2	4	4	*	5	3	2	2	1	2
17.Ren(f;16;08)	5	4	5	1	4	3	1	1	1	1
18.Luc(f;18;08)	1	1	3	2	5	2	2	1	1	2
19.Pat(f;18;04)	1	3	1	1	4	2	1	3	1	1
20.Pat(f;17;02)	5	5	5	1	5	1	5	1	1	1
21.Pri(f;18;10)	1	5	1	1	5	1	1	1	1	2
22.Mar(m;16;09)	1	4	2	2	4	1	1	1	1	1
23.Jul(f;18;04)	1	3	*	1	4	5	1	1	1	1
24.Ale(m;18;02)	1	5	3	1	1	3	1	1	1	1
25.Ale(m;17;08)	1	2	1	5	5	1	1	1	1	1
26.Aff(m;18;03)	1	5	3	1	1	5	1	1	1	1
27.Ale(f;17;05)	*	*	5	1	1	5	5	1	5	4
28.Car(f;16;09)	5	5	5	1	5	1	1	1	1	1
29.Aud(f;18;03)	1	1	1	1	5	4	1	1	1	1
30.Chr(f;17;09)	5	1	3	1	5	1	1	1	1	1

*Table 1. Location of matter for 16-18 year-olds (range: 1 to 5; *-don't know answer).*

Obs.: All students from 3rd grade secondary school(initials(sex;age:years;months))

Dimensions:

- D1: conserved(1)/not conserved(5)
- D2: in motion(1)/static(5)
- D3: active(1)/passive(5)
- D4: substance(1)/action(5)
- D5: place(1)/localized(5)
- D6: cause(1)/effect(5)
- D7: material(1)/immaterial(5)
- D8: concrete(1)/abstract(5)
- D9: real(1)/imaginary(5)
- D10: object(1)/vacuum(5)

students	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Luc(f;16;11)	5	2	2	2	*	1	3	3	1	3
2.Luc(f;17;06)	5	1	1	4	5	4	5	2	1	4
3.Lui(m;17;02)	1	5	1	5	5	2	5	5	1	5
4.Mar(f;17;10)	1	1	2	4	4	*	*	3	2	4
5.Mar(m;17;04)	4	3	1	5	4	4	4	4	2	2
6.Lil(f;16;11)	3	1	2	5	*	5	4	4	1	2
7.Mar(m;18;11)	5	3	2	4	*	5	5	1	2	3
8.Luc(f;16;09)	1	1	1	5	3	5	3	1	1	3
9.Luc(f;17;04)	5	2	1	4	4	2	4	4	4	4
10.Pri(f;17;01)	1	1	1	5	5	1	5	5	1	4
11.Mar(m;16;07)	1	2	1	5	4	1	5	5	4	3
12.Rei(m;18;10)	2	1	1	3	5	5	4	4	4	2
13.Luc(f;16;08)	3	1	1	5	*	1	5	5	3	5
14.Reg(m;16;00)	1	1	1	2	3	5	5	3	1	3
15.Lin(f;17;01)	1	1	1	5	5	5	5	4	1	2
16.Reg(f;16;10)	4	1	1	5	5	5	5	2	1	4
17.Ren(f;16;08)	5	1	1	5	1	1	4	4	1	4
18.Luc(f;18;08)	2	1	1	4	4	4	3	4	1	3
19.Pat(f;18;04)	5	*	3	4	2	4	4	2	1	2
20.Pat(f;17;02)	1	4	1	5	5	1	5	1	1	5
21.Pri(f;18;10)	1	3	1	2	5	4	5	3	4	3
22.Mar(m;16;09)	4	2	1	5	4	2	5	4	1	4
23.Jul(f;18;04)	3	1	1	3	4	5	5	3	1	3
24.Ale(m;18;02)	1	3	3	5	5	1	5	5	5	5
25.Ale(m;17;08)	5	1	1	5	5	5	1	2	1	3
26.Aff(m;18;03)	5	5	1	5	1	5	5	5	5	5
27.Ale(f;17;05)	1	1	1	5	5	1	5	5	5	4
28.Car(f;16;09)	5	1	1	5	5	5	5	5	2	4
29.Aud(f;18;03)	1	1	1	5	3	1	5	5	5	5
30.Chr(f;17;09)	2	1	1	5	5	5	3	1	1	5

*Table 2. Location of energy for 16-18 year-olds (range: 1 to 5; *-don't know answer).*

students	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Luc(f;16;11)	5	3	2	5	1	4	5	2	1	3
2.Luc(f;17;06)	5	1	1	1	1	1	5	2	1	5
3.Lui(m;17;02)	5	1	1	5	3	3	5	5	5	5
4.Mar(f;17;10)	*	1	4	*	3	*	5	*	*	5
5.Mar(m;17;04)	3	1	4	3	1	3	3	3	5	3
6.Lil(f;16;11)	5	3	1	*	1	*	5	5	2	3
7.Mar(m;18;11)	5	3	3	5	*	1	5	5	2	5
8.Luc(f;16;09)	5	1	1	3	3	5	3	3	3	3
9.Luc(f;17;04)	5	1	1	3	3	1	5	5	4	5
10.Pri(f;17;01)	5	1	1	5	1	3	5	5	1	1
11.Mar(m;16;07)	4	1	2	2	2	4	4	2	2	2
12.Rei(m;18;10)	1	1	1	5	2	5	4	4	4	2
13.Luc(f;16;08)	5	1	1	3	*	5	5	5	5	5
14.Reg(m;16;00)	*	1	1	3	3	3	3	3	3	3
15.Lin(f;17;01)	5	1	2	5	2	1	5	5	1	5
16.Reg(f;16;10)	5	1	1	5	3	3	5	2	1	4
17.Ren(f;16;08)	*	1	2	4	4	1	5	5	5	5
18.Luc(f;18;08)	3	3	3	3	1	1	3	5	5	5
19.Pat(f;18;04)	1	1	4	3	1	2	2	4	4	4
20.Pat(f;17;02)	3	1	5	5	1	3	5	5	5	5
21.Pri(f;18;10)	1	3	3	3	3	5	5	4	5	3
22.Mar(m;16;09)	5	1	1	5	4	2	5	4	1	4
23.Jul(f;18;04)	5	1	1	3	*	5	5	3	1	3
24.Ale(m;18;02)	5	1	5	3	5	4	5	5	5	5
25.Ale(m;17;08)	5	1	3	3	5	5	5	5	5	5
26.Aff(m;18;03)	*	1	1	5	5	1	5	5	5	5
27.Ale(f;17;05)	5	1	1	5	3	1	5	3	5	5
28.Car(f;16;09)	5	1	1	1	3	1	5	5	3	4
29.Aud(f;18;03)	5	5	3	3	3	3	5	5	5	5
30.Chr(f;17;09)	5	1	1	1	1	1	3	5	1	5

*Table 3. Location of time for 16-18 year-olds (range: 1 to 5; *-don't know answer).*

students	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Luc(f;16;11)	*	5	3	*	4	5	4	5	1	5
2.Luc(f;17;06)	1	5	5	1	1	3	1	1	1	2
3.Lui(m;17;02)	5	4	1	5	5	3	5	5	5	5
4.Mar(f;17;10)	1	4	5	*	1	3	3	1	1	1
5.Mar(m;17;04)	1	5	5	2	1	4	1	2	1	1
6.Lil(f;16;11)	1	5	4	*	1	5	5	5	2	5
7.Mar(m;18;11)	1	2	5	*	*	2	3	3	1	3
8.Luc(f;16;09)	5	3	3	3	3	1	3	3	3	5
9.Luc(f;17;04)	1	4	4	3	1	1	4	2	4	3
10.Pri(f;17;01)	1	5	5	3	5	3	5	1	1	5
11.Mar(m;16;07)	3	3	3	3	1	3	3	3	5	5
12.Rei(m;18;10)	1	4	5	5	1	1	4	4	4	2
13.Luc(f;16;08)	1	5	3	1	5	*	1	5	3	5
14.Reg(m;16;00)	*	5	5	3	1	3	3	3	3	5
15.Lin(f;17;01)	3	1	2	4	1	1	1	1	1	2
16.Reg(f;16;10)	5	5	1	5	1	3	5	2	2	4
17.Ren(f;16;08)	1	4	5	1	1	3	1	1	1	1
18.Luc(f;18;08)	1	1	5	3	1	1	2	4	5	5
19.Pat(f;18;04)	3	4	2	5	*	*	5	1	5	2
20.Pat(f;17;02)	1	5	5	3	1	1	3	5	1	5
21.Pri(f;18;10)	3	3	3	3	3	5	5	4	4	3
22.Mar(m;16;09)	*	*	1	*	*	*	5	4	1	*
23.Jul(f;18;04)	5	3	3	3	1	3	5	3	1	5
24.Ale(m;18;02)	1	5	5	3	1	2	1	1	1	1
25.Ale(m;17;08)	2	5	5	2	1	*	2	2	2	*
26.Aff(m;18;03)	*	5	5	5	1	1	5	5	5	5
27.Ale(f;17;05)	5	2	3	3	1	3	5	2	5	3
28.Car(f;16;09)	1	2	5	1	5	3	5	3	2	5
29.Aud(f;18;03)	2	5	5	1	1	3	5	5	1	5
30.Chr(f;17;09)	1	3	3	1	1	3	5	1	1	3

*Table 4. Location of space for 16-18 year-olds (range: 1 to 5; *-don't know answer).*

students	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Luc(f;16;11)	3	2	3	*	*	5	5	*	1	5
2.Luc(f;17;06)	2	1	5	1	5	*	1	1	1	4
3.Lui(m;17;02)	1	5	1	5	5	3	5	5	1	5
4.Mar(f;17;10)	4	2	2	3	4	3	*	3	2	4
5.Mar(m;17;04)	4	2	4	4	5	5	4	4	4	3
6.Lil(f;16;11)	2	1	1	5	5	5	5	5	1	3
7.Mar(m;18;11)	5	1	1	5	5	5	5	4	1	2
8.Luc(f;16;09)	1	1	1	5	5	5	3	1	1	5
9.Luc(f;17;04)	2	1	4	3	3	4	5	5	2	4
10.Pri(f;17;01)	1	1	1	5	3	5	5	1	1	4
11.Mar(m;16;07)	2	*	5	4	4	5	5	4	2	2
12.Rei(m;18;10)	2	1	1	3	5	5	4	4	4	2
13.Luc(f;16;08)	5	1	1	3	*	1	5	5	3	5
14.Reg(m;16;00)	1	1	1	1	3	5	1	1	1	3
15.Lin(f;17;01)	5	1	1	5	2	5	4	4	1	4
16.Reg(f;16;10)	1	1	1	5	5	5	5	2	1	4
17.Ren(f;16;08)	2	1	1	5	5	1	4	4	1	4
18.Luc(f;18;08)	3	3	2	4	2	1	2	5	2	4
19.Pat(f;18;04)	1	4	4	1	*	1	*	5	2	5
20.Pat(f;17;02)	2	1	1	5	5	5	5	5	1	5
21.Pri(f;18;10)	5	3	4	4	3	2	5	5	2	4
22.Mar(m;16;09)	*	1	1	5	5	4	5	4	1	4
23.Jul(f;18;04)	3	1	1	3	3	5	5	3	1	2
24.Ale(m;18;02)	5	1	1	5	5	1	5	5	1	5
25.Ale(m;17;08)	1	1	1	4	4	5	1	1	1	4
26.Aff(m;18;03)	5	1	1	5	1	5	1	5	5	5
27.Ale(f;17;05)	5	1	2	1	5	5	5	5	5	1
28.Car(f;16;09)	1	1	1	5	1	5	5	5	1	4
29.Aud(f;18;03)	1	1	1	4	3	1	4	4	1	1
30.Chr(f;17;09)	1	1	1	1	3	1	5	3	1	3

*Table 5. Location of light for 16-18 year-olds (range: 1 to 5; *-don't know answer).*

students	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Luc(f;16;11)	5	1	1	3	4	1	1	5	1	1
2.Luc(f;17;06)	5	2	1	5	5	4	5	2	1	2
3.Lui(m;17;02)	5	5	1	5	3	5	5	5	1	5
4.Mar(f;17;10)	3	1	1	5	4	2	5	3	1	5
5.Mar(m;17;04)	5	2	1	5	4	4	3	2	2	3
6.Lil(f;16;11)	2	3	2	5	3	1	5	5	2	3
7.Mar(m;18;11)	1	3	1	5	5	1	1	3	1	2
8.Luc(f;16;09)	5	3	1	5	5	5	1	1	1	3
9.Luc(f;17;04)	5	2	1	5	4	1	5	4	2	4
10.Pri(f;17;01)	1	1	1	5	5	1	5	5	1	4
11.Mar(m;16;07)	1	2	1	5	4	1	5	5	4	3
12.Rei(m;18;10)	1	1	1	5	5	5	4	4	4	2
13.Luc(f;16;08)	1	4	1	5	5	5	1	5	*	*
14.Reg(m;16;00)	1	*	1	3	3	5	5	5	5	3
15.Lin(f;17;01)	1	1	1	5	5	5	5	4	1	3
16.Reg(f;16;10)	4	*	1	5	5	1	5	2	1	3
17.Ren(f;16;08)	1	1	1	5	4	5	2	4	2	1
18.Luc(f;18;08)	2	5	1	4	4	4	3	2	1	3
19.Pat(f;18;04)	4	1	4	5	3	5	1	5	3	*
20.Pat(f;17;02)	1	2	1	5	5	5	5	5	5	5
21.Pri(f;18;10)	3	1	1	5	5	5	3	3	1	3
22.Mar(m;16;09)	1	*	1	5	5	2	5	5	1	4
23.Jul(f;18;04)	3	1	1	4	3	5	5	3	1	3
24.Ale(m;18;02)	5	1	1	5	5	5	5	5	1	5
25.Ale(m;17;08)	5	5	1	5	5	5	5	2	1	2
26.Aff(m;18;03)	5	5	1	5	5	5	5	5	5	5
27.Ale(f;17;05)	5	3	1	5	2	1	5	1	1	2
28.Car(f;16;09)	5	5	1	5	5	1	5	4	2	3
29.Aud(f;18;03)	5	2	1	1	3	1	5	5	5	5
30.Chr(f;17;09)	5	1	1	5	5	5	5	1	1	3

*Table 6. Location of force for 16-18 year-olds (range: 1 to 5; *-don't know answer).*

students	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Luc(f;16;11)	*	1	2	3	5	5	3	5	2	3
2.Luc(f;17;06)	1	1	1	5	5	5	5	2	1	2
3.Lui(m;17;02)	1	1	5	5	*	1	5	5	1	5
4.Mar(f;17;10)	4	1	1	5	4	4	4	3	1	5
5.Mar(m;17;04)	4	1	2	5	5	1	2	2	1	2
6.Lil(f;16;11)	1	1	1	5	3	5	5	5	2	3
7.Mar(m;18;11)	5	3	1	4	4	5	1	1	1	3
8.Luc(f;16;09)	5	1	1	5	5	5	1	1	1	3
9.Luc(f;17;04)	5	1	1	4	3	4	5	4	2	5
10.Pri(f;17;01)	5	1	1	5	5	1	5	1	1	5
11.Mar(m;16;07)	1	2	2	5	4	5	2	2	2	2
12.Rei(m;18;10)	1	1	1	5	5	5	4	4	4	2
13.Luc(f;16;08)	*	1	1	5	*	5	5	5	*	*
14.Reg(m;16;00)	5	1	1	5	5	5	5	1	5	3
15.Lin(f;17;01)	3	1	1	5	4	5	5	5	1	4
16.Reg(f;16;10)	2	1	1	5	5	2	5	2	1	3
17.Ren(f;16;08)	1	1	1	5	4	5	2	4	2	1
18.Luc(f;18;08)	1	5	1	3	3	3	3	2	1	3
19.Pat(f;18;04)	5	1	2	5	4	2	2	3	4	*
20.Pat(f;17;02)	5	1	1	5	3	5	3	1	5	5
21.Pri(f;18;10)	3	*	1	5	5	2	3	4	2	3
22.Mar(m;16;09)	3	1	1	5	5	4	5	3	1	3
23.Jul(f;18;04)	3	1	1	4	3	5	5	3	1	3
24.Ale(m;18;02)	5	1	1	5	5	5	5	1	1	5
25.Ale(m;17;08)	4	*	3	5	5	1	5	2	1	2
26.Aff(m;18;03)	5	1	1	5	*	5	1	5	5	5
27.Ale(f;17;05)	5	1	1	3	3	5	5	1	5	2
28.Car(f;16;09)	4	1	1	5	3	5	5	2	2	2
29.Aud(f;18;03)	1	1	1	1	3	4	5	5	1	5
30.Chr(f;17;09)	1	1	1	5	5	5	5	1	1	3

*Table 7. Location of movement for 16-18 year-olds (range: 1 to 5; *-don't know answer).*

students	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Luc(f;16;11)	5	5	2	5	3	1	4	5	3	3
2.Luc(f;17;06)	1	1	4	2	5	2	5	1	1	2
3.Lui(m;17;02)	5	5	1	5	5	3	5	5	1	5
4.Mar(f;17;10)	5	1	4	5	4	*	4	*	1	5
5.Mar(m;17;04)	5	3	4	4	3	4	4	4	2	4
6.Lil(f;16;11)	2	1	1	3	5	*	5	5	1	3
7.Mar(m;18;11)	5	2	2	4	*	5	5	4	1	3
8.Luc(f;16;09)	5	1	1	5	5	5	3	1	1	3
9.Luc(f;17;04)	5	2	4	4	3	5	5	5	4	5
10.Pri(f;17;01)	5	*	1	5	5	1	5	5	1	5
11.Mar(m;16;07)	*	1	5	*	5	4	4	2	5	4
12.Rei(m;18;10)	1	1	5	5	5	5	4	4	4	2
13.Luc(f;16;08)	*	*	1	5	*	5	5	5	*	3
14.Reg(m;16;00)	1	1	1	5	5	5	1	1	1	3
15.Lin(f;17;01)	5	1	1	5	4	5	5	4	1	3
16.Reg(f;16;10)	5	1	1	5	5	2	5	2	1	*
17.Ren(f;16;08)	1	1	2	5	5	1	4	4	1	4
18.Luc(f;18;08)	5	3	3	3	5	1	5	5	3	*
19.Pat(f;18;04)	*	5	*	2	1	3	3	2	2	3
20.Pat(f;17;02)	4	1	2	5	5	5	5	1	1	5
21.Pri(f;18;10)	3	5	2	4	5	5	4	5	4	3
22.Mar(m;16;09)	5	1	1	4	5	3	5	5	1	4
23.Jul(f;18;04)	3	1	1	4	3	5	5	3	1	3
24.Ale(m;18;02)	5	1	1	5	5	5	5	5	1	5
25.Ale(m;17;08)	5	1	1	5	5	5	5	3	1	1
26.Aff(m;18;03)	5	1	5	5	1	5	5	5	5	5
27.Ale(f;17;05)	1	1	1	3	4	5	5	2	3	3
28.Car(f;16;09)	3	2	2	5	5	5	5	2	2	5
29.Aud(f;18;03)	1	3	3	1	5	4	5	5	5	5
30.Chr(f;17;09)	1	1	3	1	3	1	5	1	1	3

*Table 8. Location of sound for 16-18 year-olds (range: 1 to 5; *-don't know answer).*

students	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Luc(f;16;11)	5	5	3	1	5	1	4	5	2	3
2.Luc(f;17;06)	5	*	4	2	1	2	5	1	1	2
3.Lui(m;17;02)	5	5	1	5	5	3	5	5	1	5
4.Mar(f;17;10)	4	1	2	4	4	4	4	*	1	5
5.Mar(m;17;04)	2	3	1	4	4	4	4	4	2	2
6.Lil(f;16;11)	4	2	2	3	5	5	5	5	1	3
7.Mar(m;18;11)	1	3	2	4	2	4	5	4	1	3
8.Luc(f;16;09)	1	1	1	5	5	5	3	1	1	3
9.Luc(f;17;04)	5	1	1	4	4	5	5	4	4	5
10.Pri(f;17;01)	1	3	1	1	5	1	5	1	1	1
11.Mar(m;16;07)	1	3	1	2	2	2	2	2	2	3
12.Rei(m;18;10)	1	2	5	3	5	5	4	4	4	2
13.Luc(f;16;08)	2	*	1	5	*	*	5	5	3	3
14.Reg(m;16;00)	1	1	1	1	5	5	1	1	1	3
15.Lin(f;17;01)	1	2	1	5	4	5	4	4	1	3
16.Reg(f;16;10)	1	4	1	5	4	3	5	2	1	4
17.Ren(f;16;08)	1	1	1	5	5	1	4	4	1	4
18.Luc(f;18;08)	5	1	1	3	3	2	1	2	1	3
19.Pat(f;18;04)	1	1	2	5	2	1	4	*	2	2
20.Pat(f;17;02)	5	3	1	3	5	5	5	5	1	5
21.Pri(f;18;10)	5	5	5	3	4	5	5	5	3	3
22.Mar(m;16;09)	1	*	2	3	5	3	5	5	1	4
23.Jul(f;18;04)	2	1	1	2	3	5	5	3	1	3
24.Ale(m;18;02)	1	5	1	5	5	5	5	5	1	5
25.Ale(m;17;08)	5	2	1	5	5	5	4	2	1	1
26.Aff(m;18;03)	5	3	1	5	1	5	1	5	5	5
27.Ale(f;17;05)	1	1	1	1	4	1	2	4	1	4
28.Car(f;16;09)	3	5	1	5	5	5	5	2	2	3
29.Aud(f;18;03)	1	3	3	1	3	4	5	4	1	5
30.Chr(f;17;09)	1	1	1	1	3	1	1	1	1	3

*Table 9. Location of heat for 16-18 year-olds (range: 1 to 5; *-don't know answer).*

students	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Luc(f;16;11)	5	5	4	5	5	5	*	5	2	3
2.Luc(f;17;06)	5	1	1	4	5	5	5	1	1	2
3.Lui(m;17;02)	5	5	1	5	5	3	5	5	1	5
4.Mar(f;17;10)	3	1	2	4	4	*	*	*	1	5
5.Mar(m;17;04)	3	2	1	5	5	4	4	4	4	3
6.Lil(f;16;11)	*	1	1	*	*	5	5	4	1	3
7.Mar(m;18;11)	5	5	1	4	2	3	5	3	2	3
8.Luc(f;16;09)	1	1	1	5	5	5	3	1	1	3
9.Luc(f;17;04)	3	1	1	4	4	4	4	4	4	4
10.Pri(f;17;01)	1	1	1	1	5	1	5	5	1	1
11.Mar(m;16;07)	2	1	1	4	5	5	5	4	4	3
12.Rei(m;18;10)	1	1	1	3	5	5	4	4	4	2
13.Luc(f;16;08)	*	1	1	4	*	5	5	5	*	3
14.Reg(m;16;00)	1	1	1	5	5	5	1	1	1	3
15.Lin(f;17;01)	1	1	1	5	5	5	4	4	1	3
16.Reg(f;16;10)	5	1	1	5	5	1	5	2	1	3
17.Ren(f;16;08)	1	1	1	5	5	1	4	4	1	4
18.Luc(f;18;08)	5	1	2	3	5	2	2	4	1	3
19.Pat(f;18;04)	1	4	3	*	*	4	5	5	*	4
20.Pat(f;17;02)	3	1	1	5	5	5	1	1	5	1
21.Pri(f;18;10)	*	3	4	*	4	2	5	4	5	3
22.Mar(m;16;09)	3	1	1	5	5	2	5	5	1	3
23.Jul(f;18;04)	1	1	1	3	3	5	5	3	1	3
24.Ale(m;18;02)	1	1	1	5	5	5	5	5	1	5
25.Ale(m;17;08)	4	1	1	5	5	5	2	2	1	1
26.Aff(m;18;03)	4	1	1	5	1	5	5	5	5	5
27.Ale(f;17;05)	1	1	1	5	5	1	1	*	5	*
28.Car(f;16;09)	5	1	1	5	5	5	5	2	2	3
29.Aud(f;18;03)	1	1	1	1	3	1	5	5	5	5
30.Chr(f;17;09)	5	1	1	5	5	5	1	3	1	1

*Table 10. Location of electricity for 16-18 year-olds (range: 1 to 5; *-don't know answer).*

entities	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
matter	2.1	3.2	3.2	1.6	3.9	2.6	1.3	1.1	1.1	1.3
energy	2.8	1.8	1.3	4.4	4.1	3.3	4.4	3.5	2.1	3.6
time	4.3	1.5	2.0	3.6	2.5	2.8	4.5	4.1	3.3	4.1
space	2.2	3.9	3.8	2.9	1.9	2.7	3.5	2.9	2.4	3.6
light	2.6	1.5	1.8	3.8	3.9	3.7	4.1	3.7	1.7	3.7
force	3.2	2.4	1.1	4.7	4.3	3.4	4.0	3.7	2.0	3.2
movement	3.2	1.3	1.3	4.6	4.2	4.0	3.9	2.8	2.0	3.3
sound	3.6	1.9	2.2	4.1	4.3	3.8	4.5	3.5	2.0	3.6
heat	2.6	2.5	1.7	3.4	3.9	3.5	3.9	3.4	1.6	3.3
electricity	2.8	1.6	1.3	4.3	4.5	3.8	4.0	3.6	2.3	3.1

Table 11. Means for position of entities for 16-18 year-olds.

Dimensions:
D1: conserved(1)/not conserved(5)
D2: in motion(1)/static(5)
D3: active(1)/passive(5)
D4: substance(1)/action(5)
D5: place(1)/localized(5)
D6: cause(1)/effect(5)
D7: material(1)/immaterial(5)
D8: concrete(1)/abstract(5)
D9: real(1)/imaginary(5)
D10: object(1)/vacuum(5)

Tables for undergraduate physicists:

physicists	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Cel(m;23;05)	4	5	0	-5	0	5	5	5	5	5
2.Iza(f;21;11)	2	1	4	3	0	-3	4	1	4	1
3.Gui(m;22;11)	5	5	0	-5	-4	-5	5	5	5	5
4.Mar(m;22;03)	0	5	5	-4	-2	-4	4	3	0	0
5.Lui(m;23;08)	5	5	0	5	3	5	5	5	-5	5
6.Car(m;25;05)	3	4	0	0	0	-2	0	4	3	-1
7.Fra(m;23;05)	1	1	-3	-4	2	0	5	1	1	5
8.Cri(m;28;01)	4	5	3	-5	-5	-3	5	5	5	5
9.Fab(m;22;05)	1	4	0	0	0	-2	2	3	3	-4
10.Sil(f;23;10)	5	5	0	0	0	0	0	5	0	5
11.Ale(m;25;06)	5	4	0	-2	0	-4	3	4	3	-4
12.Vic(m;31;11)	2	5	0	0	0	-3	4	2	1	5
13.Zos(f;24;00)	4	4	3	3	3	3	3	4	1	4
14.Edu(m;30;02)	5	4	0	0	0	0	3	4	4	0
15.Tan(f;24;00)	1	3	-3	4	3	-1	3	2	1	-2
16.Ric(m;30;03)	3	3	-3	-3	0	-4	4	4	4	-3
17.Cla(f;21;08)	5	5	0	-4	3	5	4	5	5	5
18.Ami(m;24;09)	2	0	0	3	4	0	-2	3	0	4

Table 1. Position of matter for undergraduate physicists (range +5 to -5).

Obs.: all undergraduated physicists finishing course(initials(sex;age:years;months))

Dimensions:
D1: material(+)/immaterial(-)
D2: real(+)/imaginary(-)
D3: cause(+)/effect(-)
D4: active(+)/passive(-)
D5: dynamic(+)/static(-)
D6: continuous(+)/discrete(-)
D7: localized(+)/place(-)
D8: concrete(+)/abstract(-)
D9: substance(+)/action(-)
D10: conserved(+)/not conserved(-)

physicists	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Cel(m;23;05)	1	5	5	5	5	5	5	5	1	5
2.Iza(f;21;11)	-5	2	0	1	2	-4	3	-4	-1	4
3.Gui(m;22;11)	-5	0	5	5	5	5	0	-5	-5	5
4.Mar(m;22;03)	0	-5	0	5	4	-5	4	-4	-4	5
5.Lui(m;23;08)	-5	0	0	5	5	-5	5	5	4	5
6.Car(m;25;05)	1	4	3	4	4	-4	3	2	0	4
7.Fra(m;23;05)	0	1	5	5	5	0	5	0	0	5
8.Cri(m;28;01)	-4	5	3	5	5	0	5	5	-5	5
9.Fab(m;22;05)	-4	1	0	2	0	0	4	-3	0	5
10.Sil(f;23;10)	-5	5	0	4	0	0	0	4	-3	5
11.Ale(m;25;06)	-4	4	0	3	3	3	0	1	0	5
12.Vic(m;31;11)	-2	-5	0	0	2	-3	4	-2	-1	5
13.Zos(f;24;00)	-4	3	-3	4	5	3	3	-4	-2	5
14.Edu(m;30;02)	3	4	0	4	4	0	0	3	3	4
15.Tan(f;24;00)	-3	3	1	3	3	-2	2	2	-3	-1
16.Ric(m;30;03)	0	2	0	0	0	-4	0	2	0	4
17.Cla(f;21;08)	1	5	1	5	5	5	0	5	4	-3
18.Ami(m;24;09)	0	0	0	3	4	0	-2	3	0	4

Table 2. Position of energy for undergraduate physicists (range +5 to -5).

physicists	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Cel(m;23;05)	1	5	0	0	5	5	0	5	0	0
2.Iza(f;21;11)	-5	3	0	-2	2	3	0	-4	4	0
3.Gui(m;22;11)	-5	-5	0	-5	5	5	-5	-5	0	2
4.Mar(m;22;03)	-5	-5	0	0	0	0	0	-5	0	0
5.Lui(m;23;08)	0	5	0	-5	0	5	5	5	0	0
6.Car(m;25;05)	-4	2	1	0	5	-4	2	-3	0	0
7.Fra(m;23;05)	-5	-5	0	0	0	0	-5	-5	0	0
8.Cri(m;28;01)	-5	5	5	0	5	5	0	-5	-3	5
9.Fab(m;22;05)	-2	1	0	0	0	0	0	-4	0	-5
10.Sil(f;23;10)	-5	5	0	0	5	4	0	0	-5	0
11.Ale(m;25;06)	-5	2	0	2	4	0	-4	-4	0	4
12.Vic(m;31;11)	-5	0	0	0	2	3	0	-2	0	0
13.Zos(f;24;00)	-5	4	0	3	5	4	3	-3	2	4
14.Edu(m;30;02)	0	0	0	3	4	3	0	-1	-4	0
15.Tan(f;24;00)	0	-5	-3	4	4	2	1	-4	-4	0
16.Ric(m;30;03)	0	2	0	0	2	0	0	2	0	4
17.Cla(f;21;08)	-5	5	0	-1	5	5	0	5	-1	5
18.Ami(m;24;09)	0	0	3	-3	4	4	0	0	0	-4

Table 3. Position of time for undergraduate physicists (range +5 to -5).

physicists	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Cel(m;23;05)	1	5	0	0	0	5	-5	5	0	0
2.Iza(f;21;11)	-5	4	0	1	1	3	-5	-1	2	0
3.Gui(m;22;11)	-5	2	-2	-3	-4	3	-5	-2	-3	-2
4.Mar(m;22;03)	-1	0	0	0	0	0	-2	-2	0	0
5.Lui(m;23;08)	5	5	0	4	0	5	5	0	0	0
6.Car(m;25;05)	-1	2	0	0	4	3	-4	-1	0	1
7.Fra(m;23;05)	-5	0	0	0	0	0	-5	-5	0	0
8.Cri(m;28;01)	-5	5	5	0	-5	5	-5	5	0	5
9.Fab(m;22;05)	-5	2	0	0	-4	0	-5	-2	0	-5
10.Sil(f;23;10)	0	0	0	0	0	0	-5	0	0	0
11.Ale(m;25;06)	-4	3	0	-2	-2	0	-4	-3	0	4
12.Vic(m;31;11)	-5	-4	0	0	-2	3	-4	-2	0	0
13.Zos(f;24;00)	4	1	0	3	3	4	-4	3	2	4
14.Edu(m;30;02)	-3	3	0	0	4	0	0	0	0	3
15.Tan(f;24;00)	-1	3	0	2	2	3	-1	-1	-1	4
16.Ric(m;30;03)	0	2	0	0	0	0	-2	2	0	4
17.Cla(f;21;08)	1	4	0	-2	-5	3	-5	5	-5	5
18.Ami(m;24;09)	0	1	0	-3	3	0	0	0	-1	4

Table 4. Position of space for undergraduate physicists (range +5 to -5).

physicists	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Cel(m;23;05)	1	5	-5	5	1	1	0	4	-4	0
2.Iza(f;21;11)	2	4	-3	0	2	4	1	1	5	-5
3.Gui(m;22;11)	-4	5	-3	4	5	-3	4	5	-3	0
4.Mar(m;22;03)	1	5	5	3	3	-5	0	-1	-2	0
5.Lui(m;23;08)	5	5	0	0	5	-5	0	5	0	-5
6.Car(m;25;05)	0	4	0	3	2	-3	3	4	-3	5
7.Fra(m;23;05)	0	1	0	5	5	0	5	1	0	5
8.Cri(m;28;01)	0	5	-5	5	5	-5	5	5	0	5
9.Fab(m;22;05)	-4	3	-4	0	4	0	2	-1	0	-5
10.Sil(f;23;10)	-2	5	0	3	3	3	-4	-1	0	4
11.Ale(m;25;06)	4	4	0	1	4	-4	0	1	2	4
12.Vic(m;31;11)	-2	-2	0	0	2	-3	3	2	1	5
13.Zos(f;24;00)	0	4	-2	3	4	-2	3	-3	2	4
14.Edu(m;30;02)	4	4	0	4	4	0	0	4	0	3
15.Tan(f;24;00)	-3	4	-3	4	4	-1	3	3	-4	1
16.Ric(m;30;03)	0	2	0	0	2	-2	3	2	-1	4
17.Cla(f;21;08)	3	5	0	2	3	0	2	5	3	-4
18.Ami(m;24;09)	0	0	0	4	3	0	0	4	-1	4

Table 5. Position of light for undergraduate physicists (range +5 to -5).

physicists	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Cel(m;23;05)	4	5	5	5	5	0	0	5	-5	0
2.Iza(f;21;11)	-5	1	3	4	2	0	4	2	-5	-5
3.Gui(m;22;11)	-4	4	4	5	5	3	5	5	-5	0
4.Mar(m;22;03)	-5	-5	-5	4	5	0	0	-1	-4	0
5.Lui(m;23;08)	0	5	0	5	-5	-5	0	5	0	5
6.Car(m;25;05)	-3	5	-3	4	2	-3	4	5	-4	4
7.Fra(m;23;05)	-5	-5	0	5	5	5	5	2	-5	5
8.Cri(m;28;01)	-5	5	5	5	5	5	5	5	-5	5
9.Fab(m;22;05)	-4	2	0	3	0	4	4	0	-4	4
10.Sil(f;23;10)	-3	-3	-2	4	0	-4	2	0	-3	0
11.Ale(m;25;06)	-4	-2	3	4	4	4	3	-2	0	-3
12.Vic(m;31;11)	-2	-2	2	2	2	0	3	-2	-1	0
13.Zos(f;24;00)	-3	3	-2	4	4	-2	2	3	-3	-2
14.Edu(m;30;02)	4	4	0	0	4	0	0	4	0	0
15.Tan(f;24;00)	-3	-3	2	3	-2	-1	2	2	-2	0
16.Ric(m;30;03)	0	2	3	3	0	0	3	2	-3	0
17.Cla(f;21;08)	-1	5	3	3	4	0	0	5	-3	-4
18.Ami(m;24;09)	0	2	0	4	3	0	2	4	-1	0

Table 6. Position of force for undergraduate physicists (range +5 to -5).

physicists	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Cel(m;23;05)	4	5	-1	4	5	0	0	4	-4	0
2.Iza(f;21;11)	-5	3	-4	0	2	4	5	4	-1	-5
3.Gui(m;22;11)	-3	3	5	5	5	0	-2	-4	4	4
4.Mar(m;22;03)	-5	0	5	5	5	-4	0	0	-5	0
5.Lui(m;23;08)	5	5	0	4	0	5	5	0	0	0
6.Car(m;25;05)	-5	4	2	4	5	4	-3	5	-3	3
7.Fra(m;23;05)	-5	3	-1	5	5	1	5	4	-5	5
8.Cri(m;28;01)	-5	5	-5	4	5	5	5	5	-5	5
9.Fab(m;22;05)	2	1	0	3	4	0	4	0	0	-2
10.Sil(f;23;10)	0	3	0	3	3	0	-3	-4	-4	0
11.Ale(m;25;06)	-4	4	-4	5	0	0	0	-3	-3	-4
12.Vic(m;31;11)	-5	-2	-2	2	2	3	3	-2	-1	0
13.Zos(f;24;00)	-4	4	3	4	5	1	2	1	-3	-2
14.Edu(m;30;02)	0	0	0	4	4	0	0	4	0	0
15.Tan(f;24;00)	0	-3	-3	1	3	-1	3	3	-3	3
16.Ric(m;30;03)	0	2	-2	-2	3	-1	3	2	-2	4
17.Cla(f;21;08)	-2	5	-5	3	5	0	0	5	2	-4
18.Ami(m;24;09)	0	3	4	0	3	0	2	4	-2	0

Table 7. Position of movement for undergraduate physicists (range +5 to -5).

physicists	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Cel(m;23;05)	4	5	0	4	0	0	4	4	5	4
2.Iza(f;21;11)	5	3	5	2	-2	4	5	5	5	-5
3.Gui(m;22;11)	5	5	5	-5	-5	-5	0	5	5	5
4.Mar(m;22;03)	0	5	0	-4	-1	-4	0	-3	0	0
5.Lui(m;23;08)	5	5	3	-5	-5	5	-5	5	5	5
6.Car(m;25;05)	5	5	3	-2	4	4	3	4	3	4
7.Fra(m;23;05)	0	-2	0	-5	0	0	1	-5	0	5
8.Cri(m;28;01)	5	5	5	5	-5	5	5	5	5	5
9.Fab(m;22;05)	3	3	0	-2	0	-3	*	3	4	-2
10.Sil(f;23;10)	5	5	0	-2	-4	-2	0	5	5	5
11.Ale(m;25;06)	5	5	0	0	0	-4	3	5	4	5
12.Vic(m;31;11)	2	4	0	5	4	-5	4	4	3	5
13.Zos(f;24;00)	3	4	1	4	3	3	3	3	3	4
14.Edu(m;30;02)	4	4	4	4	4	4	4	4	4	4
15.Tan(f;24;00)	5	3	-2	4	5	-4	4	1	3	1
16.Ric(m;30;03)	2	3	0	-1	0	-3	0	3	5	-5
17.Cla(f;21;08)	5	5	0	0	-5	-5	1	5	5	-3
18.Ami(m;24;09)	4	5	4	-4	-4	4	4	4	4	3

Table 8. Position of mass for undergraduate physicists (range +5 to -5).

physicists	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Cel(m;23;05)	-1	5	0	0	-4	0	4	1	0	1
2.Iza(f;21;11)	5	3	4	3	-2	-4	5	4	5	4
3.Gui(m;22;11)	0	4	4	4	4	-4	4	0	4	5
4.Mar(m;22;03)	-5	-5	-3	3	3	-5	0	-4	-3	3
5.Lui(m;23;08)	5	5	4	0	-5	-5	-5	-5	5	5
6.Car(m;25;05)	2	4	2	5	-5	-4	2	2	2	4
7.Fra(m;23;05)	-5	5	0	4	0	5	5	0	5	5
8.Cri(m;28;01)	5	5	5	5	-5	-5	5	5	5	5
9.Fab(m;22;05)	-1	1	-3	0	-4	-5	5	-3	0	5
10.Sil(f;23;10)	5	5	3	4	0	-3	0	3	0	5
11.Ale(m;25;06)	1	4	0	0	0	-4	3	-1	3	5
12.Vic(m;31;11)	2	1	0	5	4	-5	2	1	3	5
13.Zos(f;24;00)	3	4	-2	4	4	-4	1	1	2	5
14.Edu(m;30;02)	-4	4	4	4	4	-4	0	-4	-4	4
15.Tan(f;24;00)	-5	-4	1	4	0	-1	0	-3	-4	1
16.Ric(m;30;03)	-2	0	0	-1	0	-5	0	0	0	5
17.Cla(f;21;08)	5	5	0	4	3	-5	0	5	3	-3
18.Ami(m;24;09)	-4	-4	4	-4	-4	-2	4	-4	4	3

Table 9. Position of charge for undergraduate physicists (range +5 to -5).

physicists	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Cel(m;23;05)	4	5	4	3	4	5	0	4	-1	0
2.Iza(f;21;11)	-5	2	-4	0	1	4	3	5	-1	-5
3.Gui(m;22;11)	-5	4	-5	5	5	5	-5	3	-5	0
4.Mar(m;22;03)	5	5	5	3	5	0	0	2	-3	0
5.Lui(m;23;08)	5	5	-5	0	5	5	5	5	5	0
6.Car(m;25;05)	4	4	5	4	4	3	-1	4	0	-1
7.Fra(m;23;05)	5	5	-5	5	5	5	5	5	5	-5
8.Cri(m;28;01)	-5	5	-5	5	5	5	0	5	-5	5
9.Fab(m;22;05)	2	2	-3	0	4	4	4	0	-2	0
10.Sil(f;23;10)	-3	4	-2	0	0	0	0	2	0	0
11.Ale(m;25;06)	-4	5	-4	0	4	3	-3	4	0	0
12.Vic(m;31;11)	-4	1	-4	0	4	-5	2	2	-3	5
13.Zos(f;24;00)	-2	5	2	-3	4	3	1	1	-1	-1
14.Edu(m;30;02)	4	4	0	4	4	4	0	4	-4	-5
15.Tan(f;24;00)	-2	1	-4	3	3	-1	-2	2	-3	-3
16.Ric(m;30;03)	0	3	-2	0	4	3	0	3	0	0
17.Cla(f;21;08)	-3	5	0	4	5	5	0	5	4	-5
18.Ami(m;24;09)	4	5	4	3	4	3	-2	4	-3	-4

Table 10. Position of sound for undergraduate physicists (range +5 to -5).

physicists	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Cel(m;23;05)	4	5	0	5	5	5	1	4	1	1
2.Iza(f;21;11)	-5	1	4	3	1	5	4	4	1	-5
3.Gui(m;22;11)	-5	5	-5	2	4	5	-5	2	4	3
4.Mar(m;22;03)	-5	5	4	3	5	0	0	3	-4	-2
5.Lui(m;23;08)	5	5	-5	0	5	-5	5	5	5	5
6.Car(m;25;05)	3	3	3	4	5	-4	0	3	0	-1
7.Fra(m;23;05)	-5	5	0	5	5	5	5	2	-5	5
8.Cri(m;28;01)	-5	5	-5	5	5	5	0	5	-5	5
9.Fab(m;22;05)	0	1	-2	0	4	-3	5	2	0	-1
10.Sil(f;23;10)	0	3	2	2	0	-2	0	-2	0	0
11.Ale(m;25;06)	-3	4	-4	0	3	0	0	2	-2	-1
12.Vic(m;31;11)	-4	-1	0	4	4	-5	2	-2	-3	5
13.Zos(f;24;00)	-3	3	-3	-2	4	2	1	1	-1	-3
14.Edu(m;30;02)	4	4	0	4	4	4	0	4	0	-5
15.Tan(f;24;00)	-3	-1	-3	3	3	3	-2	2	-2	-3
16.Ric(m;30;03)	-2	3	-2	0	4	3	0	3	0	5
17.Cla(f;21;08)	-2	5	0	5	5	5	0	5	4	-5
18.Ami(m;24;09)	3	4	4	3	2	3	2	4	-3	2

Table 11. Position of heat for undergraduate physicists (range +5 to -5).

physicists	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Cel(m;23;05)	1	5	5	4	5	5	1	4	0	0
2.Iza(f;21;11)	-5	2	2	1	-1	4	-1	-1	-1	0
3.Gui(m;22;11)	-5	3	-5	5	-3	5	4	2	-4	0
4.Mar(m;22;03)	-5	-1	0	4	3	-2	0	-3	-4	0
5.Lui(m;23;08)	5	5	-5	-5	-5	5	0	5	0	5
6.Car(m;25;05)	0	1	5	5	5	3	1	1	-2	4
7.Fra(m;23;05)	-5	5	5	5	5	5	-5	0	-5	5
8.Cri(m;28;01)	-5	5	-5	5	5	5	5	5	-5	5
9.Fab(m;22;05)	5	-1	0	4	3	3	4	-2	-4	0
10.Sil(f;23;10)	-4	5	4	5	3	-5	0	0	-4	0
11.Ale(m;25;06)	-4	4	0	1	0	2	-4	3	0	4
12.Vic(m;31;11)	-4	-1	0	4	2	-4	2	-2	-3	3
13.Zos(f;24;00)	-4	5	1	4	-1	3	1	1	-1	-2
14.Edu(m;30;02)	-3	-3	4	4	0	4	3	-4	-4	4
15.Tan(f;24;00)	-3	1	1	2	-2	-2	-2	2	-1	0
16.Ric(m;30;03)	0	3	2	1	0	0	0	3	-5	5
17.Cla(f;21;08)	5	5	0	5	-3	3	0	4	1	2
18.Ami(m;24;09)	-4	4	-4	-4	-3	-2	-4	-4	-3	0

Table 12. Position of gravity for undergraduate physicists (range +5 to -5).

physicists	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Cel(m;23;05)	-5	5	-4	4	0	0	1	1	-1	0
2.Iza(f;21;11)	-3	2	2	4	4	-5	5	4	5	-5
3.Gui(m;22;11)	2	4	4	5	5	-5	5	-3	0	0
4.Mar(m;22;03)	-5	-5	0	0	3	-5	0	-5	-3	-2
5.Lui(m;23;08)	5	-5	-5	0	5	-5	0	5	0	5
6.Car(m;25;05)	-1	1	0	2	0	-5	2	-1	0	3
7.Fra(m;23;05)	0	-1	0	5	5	-5	5	0	0	5
8.Cri(m;28;01)	5	5	-5	5	5	-5	5	5	-5	5
9.Fab(m;22;05)	-5	-4	-4	4	5	-5	0	-4	0	0
10.Sil(f;23;10)	-5	0	-4	4	4	-5	0	-3	-2	3
11.Ale(m;25;06)	-4	2	0	0	3	-5	4	4	0	0
12.Vic(m;31;11)	2	1	0	4	4	-4	2	2	2	5
13.Zos(f;24;00)	3	4	1	4	4	-4	1	-1	2	-2
14.Edu(m;30;02)	-5	-4	4	4	4	-4	0	-5	-4	4
15.Tan(f;24;00)	1	0	-1	2	3	0	2	-3	0	1
16.Ric(m;30;03)	0	0	0	1	4	-5	0	0	0	5
17.Cla(f;21;08)	5	3	1	1	5	2	2	3	2	0
18.Ami(m;24;09)	2	2	0	2	2	0	0	-3	3	0

Table 13. Position of photon for undergraduate physicists (range +5 to -5).

physicists	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
1.Cel(m;23;05)	1	5	4	4	4	0	1	4	-1	1
2.Iza(f;21;11)	-5	2	-2	1	-1	3	2	-1	-1	-5
3.Gui(m;22;11)	-5	-3	2	3	3	-5	0	-2	0	0
4.Mar(m;22;03)	-5	5	-3	5	5	0	0	-2	-4	0
5.Lui(m;23;08)	5	-5	-4	0	5	-5	0	5	0	5
6.Car(m;25;05)	2	4	-1	1	4	-2	-3	1	-2	-1
7.Fra(m;23;05)	3	3	-5	5	5	5	5	3	0	5
8.Cri(m;28;01)	5	5	-5	5	5	-5	5	5	-5	5
9.Fab(m;22;05)	4	2	0	4	4	-3	4	2	1	0
10.Sil(f;23;10)	2	3	4	3	4	0	0	-1	-3	0
11.Ale(m;25;06)	1	3	-4	3	3	3	-3	2	-2	0
12.Vic(m;31;11)	2	1	0	4	4	-4	2	2	-2	5
13.Zos(f;24;00)	0	5	-2	1	4	-3	1	1	-1	4
14.Edu(m;30;02)	4	4	0	4	4	-4	0	-4	-4	-4
15.Tan(f;24;00)	-3	3	3	3	4	1	-3	1	-3	3
16.Ric(m;30;03)	0	3	2	1	0	0	0	3	-5	5
17.Cla(f;21;08)	4	3	0	0	5	5	1	5	5	-2
18.Ami(m;24;09)	-4	4	-4	3	3	-2	-2	3	-3	2

Table 14. Position of electricity for undergraduate physicists (range +5 to -5).

entities	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
matter	3.2	3.8	.3	-.8	.4	-.7	3.2	3.6	2.2	1.9
energy	-1.9	1.9	1.1	3.5	3.4	-.3	2.3	.8	-.7	3.9
time	-3.1	1.1	.3	-.2	3.2	2.4	-.2	-1.6	-.6	.8
space	-1.6	2.1	.2	0	-.3	2.1	-3.1	.1	-.3	1.5
light	.3	3.5	-1.1	2.6	3.4	-1.4	1.7	2.2	-.3	1.4
force	-2.2	1.3	1	3.7	2.4	.3	2.4	2.4	-2.9	.5
movement	-1.8	2.5	-.4	3	3.6	.9	1.6	1.6	-1.9	.4
mass	3.7	4	1.6	-.1	-.6	-.3	2.1	3.2	3.8	2.2
charge	.3	2.3	1.3	2.4	-.4	-3.3	1.9	-.1	1.7	3.7
sound	0	3.9	-1.3	2	3.9	2.8	.4	3.3	-.9	-1.1
heat	-1.3	3.3	-.7	2.6	3.8	1.4	1	2.6	-.6	.3
gravity	-1.9	2.6	.6	2.8	.7	1.8	.3	.8	-2.5	1.9
photon	-.4	.6	-.6	2.8	3.6	-3.6	1.9	-.2	-.1	1.5
electricity	.6	2.6	-.8	2.8	3.6	-.9	.6	1.5	-1.7	1.3

Table 15. Means of positions of entities for undergraduate physicists.

Dimensions:
D1: material(+)/immaterial(-)
D2: real(+)/imaginary(-)
D3: cause(+)/effect(-)
D4: active(+)/passive(-)
D5: dynamic(+)/static(-)
D6: continuous(+)/discrete(-)
D7: localized(+)/place(-)
D8: concrete(+)/abstract(-)
D9: substance(+)/action(-)
D10: conserved(+)/not conserved(-)

Tables with the coordinates in the space of factors obtained:

dimensions	**Principal Component 1**	**Principal Component 2**
conserved/not conserved	-0.720	-0.277
movement/static	0.821	-0.298
active/passive	0.769	-0.518
substance/action	-0.910	0.204
place/localised	-0.280	0.931
cause/effect	-0.649	0.635
material/immaterial	-0.934	-0.238
concrete/abstract	-0.894	-0.294
real/imaginary	-0.546	-0.767
object/vacuum	-0.797	-0.498
entities	**Principal Component 1**	**Principal Component 2**
matter	2.403	0.732
energy	-0.479	0.187
time	-0.778	-1.877
space	1.110	-1.819
light	-0.333	0.382
force	-0.438	0.392
movement	-0.539	0.835
sound	-0.553	0.135
heat	0.101	0.371
electricity	-0.493	0.659

Table 1. Coordinates of dimensions and entities in the space of Principal Components for 16-18 year olds.

entities	Principal Component 1	Principal Component 2	Principal Component 3	Principal Component 4
matter	-1.8296	-0.8126	-0.0994	-0.4228
energy	0.2410	0.8898	0.9495	1.1667
time	0.9223	1.2530	-0.9598	-1.0350
space	0.1871	1.2311	-2.0184	-0.8720
light	-0.0677	-0.9548	0.5285	-0.5190
force	0.8100	0.1764	0.5882	1.7114
movement	0.8574	-0.4684	0.2630	0.6719
mass	-2.2978	-0.0695	-0.5562	0.7473
charge	-1.0069	1.4561	0.9642	-0.2459
sound	0.5267	-1.6316	-1.1593	-0.1424
heat	0.6111	-1.1454	-0.0710	-0.0798
gravity	0.3345	0.5348	-0.7034	1.3890
photon	0.3218	0.4065	1.7410	-1.7307
electricity	0.3898	-0.8652	0.5331	-0.6385
dimensions	Principal Component 1	Principal Component 2	Principal Component 3	Principal Component 4
immaterial /material	-0.855	-0.414	0.106	-0.147
imaginary/real	-0.535	-0.681	-0.278	0.070
effect/cause	-0.463	0.548	-0.068	0.665
passive/active	0.583	-0.129	0.598	0.396
static/dynamic	0.765	-0.429	0.325	-0.199
discrete/continuous	0.357	-0.149	-0.834	0.325
place/localized	-0.373	-0.268	0.772	0.215
abstract/concrete	-0.388	-0.819	0.011	0.334
action/substance	-0.919	0.109	-0.049	-0.252
not conserved / conserved	-0.472	0.690	0.299	-0.008

Table 2. Coordinates of dimensions and entities in the space of Principal Components for undergraduate physicists.

Tables with the coordinates of individuals in the space of factors obtained:

Tables obtained for 16-18 year-olds:

entities	matter		energy		time		space		ligh	
	Principal Components		Principal Components		Principal Components		Principal Components		Principal Components	
students	1	2	1	2	1	2	1	2	1	2
1.Luc(f;16;11)	1.953	0.474	*	*	-0.212	-0.473	*	*	*	
2.Luc(f;17;06)	2.219	0.791	-0.946	1.286	0.285	-2.187	3.336	0.788	*	
3.Lui(m;17;02)	2.126	0.961	0.034	-0.079	-2.204	-2.541	-1.814	-2.123	-0.191	0.38
4.Mar(f;17;10)	2.797	-0.601	*	*	*	*	*	*	*	
5.Mar(m;17;04)	2.702	1.317	-0.530	0.677	0.189	-2.912	2.937	-0.135	-0.879	-0.30
6.Lil(f;16;11)	1.909	1.293	*	*	*	*	*	*	1.142	2.14
7.Mar(m;18;11)	*	*	*	*	*	*	*	*	-1.349	2.05
8.Luc(f;16;09)	2.762	0.944	0.270	2.206	-0.878	0.160	0.298	2.858	-0.212	2.52
9.Luc(f;17;04)	2.500	2.143	-0.980	-1.842	-1.244	-3.122	1.711	-3.373	-0.359	-0.66
10.Pri(f;17;01)	2.928	0.952	-0.232	0.213	-0.672	-0.369	1.508	-0.122	0.268	1.77
11.Mar(m;16;07)	2.806	-1.502	-0.335	-1.587	0.284	-0.066	0.007	-3.433	*	
12.Rei(m;18;10)	3.057	0.452	-0.768	0.942	-0.741	0.052	1.334	-3.447	-0.768	0.94
13.Luc(f;16;08)	3.234	0.520	*	*	*	*	*	*	*	
14.Reg(m;16;00)	2.839	1.984	0.049	1.518	*	*	*	*	1.302	2.07
15.Lin(f;17;01)	2.460	0.367	-0.579	2.672	-0.860	-2.070	1.761	-0.623	-1.366	0.46
16.Reg(f;16;10)	*	*	-1.148	1.984	-0.775	0.101	-0.156	-1.720	-0.570	2.45
17.Ren(f;16;08)	2.408	0.165	-0.407	-1.791	*	*	3.351	-0.419	-0.060	0.28
18.Luc(f;18;08)	2.004	1.287	-0.148	1.522	0.082	-4.616	0.800	-4.257	0.576	-2.07
19.Pat(f;18;04)	2.249	1.057	*	*	0.776	-2.835	*	*	*	
20.Pat(f;17;02)	2.260	-0.865	0.840	0.105	-1.094	-3.897	1.793	-2.981	-1.509	1.66
21.Pri(f;18;10)	2.945	0.758	-0.017	0.093	-0.349	-1.233	-0.563	-1.040	-0.319	-2.23
22.Mar(m;16;09)	3.001	0.589	-0.621	-0.192	-0.982	-0.218	*	*	*	
23.Jul(f;18;04)	*	*	-0.563	1.689	*	*	-0.049	-1.920	-0.322	1.52
24.Ale(m;18;02)	3.214	-0.116	-0.457	-2.729	-1.595	-2.298	3.406	-0.850	-1.186	-0.64
25.Ale(m;17;08)	1.945	1.702	-0.448	2.448	-2.126	-1.404	*	*	0.553	2.47
26.Aff(m;18;03)	2.764	0.809	-1.865	-2.933	*	*	*	*	-1.831	-2.04
27.Ale(f;17;05)	*	*	-0.916	-1.800	-1.379	-3.207	-0.347	-3.195	-1.206	-0.38
28.Car(f;16;09)	2.969	-0.486	-2.074	0.937	-0.551	-2.537	0.795	-0.658	-0.902	0.45
29.Aud(f;18;03)	1.779	2.898	-0.984	-2.844	-0.886	-3.645	1.135	-2.560	0.967	0.27
30.Chr(f;17;09)	1.989	0.459	-0.405	2.373	0.077	-2.385	1.801	-0.719	1.119	-0.41
MEAN - entity	*2.403*	*0.733*	*-0.479*	*0.188*	*-0.779*	*-1.878*	*1.110*	*-1.820*	*-0.333*	*0.38*

entities	Force		Movement		Sound		Heat		Electricity	
	Principal Components		Principal Components		Principal Components		Principal Components		Principal Components	
students	1	2	1	2	1	2	1	2	1	2
1.Luc(f;16;11)	0.653	0.131	*	*	-0.041	-2.612	0.845	-1.840	*	
2.Luc(f;17;06)	-0.580	1.719	-0.204	2.931	1.626	0.787	*	*	-0.617	2.35
3.Lui(m;17;02)	-1.297	-0.117	*	*	-0.962	-0.238	-0.962	-0.238	-0.962	-0.23
4.Mar(f;17;10)	-0.593	-0.019	-1.059	0.845	*	*	*	*	*	
5.Mar(m;17;04)	-0.522	0.763	0.804	0.684	-0.404	-1.088	0.025	0.908	-1.089	0.11
6.Lil(f;16;11)	0.193	-1.481	-1.005	0.996	*	*	-0.867	1.333	*	
7.Mar(m;18;11)	1.556	1.075	0.303	1.839	*	*	0.295	0.212	-0.049	-1.28
8.Luc(f;16;09)	0.076	2.320	-0.261	2.577	-0.615	2.388	0.155	3.009	0.155	3.00
9.Luc(f;17;04)	-0.760	-1.312	-1.560	-0.519	-1.688	-1.969	-2.185	-0.662	-1.214	-0.47
10.Pri(f;17;01)	-0.232	0.213	-0.436	-0.132	*	*	2.083	0.876	0.996	0.61
11.Mar(m;16;07)	-0.335	-1.587	0.536	1.966	*	*	1.667	-0.617	-1.298	0.68
12.Rei(m;18;10)	-0.914	1.257	-0.914	1.257	-0.303	0.394	0.204	0.106	-0.575	1.09
13.Luc(f;16;08)	*	*	*	*	*	*	*	*	*	
14.Reg(m;16;00)	*	*	-1.653	0.185	0.509	3.198	1.187	2.880	0.509	3.19
15.Lin(f;17;01)	-0.762	2.432	-1.460	1.350	-1.475	1.409	-0.359	1.996	-0.585	2.52
16.Reg(f;16;10)	*	*	0.096	1.148	*	*	0.443	0.738	-0.257	0.22
17.Ren(f;16;08)	0.023	2.292	0.023	2.292	0.285	0.221	0.133	0.437	0.133	0.43
18.Luc(f;18;08)	0.901	1.267	1.546	0.479	*	*	0.681	0.098	0.166	0.33
19.Pat(f;18;04)	*	*	*	*	*	*	*	*	*	
20.Pat(f;17;02)	-1.831	-0.320	-1.551	-0.910	-0.991	1.657	-1.410	0.784	-0.193	1.35
21.Pri(f;18;10)	-0.605	2.440	*	*	-0.674	-0.233	-0.380	-1.263	*	
22.Mar(m;16;09)	*	*	-0.734	1.788	-1.283	0.436	*	*	-0.659	0.60
23.Jul(f;18;04)	-0.675	1.367	-0.675	1.367	-0.675	1.367	-0.144	1.363	-0.121	1.59
24.Ale(m;18;02)	-2.086	1.200	-1.337	1.717	-2.086	1.200	-0.642	1.308	-1.316	1.82
25.Ale(m;17;08)	-0.299	1.796	*	*	-0.978	2.420	-0.445	2.516	-0.066	2.98
26.Aff(m;18;03)	-2.096	-1.327	*	*	-1.929	-3.283	-1.494	-2.298	-2.347	-2.26
27.Ale(f;17;05)	0.624	-0.872	-1.016	-0.538	-0.332	1.122	1.222	-0.094	*	
28.Car(f;16;09)	-0.128	-1.055	-0.837	1.158	-0.989	1.051	-0.269	1.363	-1.328	1.56
29.Aud(f;18;03)	-0.908	-3.913	-0.298	0.237	-0.454	-1.661	0.532	-0.322	-0.306	-3.16
30.Chr(f;17;09)	-0.970	2.198	-0.200	2.819	1.799	-0.583	2.203	0.227	-0.269	2.80
MEAN - entity	*-0.438*	*0.393*	*-0.539*	*0.836*	*-0.554*	*0.135*	*0.102*	*0.371*	*-0.493*	*0.65*

Table 1. Coordinates of individuals in the space of factors. (- don't know answers were excluded).*

Obs. : All students from 3rd grade secondary school (initials(sex;age:years;months))

Tables obtained for undergraduate physicists:

physicists	Principal Component 1	Principal Component 2	Principal Component 3	Principal Component 4
1.Cel(m;23;05)	-3.0333	0.8950	1.4425	-0.3339
2.Iza(f;21;11)	-1.5955	1.2782	1.4096	2.0542
3.Gui(m;22;11)	-4.0995	0.2772	0.3940	-1.6289
4.Mar(m;22;03)	-2.4736	0.4296	0.5004	2.4196
5.Lui(m;23;08)	-0.5066	-1.8418	0.8673	3.0328
6.Car(m;25;05)	-1.4426	-1.1638	-0.8152	-0.8928
7.Fra(m;23;05)	-0.9223	0.3440	0.5711	-3.4820
8.Cri(m;28;01)	-4.3809	0.5328	0.2642	0.9009
9.Fab(m;22;05)	-1.0123	1.5238	0.6645	-0.6532
10.Sil(f;23;10)	-1.9071	-0.7370	-0.6400	-0.0700
11.Ale(m;25;06)	-1.9043	2.0249	-0.2308	-1.4100
12.Vic(m;31;11)	-1.9127	0.0181	0.9595	-0.5351
13.Zos(f;24;00)	-1.4440	-0.3837	0.2017	2.9543
14.Edu(m;30;02)	-2.0005	-1.3977	-0.3131	-0.4153
15.Tan(f;24;00)	0.3636	-1.9339	0.8698	-1.7276
16.Ric(m;30;03)	-1.5503	-2.1164	0.1130	-3.5803
17.Cla(f;21;08)	-2.6423	-1.2306	-1.2185	-0.6325
18.Ami(m;24;09)	0.1813	0.6394	0.1845	-0.5592
Mean - matter	*-1.8296*	*-0.8126*	*-0.0994*	*-0.4228*

Table 1. Matter: coordinates of individuals in the space of factors.

physicists	Principal Component 1	Principal Component 2	Principal Component 3	Principal Component 4
1.Cel(m;23;05)	-1.2478	-0.3993	0.6851	5.6707
2.Iza(f;21;11)	0.3752	2.2319	1.3635	-1.4743
3.Gui(m;22;11)	1.8797	3.7066	-0.1317	3.7917
4.Mar(m;22;03)	1.4939	3.2845	3.9238	-1.1357
5.Lui(m;23;08)	-0.1726	0.5809	3.4512	0.3873
6.Car(m;25;05)	-0.9665	0.3664	1.9260	1.8631
7.Fra(m;23;05)	-0.4073	1.8716	2.2344	3.7588
8.Cri(m;28;01)	0.1337	-0.4184	1.7858	4.6613
9.Fab(m;22;05)	0.0986	2.3628	1.0114	-0.2707
10.Sil(f;23;10)	0.1060	0.1281	-0.1229	1.8229
11.Ale(m;25;06)	0.3110	0.6485	-0.5898	0.5897
12.Vic(m;31;11)	0.5787	3.3966	2.2820	-1.6392
13.Zos(f;24;00)	1.5390	0.7741	0.8072	-1.8119
14.Edu(m;30;02)	-0.8779	-0.5397	0.3915	-0.2580
15.Tan(f;24;00)	0.6783	-0.4301	0.5451	1.2281
16.Ric(m;30;03)	-0.8564	0.9968	0.3481	-1.1728
17.Cla(f;21;08)	-0.0817	-2.4665	-1.3774	1.9069
18.Ami(m;24;09)	0.4131	0.8105	0.1304	-0.4134
Mean - energy	*0.2410*	*0.8898*	*0.9495*	*1.1667*

Table 2. Energy: coordinates of individuals in the space of factors.

physicists	Principal Component 1	Principal Component 2	Principal Component 3	Principal Component 4
1.Cel(m;23;05)	-0.1806	-2.0316	-1.9108	0.5339
2.Iza(f;21;11)	0.2002	1.4120	-2.1242	-2.0593
3.Gui(m;22;11)	2.1203	4.0110	-2.9154	-3.6752
4.Mar(m;22;03)	1.6316	3.7207	-0.2394	-2.0153
5.Lui(m;23;08)	-1.4611	-1.6668	-2.0150	0.6500
6.Car(m;25;05)	0.6017	1.2076	0.7427	-1.4897
7.Fra(m;23;05)	1.9707	4.0918	-1.5555	-2.7330
8.Cri(m;28;01)	0.4915	2.6891	-1.7161	2.6122
9.Fab(m;22;05)	0.9021	0.7804	-1.4272	-1.6335
10.Sil(f;23;10)	1.4591	-0.5393	-1.8080	0.4246
11.Ale(m;25;06)	1.2408	2.4222	-0.9917	-1.9233
12.Vic(m;31;11)	1.1737	1.5611	-1.3174	-0.8036
13.Zos(f;24;00)	0.5903	0.9891	-0.0097	-0.0566
14.Edu(m;30;02)	1.5784	0.5306	-0.3808	0.0867
15.Tan(f;24;00)	2.7753	1.6356	1.0013	-2.6409
16.Ric(m;30;03)	-0.4308	0.6766	-0.3394	-0.7274
17.Cla(f;21;08)	0.1029	-0.5157	-1.7176	0.8346
18.Ami(m;24;09)	0.4204	0.4746	-2.3046	0.5073
Mean - time	*0.9223*	*1.2530*	*-0.9598*	*-1.0350*

Table 3. Time: coordinates of individuals in the space of factors.

physicists	Principal Component 1	Principal Component 2	Principal Component 3	Principal Component 4
1.Cel(m;23;05)	-0.4104	-1.1750	-3.6807	0.3588
2.Iza(f;21;11)	0.6574	0.8465	-3.0539	-0.9832
3.Gui(m;22;11)	1.1140	1.1918	-4.0911	-2.4137
4.Mar(m;22;03)	0.4697	1.6560	-1.2655	-1.6622
5.Lui(m;23;08)	-0.8297	-1.3234	-0.2068	1.4291
6.Car(m;25;05)	0.7994	0.8146	-2.2184	-1.5609
7.Fra(m;23;05)	1.3357	2.8615	-2.1741	-2.4292
8.Cri(m;28;01)	-1.3681	1.9681	-3.9431	4.6740
9.Fab(m;22;05)	0.8740	1.1234	-3.3039	-1.2189
10.Sil(f;23;10)	0.4246	1.3660	-2.0209	-1.7470
11.Ale(m;25;06)	-0.1418	2.5916	-2.3809	-2.0487
12.Vic(m;31;11)	1.4978	3.2307	-2.2385	-1.1868
13.Zos(f;24;00)	-0.2224	0.3899	-1.3977	-0.4267
14.Edu(m;30;02)	0.2393	0.7212	-0.4759	-1.0783
15.Tan(f;24;00)	0.3013	1.0465	-1.0270	-0.2486
16.Ric(m;30;03)	-0.5227	1.0192	-1.0473	-0.7974
17.Cla(f;21;08)	-0.9309	0.5593	-3.3561	0.6614
18.Ami(m;24;09)	-0.2179	1.3274	-0.6827	-1.9125
Mean - space	*0.1871*	*1.2311*	*-2.0184*	*-0.8720*

Table 4. Space: coordinates of individuals in the space of factors.

physicists	Principal Component 1	Principal Component 2	Principal Component 3	Principal Component 4
1.Cel(m;23;05)	0.8882	-2.7149	0.2397	-1.5162
2.Iza(f;21;11)	-0.1961	-2.3322	-2.0563	-2.7898
3.Gui(m;22;11)	0.9019	2.5430	1.6419	-0.4962
4.Mar(m;22;03)	-0.5848	0.7622	0.4719	2.1969
5.Lui(m;23;08)	-0.6927	-3.0527	-0.1604	-1.3871
6.Car(m;25;05)	-0.5684	-0.3430	1.5710	0.8709
7.Fra(m;23;05)	0.1638	0.5077	2.4146	0.6063
8.Cri(m;28;01)	-0.2197	-2.3236	3.1970	2.5030
9.Fab(m;22;05)	1.5103	-1.6385	0.6871	-3.5744
10.Sil(f;23;10)	0.4455	0.7565	-1.8256	-0.4830
11.Ale(m;25;06)	-1.2197	0.0026	0.7298	-2.0092
12.Vic(m;31;11)	-0.2648	1.9265	1.6357	-1.0292
13.Zos(f;24;00)	-0.1449	0.3873	1.4089	-2.6511
14.Edu(m;30;02)	-0.5734	-1.1097	0.3556	0.2831
15.Tan(f;24;00)	1.1419	-1.6723	1.1162	-0.6247
16.Ric(m;30;03)	-0.6008	0.4929	0.8979	-0.4949
17.Cla(f;21;08)	-0.8680	-2.7883	-0.5134	0.1730
18.Ami(m;24;09)	0.3274	0.4886	0.7707	0.5681
Mean - light	*-0.0677*	*-0.9548*	*0.5285*	*-0.5190*

Table 5. Light: coordinates of individuals in the space of factors.

physicists	Principal Component 1	Principal Component 2	Principal Component 3	Principal Component 4
1.Cel(m;23;05)	-0.2626	-1.2654	0.0851	4.7315
2.Iza(f;21;11)	1.4784	-0.2971	0.4591	3.8549
3.Gui(m;22;11)	0.7283	-1.0306	0.6923	5.7963
4.Mar(m;22;03)	3.4932	1.0026	1.2096	-3.5761
5.Lui(m;23;08)	-1.6559	0.1690	0.7967	1.2262
6.Car(m;25;05)	0.2199	-1.5662	1.8340	-0.1319
7.Fra(m;23;05)	2.3488	1.9207	2.0048	2.3094
8.Cri(m;28;01)	0.2422	-0.0302	0.6019	6.9069
9.Fab(m;22;05)	0.6874	1.0223	0.1639	1.8618
10.Sil(f;23;10)	1.5235	1.3033	1.8424	-1.3399
11.Ale(m;25;06)	1.6615	1.4814	0.0384	2.3879
12.Vic(m;31;11)	0.8009	2.0386	0.7708	0.7545
13.Zos(f;24;00)	1.2952	-1.6627	0.8273	-0.4394
14.Edu(m;30;02)	-0.6962	-1.5741	-0.7141	-0.6745
15.Tan(f;24;00)	0.5717	1.9533	0.6740	2.1056
16.Ric(m;30;03)	-0.1967	0.3724	0.3418	3.0882
17.Cla(f;21;08)	0.3549	-1.8818	-0.8964	3.1283
18.Ami(m;24;09)	0.2950	-0.9470	0.6256	0.9980
Mean - force	*0.8100*	*0.1764*	*0.5882*	*1.7114*

Table 6. Force: coordinates of individuals in the space of factors.

physicists	Principal Component 1	Principal Component 2	Principal Component 3	Principal Component 4
1.Cel(m;23;05)	0.3386	-2.3753	0.0925	0.1114
2.Iza(f;21;11)	1.1940	-2.7990	-0.9438	-1.0115
3.Gui(m;22;11)	-0.0141	2.9071	-0.1098	1.7298
4.Mar(m;22;03)	1.5489	1.9285	1.3114	3.3748
5.Lui(m;23;08)	-0.8297	-1.3234	-0.2068	1.4291
6.Car(m;25;05)	1.0607	-0.1657	-1.4832	3.0163
7.Fra(m;23;05)	1.1294	-0.5790	1.9267	1.8794
8.Cri(m;28;01)	1.4195	-2.2980	0.7672	-0.0601
9.Fab(m;22;05)	0.3823	-0.6039	0.9930	-0.2334
10.Sil(f;23;10)	1.3375	0.8472	-0.9915	-1.1780
11.Ale(m;25;06)	1.9929	-0.9587	-0.6225	-2.1745
12.Vic(m;31;11)	1.8070	1.2805	0.1793	-1.2193
13.Zos(f;24;00)	1.0416	-0.4374	-0.0683	3.0257
14.Edu(m;30;02)	0.6660	-0.3795	0.4242	0.3478
15.Tan(f;24;00)	0.9655	0.4111	1.6078	-2.0343
16.Ric(m;30;03)	-0.2454	-0.0540	0.4794	-2.1362
17.Cla(f;21;08)	0.9422	-3.6138	-0.6158	-2.9518
18.Ami(m;24;09)	-0.6002	-0.1649	-0.3778	2.9077
Mean - movement	*0.8574*	*-0.4684*	*0.2630*	*0.6719*

Table 7. Movement: coordinates of individuals in the space of factors.

physicists	Principal Component 1	Principal Component 2	Principal Component 3	Principal Component 4
1.Cel(m;23;05)	-2.1784	-0.9452	0.9620	0.6811
2.Iza(f;21;11)	-2.2331	-1.3306	-1.0540	4.6421
3.Gui(m;22;11)	-4.5117	1.3414	-1.1895	1.1238
4.Mar(m;22;03)	-1.0530	0.7602	-1.3075	-2.8812
5.Lui(m;23;08)	-3.4224	0.9374	-4.6074	0.7174
6.Car(m;25;05)	-2.2769	-0.6310	-0.9872	1.5160
7.Fra(m;23;05)	-0.3314	3.6392	-0.6215	-3.2979
8.Cri(m;28;01)	-3.3789	0.3259	-0.1669	5.9315
9.Fab(m;22;05)	*	*	*	*
10.Sil(f;23;10)	-3.3189	-0.0994	-1.0101	-1.1195
11.Ale(m;25;06)	-2.8384	-0.7375	0.9660	-0.8342
12.Vic(m;31;11)	-1.3389	-0.6413	2.8011	0.0085
13.Zos(f;24;00)	-1.1741	-0.5296	0.4033	1.4503
14.Edu(m;30;02)	-1.7758	-0.3173	0.4515	3.6714
15.Tan(f;24;00)	-0.6826	-1.3621	2.3273	-2.4089
16.Ric(m;30;03)	-1.1883	-1.3012	-1.1432	-1.7438
17.Cla(f;21;08)	-2.7393	-1.6381	-0.6584	-0.8348
18.Ami(m;24;09)	-3.5051	0.2785	-2.0074	2.6582
Mean - mass	*-2.2978*	*-0.0695*	*-0.5562*	*0.7473*

Table 8. Mass: coordinates of individuals in the space of factors.

physicists	Principal Component 1	Principal Component 2	Principal Component 3	Principal Component 4
1.Cel(m;23;05)	-1.3157	-0.0729	0.5510	0.5596
2.Iza(f;21;11)	-3.1414	0.6607	1.8579	2.6309
3.Gui(m;22;11)	-1.5324	1.3297	2.1731	1.7954
4.Mar(m;22;03)	2.4640	3.1084	2.1500	-3.8630
5.Lui(m;23;08)	-2.8933	3.4530	-1.5668	-1.1430
6.Car(m;25;05)	-2.0783	1.0142	1.0699	1.9280
7.Fra(m;23;05)	-0.7798	0.6460	-0.0128	1.4662
8.Cri(m;28;01)	-3.8741	0.6408	2.0056	4.2755
9.Fab(m;22;05)	-0.8324	1.9535	1.8091	-3.2439
10.Sil(f;23;10)	-1.9148	0.3430	0.6501	2.0052
11.Ale(m;25;06)	-1.7174	1.1079	0.9731	-1.7264
12.Vic(m;31;11)	-0.6232	0.8859	2.6350	-1.0890
13.Zos(f;24;00)	-0.7130	-0.3463	1.7064	-2.4126
14.Edu(m;30;02)	0.6167	2.4319	0.9968	1.7457
15.Tan(f;24;00)	2.0261	3.2800	0.7362	0.4717
16.Ric(m;30;03)	-0.4745	2.3503	0.6697	-1.9815
17.Cla(f;21;08)	-1.1056	-2.5207	0.5823	-0.6065
18.Ami(m;24;09)	-1.2014	5.0747	0.1645	0.0262
Mean - charge	*-1.0069*	*1.4561*	*0.9642*	*-0.2459*

Table 9. Charge: coordinates of individuals in the space of factors.

physicists	Principal Component 1	Principal Component 2	Principal Component 3	Principal Component 4
1.Cel(m;23;05)	-0.6602	-1.1802	-1.4886	3.7670
2.Iza(f;21;11)	1.2765	-2.5210	-1.4337	-1.0414
3.Gui(m;22;11)	2.9015	-1.9095	-2.0907	-1.7049
4.Mar(m;22;03)	-0.6397	-0.5963	-0.3007	3.2774
5.Lui(m;23;08)	-1.0079	-3.7751	-0.3757	-3.0675
6.Car(m;25;05)	-0.6374	-0.7746	-1.1602	4.0196
7.Fra(m;23;05)	-0.0731	-4.9337	0.0336	-1.8238
8.Cri(m;28;01)	1.8562	-1.9599	-0.3610	-0.5344
9.Fab(m;22;05)	0.6291	-1.2178	-0.2190	-2.0020
10.Sil(f;23;10)	0.0474	-0.6199	-1.2029	-1.4935
11.Ale(m;25;06)	0.9657	-1.9280	-2.3542	-2.6535
12.Vic(m;31;11)	0.8221	0.2860	1.7572	-3.5498
13.Zos(f;24;00)	-0.1745	-0.4987	-2.1266	0.5890
14.Edu(m;30;02)	0.8689	-2.9218	-1.3091	1.5206
15.Tan(f;24;00)	1.9533	-1.3061	-0.4860	-2.7260
16.Ric(m;30;03)	0.3642	-1.3269	-1.2832	-1.5008
17.Cla(f;21;08)	0.5902	-2.7190	-1.8502	1.2935
18.Ami(m;24;09)	-0.0014	-1.8119	-1.9783	3.4363
Mean - sound	*0.5267*	*-1.6316*	*-1.1593*	*-0.1424*

Table 10. Sound: coordinates of individuals in the space of factors.

physicists	Principal Component 1	Principal Component 2	Principal Component 3	Principal Component 4
1.Cel(m;23;05)	-0.2631	-2.0909	-0.5378	1.3279
2.Iza(f;21;11)	0.4596	-0.3773	-1.0129	4.8405
3.Gui(m;22;11)	0.9740	-0.9335	-2.6728	-3.6892
4.Mar(m;22;03)	0.8912	-0.6061	-0.7310	3.6876
5.Lui(m;23;08)	-1.9496	-2.4664	2.3269	-4.7502
6.Car(m;25;05)	-0.3738	-0.6405	0.8783	1.3534
7.Fra(m;23;05)	1.0787	-0.5399	0.7677	2.9169
8.Cri(m;28;01)	1.8562	-1.9599	-0.3610	-0.5344
9.Fab(m;22;05)	0.1376	-1.0022	1.4742	-2.1023
10.Sil(f;23;10)	-0.3215	1.1411	-0.3435	0.2345
11.Ale(m;25;06)	0.9980	-1.6182	-0.9397	-2.8921
12.Vic(m;31;11)	1.2221	2.4207	2.6005	-0.8458
13.Zos(f;24;00)	1.0596	-1.4704	-1.5365	-2.7329
14.Edu(m;30;02)	0.3390	-2.8257	-1.3617	0.9882
15.Tan(f;24;00)	2.2613	-0.6003	-1.1830	-1.5729
16.Ric(m;30;03)	0.1494	-0.1621	-0.8071	-1.3816
17.Cla(f;21;08)	0.5720	-2.8375	-1.6352	1.4640
18.Ami(m;24;09)	-0.7932	-0.3903	-0.3741	4.2076
Mean - heat	*0.6111*	*-1.1454*	*-0.0710*	*-0.0798*

Table 11. Heat: coordinates of individuals in the space of factors.

physicists	Principal Component 1	Principal Component 2	Principal Component 3	Principal Component 4
1.Cel(m;23;05)	-0.4289	-0.8738	-1.0763	4.8035
2.Iza(f;21;11)	0.6044	1.5927	-2.1836	1.5961
3.Gui(m;22;11)	1.4418	-1.3168	-0.3409	0.0516
4.Mar(m;22;03)	2.1537	1.8530	0.7839	-0.5042
5.Lui(m;23;08)	-2.0792	-1.3944	-2.9429	-3.2783
6.Car(m;25;05)	0.3004	1.6137	0.4536	4.1624
7.Fra(m;23;05)	1.2521	1.7796	-2.0483	4.4247
8.Cri(m;28;01)	1.5172	-2.3309	0.9551	0.1833
9.Fab(m;22;05)	0.9050	0.3298	1.0244	0.3780
10.Sil(f;23;10)	0.5159	0.6323	0.7778	2.8516
11.Ale(m;25;06)	-0.0473	0.7082	-2.1723	0.1127
12.Vic(m;31;11)	1.2227	2.1860	1.9897	-0.4525
13.Zos(f;24;00)	0.3888	-0.5016	-1.3899	2.3142
14.Edu(m;30;02)	1.1275	3.9828	0.5785	3.4369
15.Tan(f;24;00)	0.1828	1.1242	-0.8222	0.5600
16.Ric(m;30;03)	-0.4361	0.9170	-0.3520	2.0081
17.Cla(f;21;08)	-1.4097	-1.0636	-0.9595	1.6429
18.Ami(m;24;09)	0.6539	0.9977	-2.7837	-5.1757
Mean - gravity	*0.3345*	*0.5348*	*-0.7034*	*1.3890*

Table 12. Gravity: coordinates of individuals in the space of factors.

physicists	Principal Component 1	Principal Component 2	Principal Component 3	Principal Component 4
1.Cel(m;23;05)	0.9288	-1.1715	-0.2857	-1.5907
2.Iza(f;21;11)	-0.2979	-1.2421	1.8314	1.2837
3.Gui(m;22;11)	-0.4946	0.5365	2.4979	1.6934
4.Mar(m;22;03)	2.3014	3.1172	0.9465	-2.7588
5.Lui(m;23;08)	0.3218	0.2452	2.3138	-5.4099
6.Car(m;25;05)	-0.3151	1.5874	1.4474	-1.1751
7.Fra(m;23;05)	0.2366	1.3708	3.7447	-0.5526
8.Cri(m;28;01)	-0.1367	-2.8715	3.3980	-2.2021
9.Fab(m;22;05)	2.6603	1.8808	2.0734	-4.8315
10.Sil(f;23;10)	1.9691	1.3284	1.8358	-4.0204
11.Ale(m;25;06)	-0.1479	-0.4399	1.3654	-0.3579
12.Vic(m;31;11)	-0.6052	0.6498	2.2467	-0.8243
13.Zos(f;24;00)	-0.3377	-0.6203	0.8509	-0.7769
14.Edu(m;30;02)	1.8150	4.6995	1.9559	1.1232
15.Tan(f;24;00)	0.6079	1.0130	0.6273	-1.9597
16.Ric(m;30;03)	-0.0558	1.7248	1.4625	-2.0746
17.Cla(f;21;08)	-0.8363	-1.2634	-0.2580	0.1418
18.Ami(m;24;09)	-0.1757	0.7843	-0.3912	-1.8113
Mean - photon	*0.3218*	*0.4065*	*1.7410*	*-1.7307*

Table 13. Photon: coordinates of individuals in the space of factors.

physicists	Principal Component 1	Principal Component 2	Principal Component 3	Principal Component 4
1.Cel(m;23;05)	-0.6196	-0.6745	0.0738	3.5394
2.Iza(f;21;11)	1.3079	-0.5126	-1.5656	-0.8017
3.Gui(m;22;11)	1.3103	2.8153	1.3755	-0.3442
4.Mar(m;22;03)	2.1321	-0.8173	0.0861	-1.5898
5.Lui(m;23;08)	0.1943	0.4752	2.2785	-4.7375
6.Car(m;25;05)	0.4183	-0.9866	-0.9906	-2.0760
7.Fra(m;23;05)	0.3146	-1.9759	1.3458	-1.6060
8.Cri(m;28;01)	-0.1367	-2.8715	3.3980	-2.2021
9.Fab(m;22;05)	-0.4711	-0.9651	1.9692	-0.2969
10.Sil(f;23;10)	0.1746	0.6601	-0.2006	2.1827
11.Ale(m;25;06)	1.2172	-1.4863	-1.4796	-2.4536
12.Vic(m;31;11)	-0.0754	0.5537	2.2993	-0.2918
13.Zos(f;24;00)	-0.2492	-0.5392	0.6540	-2.2930
14.Edu(m;30;02)	0.9142	-0.7628	0.5061	-1.4846
15.Tan(f;24;00)	0.7339	1.2181	-0.9821	2.0128
16.Ric(m;30;03)	-0.4361	0.9170	-0.3520	2.0081
17.Cla(f;21;08)	-0.8257	-2.1477	-1.5969	-0.3177
18.Ami(m;24;09)	1.2416	-1.0614	-0.1601	-2.3808
Mean - electricity	*0.3898*	*-0.8652*	*0.5331*	*-0.6385*

Table 14. Electricity: coordinates of individuals in the space of factors.

Tables for interviews:

Correlation of results by questionnaires and interviews for 16-18 year-old

features	matter	energy	heat	sound	light	gravity	force	mass
can see it	11	3	2	0	5	1	1	9
can touch it	14	1	1	0	2	0	0	12
can hear it	1	1	2	14	1	0	0	1
can feel it	4	10	15	2	9	5	5	3
can touch through	7	2	1	1	0	2	2	7
c an see effects	1	9	8	1	7	3	4	1
can transfer it	4	6	4	0	4	1	4	4
can conserve it	3	7	6	0	4	2	4	3
can create it	2	5	3	1	3	2	3	2
can spread it	4	2	3	1	2	1	2	4
can concentrate it	5	4	2	0	2	1	3	5
can destroy it	5	1	0	0	0	1	1	5
can transform it	4	4	5	0	3	2	2	4
can stop it	1	1	1	1	2	2	3	1
can't do anything	0	0	0	0	0	4	0	0
like a solid	11	1	1	0	1	0	0	11
like a gas	0	1	1	1	1	3	1	1
like particles	7	2	2	1	2	2	2	6
like a force	0	7	6	1	5	9	15	2
like a wave	0	5	5	7	7	2	2	0
like a fluid	1	2	1	1	2	1	3	1
like movement	0	4	3	4	4	1	3	0
like a field	1	3	3	3	5	7	4	0
like a substance	6	0	0	0	1	0	0	5
like a place	1	1	1	1	1	6	2	1
like a vacuum	0	1	2	3	1	4	1	0
like an energy	1	13	13	3	10	3	4	0
macroscopic	8	0	0	0	0	1	0	8
microscopic	6	0	0	0	0	0	0	5
an effect	1	3	4	2	3	4	4	1
a cause	0	5	6	1	4	3	7	0
can be inside it	1	0	1	2	0	3	2	2
it is nowhere	0	1	1	1	1	3	1	0
it is localized	4	3	5	1	3	2	1	4
imaterial	0	4	4	3	5	3	3	1
imaginary	2	2	2	1	2	5	2	1
real	8	3	3	2	4	3	2	7
material	11	1	2	0	1	2	2	11
at rest	0	1	3	2	1	2	1	0
concrete	12	1	1	1	2	2	1	12
like an action	0	4	3	1	3	5	8	0
act by contact	1	8	7	0	6	3	5	1
act at distance	0	6	5	6	7	4	3	1
act by itself	0	2	3	3	2	2	2	0
destroy things	0	9	9	1	9	5	6	0
create things	1	7	6	1	5	3	4	1
transform things	0	8	8	2	8	4	5	0
transfer things	0	6	4	2	5	5	9	0
cause movement	0	10	8	2	6	11	15	1
exist without acting	4	0	0	1	0	2	1	5
spread by itself	0	5	7	4	5	2	2	0
concentrate by itself	0	3	2	2	2	2	3	0
multiply by itself	1	4	3	2	4	2	3	0
appear and disappear	0	3	3	2	3	3	5	0
CORRELATION	**0.760**	**0.749**	**0.678**	**0.549**	**0.456**	**0.573**	**0.625**	**0.829**

Table 1. Number of times an entity was grouped with a feature during interviews and the correlations obtained with the frequencies of 'yes' responses of the first study.

(Pearson Product-Moment Correlations).

features	time	space	atom	atmosphere	movement	weight	temperature
can see it	0	1	6	0	3	4	2
can touch it	0	0	7	0	0	4	1
can hear it	1	1	1	2	1	0	0
can feel it	3	1	2	0	4	3	11
can touch through	0	2	5	0	1	3	2
c an see effects	4	0	2	0	4	2	6
can transfer it	0	0	3	0	3	1	4
can conserve it	2	0	2	1	3	1	8
can create it	1	0	1	0	3	1	3
can spread it	0	0	3	0	1	2	3
can concentrate it	0	0	5	0	1	1	3
can destroy it	0	0	4	1	1	3	0
can transform it	1	2	1	0	2	3	2
can stop it	1	0	1	0	4	3	1
can't do anything	3	4	1	4	0	0	0
like a solid	0	0	8	0	0	5	1
like a gas	1	3	1	7	1	1	1
like particles	0	2	12	3	2	4	2
like a force	3	2	0	1	11	11	7
like a wave	2	1	1	1	2	2	4
like a fluid	1	1	1	1	2	1	1
like movement	3	2	3	1	5	1	2
like a field	2	6	2	6	3	4	3
like a substance	0	0	3	0	0	1	0
like a place	0	11	1	8	2	2	1
like a vacuum	3	6	0	7	1	1	1
like an energy	1	1	1	1	4	2	9
macroscopic	1	2	4	2	0	3	0
microscopic	1	1	10	1	0	2	0
an effect	3	0	1	1	4	2	4
a cause	1	1	1	1	5	4	5
can be inside it	7	9	1	10	1	0	1
it is nowhere	4	3	0	4	1	1	1
it is localized	1	3	5	2	1	2	4
imaterial	5	1	0	2	5	3	4
imaginary	3	4	4	6	1	3	2
real	1	1	4	0	2	5	2
material	1	1	5	0	1	7	1
at rest	1	3	0	3	1	1	1
concrete	0	2	7	1	1	6	1
like an action	3	1	0	2	9	6	3
act by contact	2	0	2	0	6	2	5
act at distance	3	1	0	2	4	3	4
act by itself	5	1	2	1	1	2	3
destroy things	1	1	1	1	5	4	7
create things	2	1	1	1	3	3	5
transform things	2	1	0	1	4	3	5
transfer things	2	1	0	1	6	5	5
cause movement	4	2	1	1	8	8	8
exist without acting	5	5	2	4	1	2	0
spread by itself	1	2	2	2	2	2	4
concentrate by itself	1	2	1	2	2	2	4
multiply by itself	2	2	1	2	2	2	3
appear and disappear	0	1	1	1	3	4	3
CORRELATION	**0.755**	**0.700**	**0.589**	**0.548**	**0.645**	**0.384**	**0.753**

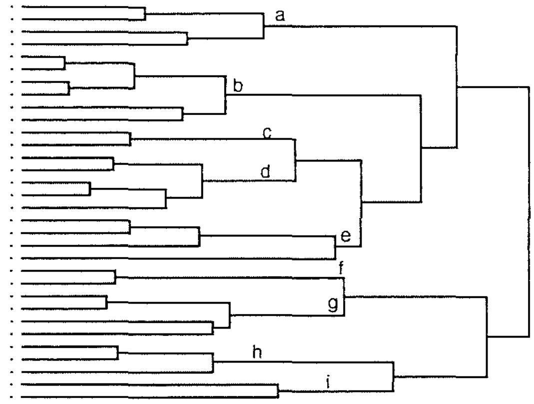
Table 1. Number of times an entity was grouped with a feature during interviews and the correlations obtained with the frequencies of 'yes' responses of the first study (continued).

features	impulse	vacuum	microwave	electricity	radioactivity	solar radiation	magnetism
can see it	1	0	1	1	2	3	1
can touch it	0	0	0	0	0	1	0
can hear it	0	1	6	1	0	0	0
can feel it	5	0	3	4	2	6	3
can touch through	2	0	1	2	0	0	2
c an see effects	4	0	3	9	7	9	5
can transfer it	3	0	0	4	1	3	2
can conserve it	5	0	1	4	1	3	4
can create it	2	0	0	3	1	2	2
can spread it	2	0	2	2	1	1	2
can concentrate it	3	0	1	5	3	1	2
can destroy it	1	0	0	1	0	0	0
can transform it	2	0	2	3	2	3	3
can stop it	2	0	2	1	1	1	1
can't do anything	0	5	0	0	0	1	1
like a solid	0	0	0	1	0	0	0
like a gas	1	4	1	1	1	1	2
like particles	2	1	1	2	4	2	3
like a force	12	2	2	7	3	5	5
like a wave	2	1	14	6	6	7	6
like a fluid	2	1	3	4	4	4	3
like movement	2	1	3	4	3	3	3
like a field	3	4	6	5	5	6	6
like a substance	0	0	0	0	0	0	0
like a place	2	8	1	1	1	1	2
like a vacuum	1	11	2	1	1	1	2
like an energy	4	1	3	8	5	9	6
macroscopic	0	0	0	0	0	0	0
microscopic	0	0	1	1	1	0	1
an effect	4	0	2	4	5	5	3
a cause	6	1	2	4	4	6	3
can be inside it	1	5	0	0	0	1	0
it is nowhere	1	5	1	1	1	1	2
it is localized	1	0	2	3	1	2	1
imaterial	3	4	3	4	2	4	3
imaginary	2	4	2	2	3	2	3
real	2	0	2	2	1	2	1
material	2	1	0	0	0	1	0
at rest	1	6	2	1	1	1	1
concrete	1	1	1	1	1	1	1
like an action	8	1	2	4	2	4	2
act by contact	4	0	4	8	7	8	5
act at distance	4	1	4	4	5	7	4
act by itself	1	1	2	2	2	1	3
destroy things	5	1	6	9	10	9	6
create things	4	1	1	6	3	4	3
transform things	5	2	7	10	8	9	6
transfer things	9	1	3	7	3	6	4
cause movement	13	2	2	9	4	4	6
exist without acting	2	6	0	0	0	0	0
spread by itself	2	2	2	4	2	4	2
concentrate by itself	3	3	1	3	1	2	2
multiply by itself	3	2	1	3	1	2	2
appear and disappear	6	1	3	3	2	2	2
CORRELATIONS	**0.625**	**0.596**	**0.619**	**0.697**	**0.734**	**0.604**	**0.646**

Table 1. Number of times an entity was grouped with a feature during interviews and the correlations obtained with the frequencies of 'yes' responses of the first study (continued).

Appendix I:
Results of the cluster Analysis.

Cluster Analysis for 8-10 year-olds (complete linkage method).



Cluster Analysis 8-10 year-olds.
(complete linkage method)

Clusters: **(from top)**

a: appear and disappear, act at a distance, immaterial, nowhere
b: move things, action, movement, hear, force, stop
c: rest, fluid
d: somewhere, destroy it, concrete, solid, spread
e: create things, touch, create it, see
f: act by itself, gas
g: transform things, feel, destroy things, act by contact
h: inside, place, can't do anything to it
i: real, imaginary

Clusters in Ontological Space (Multidimensional Scaling).

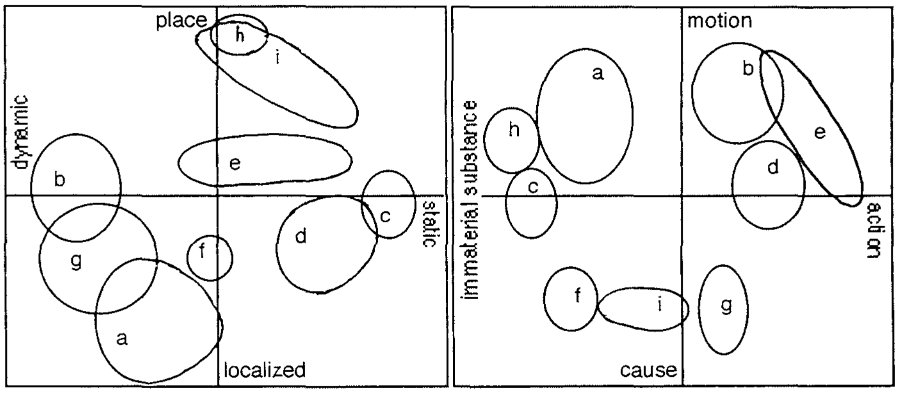
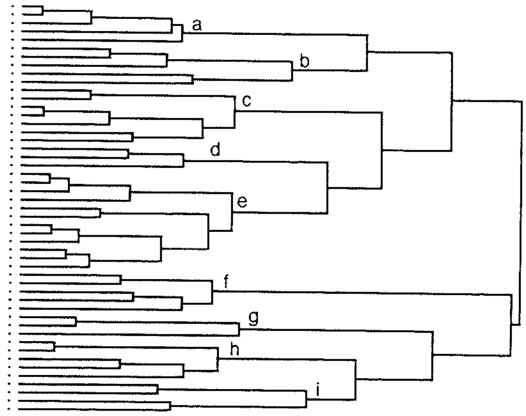


Fig 1. Clusters in ontological space for 8-10 year-olds.

Cluster Analysis for 13-14 year-olds (complete linkage method).



Clusters: (from top)

a: cause movemement, force, action, stop, movement
b: effect, see effects, wave, create it, hear
c: fluid, touch throught, transfer it, spread it, concentrate it, appears and disappears, act at a distance
d: gas, see, rest
e: somewhere, conserve, particles, real, destroy it, transform it, microscopic, substance,
touch, macroscopic, concrete, solid
f: transform things, feel, destroy things, act by contact, create things
g: inside, place, exist without acting
h: multiply by itself, act by itself, concentrate by itself, spread by itself,immaterial
i: nowhere, cause, imaginary, can't do anything to it

Clusters in Ontological Space(Multidimensional Scaling).

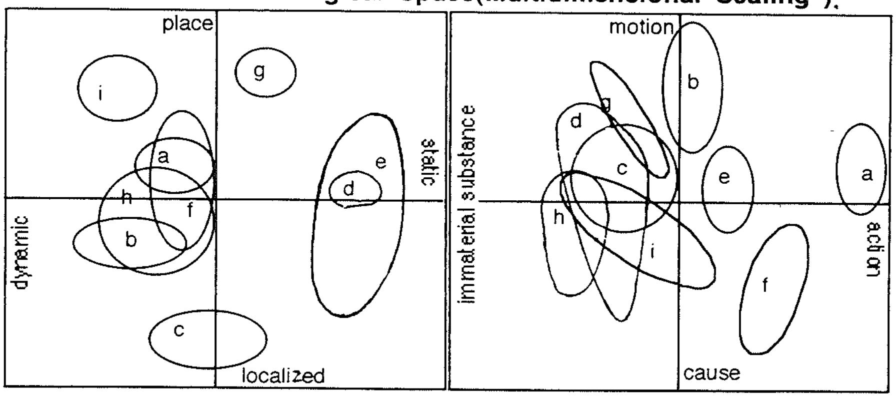
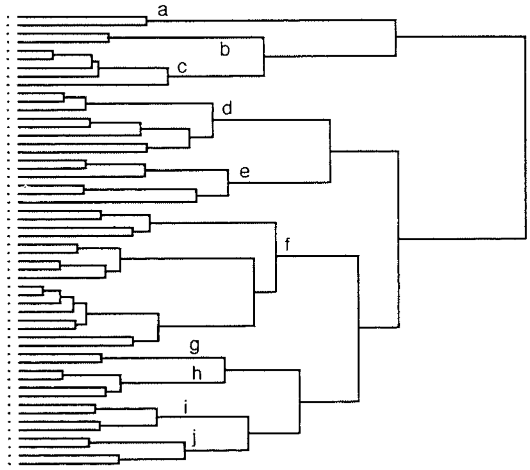


Fig. 2. Clusters in ontological space for 13-14 year-olds.

Cluster Analysis for 16-18 year-olds.
(complete linkage method).



Clusters: (from top)
a: microscopic, particles
b: imaginary, field
c: movement, force, cause movement, transfer things, nowhere
d: vacuum, place, inside, act by itself, gas, can't do anything to it, exist without acting, rest
e: cause, stop, feel, appear and disappear, effect, hear
f: create it, transfer it, act by contact, transform it, real, localized, spread it, conserve it,
touch throught it, material, touch, solid, concrete, substance, destroy it, macroscopic
g: multiply by itself, concentrate by itself
h: transform things, destroy things, create things, concentrate things
i: spread it, act at a distance, immaterial, fluid
j: action, see effects, energy, wave

Clusters in Ontological Space(Multidimensional Scaling).

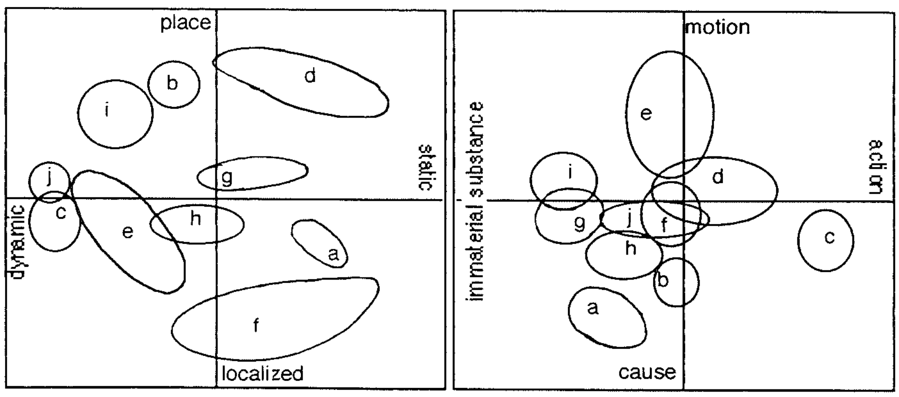
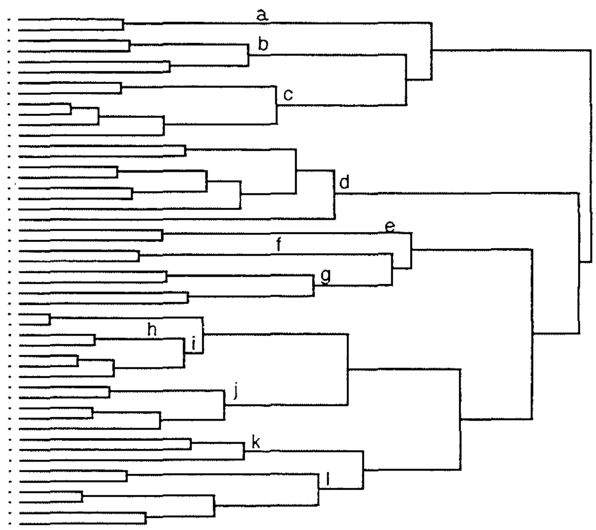


Fig. 3. Clusters in ontological space for 16-18 year-olds.

Cluster Analysis for young working adults (complete linkage method).



Clusters: (from top)

a: inside, place
b: concentrate by itself, gas, rest, touch throught
c: macroscopic, see, solid, touch, concrete, substance
d: wave, hear, action, force, create it, stop it, cause movement, movement
e: multiply by itself, spread by itself
f: microscopic, particles
g: exist without acting, can't do anything to it, act by itself, imaginary
h: effect, cause
i: immaterial, fluid, appear and disappear, act at a distance, nowhere
j: somewhere, conserve it, concentrate it, spread it, transfer it
k: transform things, feel, real
l: destroy things, see effects, create things, transform it, act by contact,destroy it

Clusters in Ontological Space(Multidimensional Scaling).

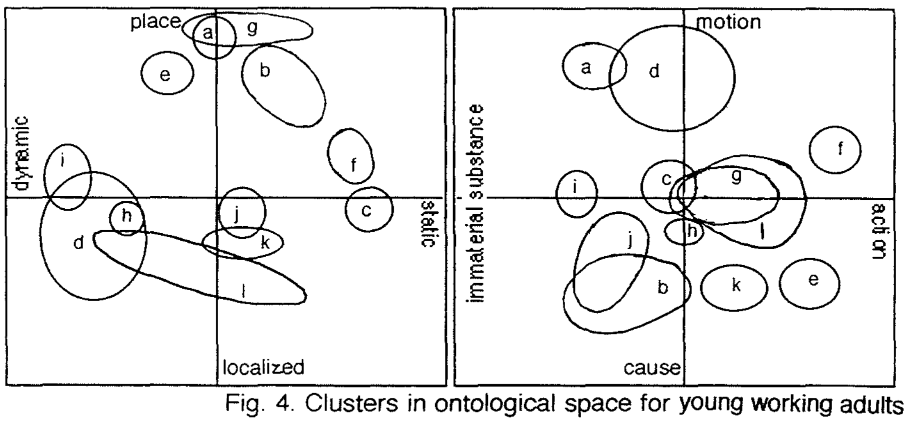
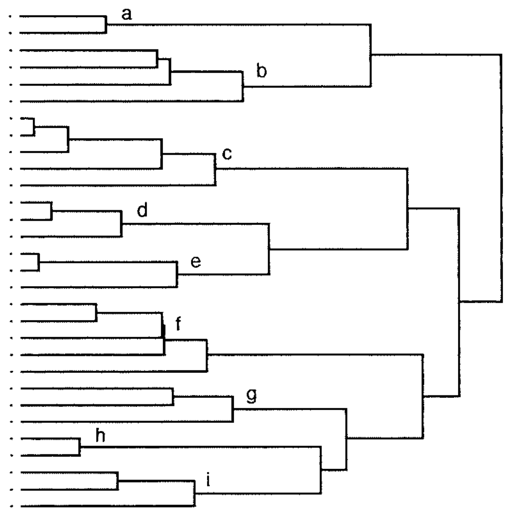
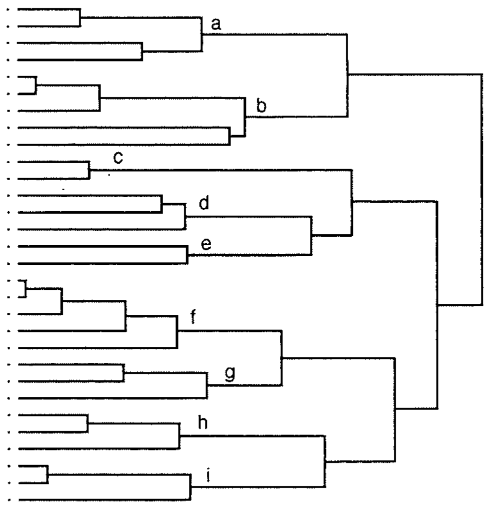


Fig. 4. Clusters in ontological space for young working adults.





Clusters: (from top)

Clusters1 (correlations using common entities):

a: inside, place
b: act by itself, imaginary, immaterial, nowhere
c: concrete, solid, touch, destroy it, see
d: action, force, movement
e: stop , create it, hear
f: destroy things, transform things, create things, feel, act by contact
g: fluid, gas, rest
h: appear and disappear, act at a distance
i: real, spread it, somewhere

Clusters 2 (correlations using all entities):

a: transform things, feel, destroy things, act by contact
b: action, force, movement, create things, nowhere
c: inside, place
d: act by itself, imaginary, immaterial
e: rest, gas
f: concrete, solid, touch, destroy it, see
g: somewhere, spread it, real
h: appear and disappear, act at a distance, fluid
i: stop, create it, hear

Clusters in Ontological Space (Multidimensional Scaling-INDSCAL).

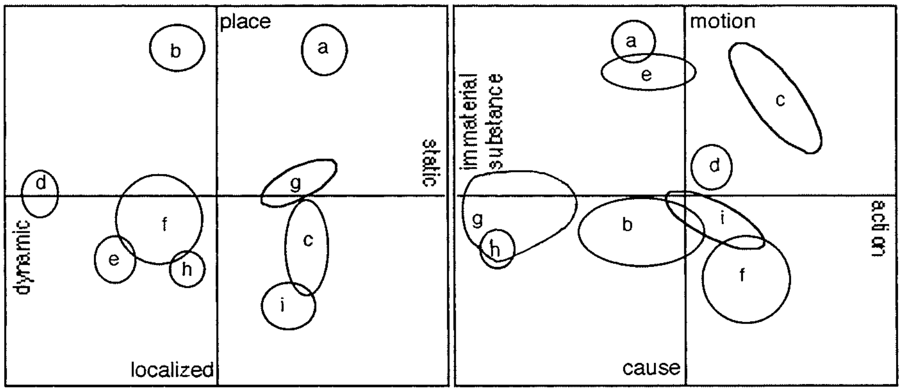


figure 6. Clusters in ontological space for all groups considering only common entities.

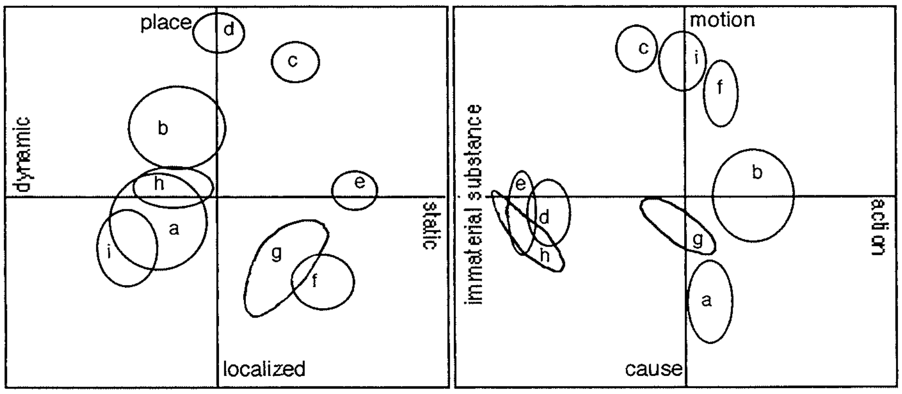


Figure 7. Clusters in ontological space for all groups considering all entities.

Appendix J:
Examples of responses categorised in the second study.

Codes:
In bold: Category used in the Network constructed (tables 3.6 and 3.7).
In italic: Sub-category used.
Underlined: Sub-category closer to actual response obtained.
"...": Example of response categorised.
(in brackets): (The response is about something...(real for example); the response is presented in complete or partial form - if partial the response is categorised in more than one category; individual identification (initials; age; years-old; months; sec. for secondary student or phys. for undergraduate physicists)

Examples:

Accessibility (What you can or cannot do..)

To sensory activity:

<u>See it:</u>

"You can see it..."(concrete; partial; Mar(m;17;04;sec.))

"That which we can see..."(real; partial;Sil(f;23;10;phys.))

<u>Can't see it:</u>

"We can't see it..."(abstract;partial;Pri(f;17;01;sec.))

"Something you can't see"(abstract;complete;Reg(f;16;10;sec.))

<u>Touch(hold) it:</u>

"...you can touch it..."(material;partial;Lin(f;17;01;sec.))

"It is touchable..."(concrete;partial;Cla(f;21;08;phys.))

<u>Can't touch(hold) it:</u>

"... you can't hold it ..."(immaterial;partial;Luc(f;16;08;sec.))

"Something which is not touchable..."(abstract;partial;Zos(f;24;00;phys.))

<u>Feel it:</u>

"...we can feel it..."(real;partial;Ale(m;17;08;sec.))

"You can feel it..."(concrete;partial;Car(m;25;05;phys.))

<u>Can't feel it:</u>

"We can't feel it"(immaterial;complete;Luc(f;18;08;sec.))

<u>Perceive it:</u>

"Something which manifests itself to our senses"(object;complete;Ale(m;17;08;sec.))

"Something perceptible"(material;complete;Reg(f;16;10;sec.))

"It reaches the senses"(concrete;complete;Gui(m;22;11;phys.))

<u>Can't perceive it:</u>

"Something which we do not perceive..."(immaterial;partial;Reg(m;16;00;sec.))

"It doesn't reach the senses"(abstract;complete;Gui(m;22;11;phys.))

To motor activity:

Keep it:

"You can keep it"(conserved;complete;Pat(f;18;04;sec.))

"That which can be kept as a complete even if the parts change"(conserved;complete;Vic(m;31;11;phys.))

Can't keep it:

"It isn't kept..."(not conserved;partial;Luc(f;17;06;sec.))

"It is not kept..."(not conserved;partial;Vic(m;31;11;phys.))

Transform it:

"...it is transformed"(conserved;partial;Mar(m;18;11;sec.))

"It is transformed"(not conserved;complete;Edu(m;30;02;phys.))

Can't transform it:

"It can't be transformed"(not conserved;complete;Jul(f;18;04;sec.))

"...it is not transformed"(conserved;partial;Edu(m;30;02;phys.))

Do(create)it:

"Something you do to do something"(action;complete;Ale(m;18;02;sec.))

Can't do(create it):

"...it is not created..."(conserved;partial;Iza(f;21;11;phys.))

Move(displace)it:

No cases

Can't move(displace)it:

"It is immovable"(static;complete;Car(m;25;05;phys.))

To thought:

Understand it:

" ...can be understood in a concrete manner"(substance;partial;Mar(m;18;11;sec.))

"... can be understood by means of a mental exercise"(abstract;partial;Mar(m;22;03;phys.))

Imagine(in mind)/idea:

"Only in imagination"(vacuum;complete;Mar(m;16;09;sec.))

"It comes from our mind, a bit of intuition"(abstract;complete;Edu(m;30;02;phys.))

Can't imagine:

"You cannot even imagine it..."(vacuum;partial;Ale(m;17;08;sec.))

Prove(explain)it:

"It was proved"(concrete;complete;Mar(m;18;11;sec.))

Can't prove(explain)it:

"We can't prove its existence"(imaginary;complete;Luc(f;17;06;sec.))

"Has no physical explanation"(imaginary;complete;Ale(m;17;08;sec.))

Divide it (as one wishes to):

"Can be indefinitely divided "(continuous;complete;Ale(m;25;06;phys.))

Can't divide it:

"Indivisible"(discrete;complete;Ami(m;24;09;phys.))

Divide to a certain point:

"That which cannot be divided infinitively"(discrete;complete;Ale(m;25;06;phys.))

Activity(What it does or not...)

Changes/moves things:

"It changes something"(active;complete;Luc(f;18;08;sec.))

"It is what moves things"(action;complete;Cel(m;23;05;phys.))

Doesn't change/move things:

"It does not change anything"(passive;complete;Ale(m;18;02;sec.))

"Something which doesn't change the environment"(passive;complete;Ale(m;25;06;phys.))

Act(react,interact) on things:

"It acts on something"(active;complete;Jul(f;18;04;sec.))

"Something which interacts"(active;complete;Zos(f;24;00;phys.))

Doesn't act(react,interact)on things:

"It doesn't act upon anything"(passive;complete;Reg(f;16;10;sec.))

"It doesn't react"(passive;complete;Edu(m;30;02;phys.))

Makes something(effects) happen:

"It makes something happen"(cause;complete;Luc(f;17;06;sec.))

"Something which provokes some modification"(cause;complete;Zos(f;24;00;phys.))

Doesn't make anything happen:

"It doesn't make anything happen"(passive;complete;Lil(f;16;11;sec.))

"It doesn't do anything"(passive;complete;Cla(f;21;08;phys.))

It changes:

"It changes when there is a phenomenon, losing its characteristics"(not conserved; complete; Mar(f;17;10;sec.))

"That which can change,..."(not conserved;partial;Fab(m;22;05;phys.))

Doesn't change:

"Something which doesn't change,..."(conserved;partial;Pri(f;17;01;sec.))

"It does not change"(conserved;complete;Cla(f;21;08;phys.))

It disappears(finishes,destroyed,lost):

"After a phenomenon it disappears, only happening during the phenomenon"(not conserved;complete;Mar(m;17;04;sec.))

"It scapes through my fingers"(not conserved;complete;Cla(f;21;08;phys.))

It isn't destroyed(lost):

"It will not disappear in time..."(conserved;partial;Luc(f;17;04;sec.))

"It is not lost..."(conserved;partial;Iza(f;21;11;phys.))

Stays the same(quantity)/constant:

"It will always stay the same"(passive;complete;Luc(f;16;09;sec.))

"That which you had before is the same afterwards"(conserved;complete;Lui(m;23;08;phys.))

Doesn't stay the same:

"It doesn't stay in its initial state"(not conserved;complete;Luc(f;16;11;sec.))

"After an action it is not possible to get back to the initial state"(not conserved;complete; Cri(m;28;01;phys.))

Relationships:

Causal:

Has cause:

"It is caused by something"(effect;complete;Mar(m;16;09;sec.))

Receives action:

"It receives the action"(passive;complete;Luc(f;16;11;sec.))

"It suffers the action"(passive;complete;Iza(f;21;11;phys.))

Origin of action/event:

"It provokes an action or force"(active;complete;Luc(f;16;08;sec.))

"Something which practises an action"(active;complete;Mar(m;22;03;phys.))

Consequence of action(cause, agent...):

"It is what resulted from an action"(effect;complete;Mar(m;18;11;sec.))

"Consequence or result of an action"(effect;complete;Vic(m;31;11;phys.))

It isn't a consequence:

"Moves by itself without previous help"(in motion;complete;Mar(m;17;04;sec.))

Needs cause to happen/change:

"It does not move with its own force"(static;complete;Jul(f;18;04;sec.))

"An event which pressuposes something which caused it"(cause;complete;Mar(m;22;03;phys.))

Doesn't need cause to happen/change:

"Moves without a force to maintain it"(in motion;complete;Reg(m;16;00;sec.))

Reason (cause, agent) of action(event):

"It is what gives the reason of an event"(cause;complete;Ale(m;17;08;sec.))

"It gives the "why" things happen"(cause;complete;Cla(f;21;08;phys.))

Temporal:

Before(beggining):

"It is the beggining of an action"(cause;complete;Ren(f;16;08;sec.))

"The beggining of the process"(cause;complete;Car(m;25;05;phys.))

After(end):

"It occurs after you did some action"(effect;complete;Luc(f;16;08;sec.))

"Appears after an interaction"(effect;complete;Ric(m;30;03;phys.))

Spatial:

Contains things/things(localized)in it:

"Things are contained in it"(place;complete;Luc(f;17;06;sec.))

"Where something is localised"(place;complete;Car(m;25;05;phys.))

It is contained/somewhere:

"It is contained in others"(localised;complete;Mar(m;17;04;sec.))

"It is found in some place"(localised;complete;Lui(m;23;08;phys.))

Part of action:

"It is a component of an action"(cause;complete;Luc(f;17;04;sec.))

Relative:

"Everything can be in motion depending on the reference"(in motion;complete;Lin(f;17;01;sec.))

"In relative motion"(dynamic;complete;Tan(f;24;00;phys.))

Do things in it:

"It is when you can do something in it"(place;complete;Mar(m;16;09;sec.))

"A space where something happens"(place;complete;Zos(f;24;00;phys.))

Can't do things in it:

"Where nothing acts"(vacuum;complete;Reg(m;16;00;sec.))

Properties(Made of/look like...)

It has form:

"It has a form..."(object;partial;Luc(f;16;08;sec.))

"...it has a form..."(material;partial;Sil(f;23;10;phys.))

Has no form:

"It has no form"(immaterial;complete;Mar(f;17;10;sec.))

"It has no form"(abstract;complete;Sil(f;23;10;phys.))

It is at rest:

"It is at rest"(static;complete;Luc(f;16;11;sec.))

"...it is at rest..."(conserved;partial;Edu(m;30;02;phys.))

It isn't at rest:

"It isn't at rest"(in motion;complete;Luc(f;16;09;sec.))

"It is not at rest"(dynamic;complete;Sil(f;23;10;phys.))

It is fixed:

"It is fixed in a determined place"(place;complete;Lil(f;16;11;sec.))

It has mass(matter...)/solid(particle...):

"It has matter"(material;complete;Luc(f;16;11;sec.))

"It has mass"(material;complete;Gui(m;22;11;phys.))

Doesn't have mass(matter...):

"It has no matter..."(immaterial;partial;Car(f;16;09;sec.))

"It is not constituted by matter, it has no mass"(immaterial;complete;Fab(m;22;05;phys.))

Like a force:

"It is a force"(action;complete;Pat(f;18;04;sec.)

Nothingness/empty:

"There is nothing"(vacuum;complete;Ale(m;18;02;sec.))

"Full of blank spaces("emptyness" not observable)"(discrete;complete;Tan(f;24;00;phys.))

Full:

"It is full"(object;complete;Pat(f;18;04;sec.))

It(really)exists:

"It is known to exist"(real;complete;Luc(f;17;04;sec.))

"Something which really exists"(real;complete;Iza(f;21;11;phys.))

Has smaller unity:

"Shows a basic unity in its composition"(discrete;complete;Ric(m;30;03;phys.))

Doesn't have a smaller unity:

"Quantity not subjected to any restriction like an elementary unity"(continuous;complete; Mar(m;22;03;phys.))

Support:

"It is a support"(place;complete;Tan(f;24;00;phys.))

Supported:

"It is supported"(localised;complete;Tan(f;24;00;phys.))

In relation to the other dimensions:

Conserved:

no cases

Not conserved:

no cases

Static:

no cases

In motion:

"It moves"(action;complete;Luc(f;17;04;sec.))

Dynamic:

"Dynamic reacting to adverse situations"(active;complete;Edu(m;30;02;phys.))

Active:

"It is in activity"(in motion;complete;Pri(f;17;01;sec.))

"..., active"(dynamic;partial;Edu(m;30;02;phys.))

Passive:

no cases

Substance:

"A determined substance or thing,..."(conserved;complete;Lui(m;17;02;sec.))

Action:

"It is action"(effect;complete;Pat(f;18;04;sec.))

Place:

no cases

Localized:

no cases

Cause:

"Causes movement to something"(action;complete;Reg(m;16;00;sec.))

"It is similar to..., cause,..."(substance;partial;Iza(f;21;11;phys.))

Effect:

"It is always an effect which not always can be compared"(abstract;complete;Luc(f;17;06;sec.))

"What is not in conditions to be a cause, which could be an effect of something else"(static; complete;Cel(m;23;05;phys.)s)

Material:

"It is material..."(concrete;partial;Luc(f;17;04;sec.))

"Something material..."(substance;partial;Ale(m;25;06;phys.))

Immaterial:

"It is immaterial"(abstract;complete;Luc(f;17;04;sec.))

"It is immaterial..."(action;partial;Vic(m;31;11;phys.))

Abstract:

"It is abstract"(immaterial;complete;Pat(f;17;02;sec.))

"Something abstract"(imaginary;complete;Zos(f;24;00;phys.))

Concrete:

"Something concrete..."(conserved;partial;Reg(f;16;10;sec.))

"Something concrete..."(substance;partial;Edu(m;30;02;phys.))

Real:

"It is real"(concrete;complete;Luc(f;16;11;sec.))

"Concept related to something real"(concrete;complete;Ale(m;25;06;phys.))

Imaginary:

"Something imaginary, mental things"(abstract;complete;Luc(f;16;08;sec.))

"...it is imaginary"(abstract;partial;Zos(f;24;00;phys.))

Object:

"It is an object"(material;complete;Lil(f;16;11;sec.))

Vacuum:

"A vacuum, I have no other idea"(immaterial;complete;Ale(m;17;08;sec.))

Discrete:

"It is similar to a discrete thing or object,..."(substance;partial;Iza(f;21;11;phys.))

Continuous:

"...something continuous"(substance;partial;Ale(m;25;06;phys.))

Not classified:

"It is stronger than time"(conserved;complete;Mar(m;16;09;sec.))

"That which has been done by nature, it is ready"(substance;complete;Car(f;16;09;sec.))

"Point of reference"(place;complete;Lin(f;17;01;sec.))

"It is an abyss"(vacuum;complete;Luc(f;16;11;sec.))

"It is beyond vision"(imaginary;complete;Pat(f;17;02;sec.))

"Here, there, somewhere"(place; complete;Edu(m;30;02;phys.))

"It is in itself"(place;complete;Ami(m;24;09;phys.))

"It is a point"(localised;complete;Fra(m;23;05;phys.))

"That which gives"(active;complete;Lui(m;23;08;phys.))

Examples:

"Space"(place;complete;Rei(m;18;10;sec.))

"Force"(action;complete;Pat(f;17;02;sec.))

"Matter"(conserved;complete;Rei(m;18;10;sec.))

"Time"(not conserved;complete;Ale(m;18;02;sec.))

"Heat always acts"(action;complete;Aff(m;18;03;sec.))

"The flow of a river"(continuous;complete;Edu(m;30;02;phys.))

Tautology:

"It moves"(in motion;complete;Luc(f;16;08;sec.))

"It doesn't move"(static;complete;Ale(f;17;05;sec.))

"It is localised"(localised;complete;Luc(f;16;09;sec.))

"Cause something"(cause;complete;Lil(f;16;11;sec.))

"It moves"(dynamic;complete;Cla(f;21;08;phys.))

"It is localised somewhere"(localised;complete;Gui(m;22;11;phys.))

Negation:

"Nothing is static, because even matter, or its atoms, are in motion"(static;complete;Lin(f;17;01;sec.))

"Nothing exists which is not conserved"(not conserved;complete;Cel(m;23;05;phys.))

"I think nothing is static"(static; complete; Fra(m;23;05;phys.))

Appendix K:

Summary Statistics

Introduction

In this Appendix a brief discussion of the techniques of analysis used in this research will be presented. These techniques are widely discussed in the literature (see for example Everitt and Dunn 1983; O'Muircheartaigh and Payne 1977; Child 1970 and Everitt 1974).

The following techniques were used:

1. Multidimensional Scaling;

2. Principal Components Analysis;

3. Cluster Analysis.

The aim of these techniques is a simplified description of the structure of the observations. In the present research we asked individuals:

1. In a first study to give 'yes or 'no' answers to a set of possible features of a set of entities;

2. In a second study to select a position for a set of entities in a set of dimensions (presented as a semantic differential for 16-18 year-olds and as coordinates in the dimension for undergraduate physicists).

In the first study the frequencies of 'yes' responses to pairs of features, across a number of entities, were correlated (Pearson Product-Moment Correlations) and the resulting matrix of correlations was transformed in a proximity (distance) matrix by using the values calculated as : (1-Correlation)*10 - instead of the correlations. These distances are to be taken ordinally and the matrix of distances is the input data for the multidimensional scaling (obtained from the SPSSx- Statistical Package for the Social Sciences, available at the Institute of Education).

The coordinates obtained for features in a number of dimensions resulting from the multidimensional scaling were the input data for a Cluster Analysis (obtained from Datadesk - Macintosh statistics' package, available in the Science Education Department).

In the second study the average position of entities (obtained for a group of individuals) in a set of dimensions were used as the input data for a Principal Components Analysis (obtained from Datadesk - Macintosh statistics' package, available in the Science Education Department).

Multidimensional Scaling

The purpose of multidimensional scaling techniques is to represent the structure in a proximity matrix by a simple geometrical model or picture. A geometrical or spatial model fro the observed proximity matrix consists of a set of points in a number of dimensions and a measure of distance between pairs of points. The object of multidimensional scaling is to determine both the dimensionality of the model and the position of the points in the resulting n-dimensional space, so that there is maximum correspondence between the observed proximities and the interpoint distances.

As in the present case the proximities do not have strict numerical significance, but are to be taken ordinally, non-metric Multidimensional Scaling technique is used. The observed dissimilarities only enter the calculations in terms of their rank order (the model used is ALSCAL available in the SPSSx package).

The central motivating concept of multidimensional scaling is that the distances between the points representing the items of interest should correspond to the observed proximities.

To assess the agreement between distances and dissimilarities a function is defined, named 'stress', as the square root of the ratio between - the sum of squares of the difference between the elements of the proximity matrix and the distances between pairs of points in a n-dimensional space proposed as a model (SS) - and a scaling factor given by the squares of these distances between pairs of points in the n-dimensional space proposed (SC). The goodness-of-fit measure given by the square root of SS/SC is known as 'stress' (For more details see Everitt and Dunn 1983).

The decision about the appropriate dimensionality of the space to be chosen as a model has to take into account the interpretability and simplicity of the solution. Also a commonly used procedure is based upon examining values of 'stress' for different numbers of dimensions.

Kruskal goodness-of-fit values of stress are suggested (Everitt and Dunn 1983):

Stress	Goodness-of-fit
0.20	poor
0.10	fair
0.05	good
0.025	excellent
0	perfect

In addition it is suggested that the stress may be plotted against the number of dimensions and the presence of an 'ebow' indicates the appropriate number of dimensions to be chosen.

Another indicator of the goodness-of-fit is the RSq (squared correlation in distances), the value indicating the proportion of the variance of the scaled data which is accounted for by the suggested distances between points in a n-dimensional model.

In the present research it is also desirable to be able to display entities in the space obtained for features. This is done by averaging the coordinates of all features, weighting each with the fraction of 'yes' responses on the entity, for that feature (obs.: fraction obtained by the formula: p/P*10; where p is the number of 'yes' responses obtained; P is the number of subjects asked). Vectors indicating the position of entities in the space are obtained. These vectors will be pointing to the region of the space which contain the features which better described the entities in the subject's view.

In the first study it was also used a technique involving an Individual Differences Scaling model (INDSCAL) (see for example O'Muircheartaigh and Payne 1977). This technique is particularly useful when it is suspected that different groups of persons may show different factor structures over the same tests.

The main difference between INDSCAL and ALSCAL is that a sub-group's similarity judgement can be represented as a weighted distance in the Group Space. These weights can be interpreted psychologically as the 'saliences' or 'importances' of a given dimension to a certain sub-group. In the present case five different sub-groups were considered: 8-10 year-olds, 13-14 year-olds, young working adults, 16-18 year-olds and undergraduate physicists. Squared weights sum to RSq. The averaged (RMS) stress and RSq over matrices can also be obtained.

The input data in the INDSCAL case were five proximity matrices, one for each sub-group to be considered. The result is a n-dimensional Group Space. By applying the sub-group's set of weights to the Group Space a sub-group space is produced. Each sub-group will be applying its own 'metric' (systematic stretching or shrinking) to the dimensions of the group space.

Each dimension of the Group Space is weighted with positive values which can vary from zero to unity . A value of zero means that the particular dimension was not used by the sub-group. A value of unity if only the particular dimension was used and RSq is equal to unity. A measurement of the degree in which the groups are alike or different is given by a quantity termed 'weirdness'. A sub-group with weights proportional to the average weights has a weirdness of zero. A sub-group with one large weight and many low weights has a weirdness near one. A sub-group with exactly one positive weight has a weirdness of one.

Similar sub-groups in their relation to the Group Space will have very small values of weirdness. Different sub-groups in their relation with the Group Space will have 'near one' values of weirdness.

The application of INDSCAL is useful as a means of summarising and presenting the correlational information obtained in the present research. It also provides an approach to deciding whether or not the different samples of subjects, measured in the same set of variables, can be described by the same set of underlying factors. A major restriction is that the only transformation allowed is that of stretching and shrinking the fixed dimensions (no rotations are allowed).

In the present research it is also desirable to be able to display the entities used for each sub-group in the common space obtained for features for all sub-groups. This is done by averaging the coordinates of all features, weighting each with the fraction of 'yes' responses on the entity, for that feature (obs.: fraction obtained by the formula: $p/P*10$; where p is the number of 'yes' responses obtained; P is the number of subjects asked). Vectors indicating the position of entities for all sub-groups in the common space are obtained. These vectors will be pointing to the region of the space which contain the features which better described the entities in the subject's view in each sub-group. The position of entities will also be affected by stretching or shrinking the fixed dimensions with the weights attributed to each sub-group.

Principal Components Analysis

Principal Components analysis is perhaps the most widely used multivariate technique. It can be described as attempting to condense a set of observed variables into a smaller number of constructed, conceptual variables - the components or factors - that have not themselves been directly measured. The observed relationships between the measured variables are viewed as being due to a structuring of the data, which these conceptual variables can be used to describe.

Principal Components Analysis (PCA) is equivalent to Classical (Metric) Multidimensional Scaling with Euclidean distances. The Euclidean distance model in the case of a Principal Component Analysis is substituted by a 'vector' model involving a linear transformation of the data.

The transformation to principal components will highlight linear relationships between the variables. PCA will show how the observed variation spreads through a n-dimensional space and to what extent it confines itself to a lower dimensionality.

Linear combinations of the variables are considered that reproduce as much as is possible the original variance in the data. Principal components are found so that: a) they have no correlation between themselves; and b) the first n of them produce the best n-dimensional reconstruction of the p variables (p less than n). The extent to which a variable is fully represented in the space of components or factors is measured by the squared multiple correlation (SMC) with the factors (or squared communality). If factors are orthogonal, this 'communality' is the sum of squared loadings on the factors or components. Visually, considering that the variables in the present study are dimensions represented as vectors in the space of factors (figures 3.16 and 3.17), the 'size' or magnitude of the vectors associated to each variable are giving an information of how 'close' to the plane of the factors (or of the page) the variable or dimension is. A small-size vector indicates that the dimension is poorly associated with the plane of factors.

The first principal component of the observations is a linear combination of the original variables whose sample variance is greatest. The second principal component is a linear combination which has greatest variance subject to being uncorrelated to the first. The components are extracted as eigenvectors of the correlation matrix (of the input data), being the first component associated to the largest eigenvalue, the second component with the second largest and so on.

For deciding about the number of principal components needed to provide an adequate summary of a given data set, it is common to : a) include just enough components to explain 75-80 % of the total variation;

and b) exclude those principal components whose eigenvalues are less than unity (if a correlation matrix is used).

The loadings of the variables in the components are the correlations of the variables with the components (if a correlation matrix is used). To be well represented by a set of components a variable must either load highly on one, or moderately highly on several different components. The sum of the squared loadings in the set of components chosen (SMC) show how well the variables are represented in the factors space.

To determine the score of each 'entity' (in the present case) on the derived factors, the eigenvectors are used. The principal components scores should have zero mean, so that the mean values of the variables are used. The scores for each of the entities on each component may be used as well as the loadings of dimensions (the variables in this research case).

Cluster Analysis

Cluster Analysis techniques seeks to separate data into constituent groups. Such techniques are generally used for the grouping of the objects, individuals or variables under investigation. In the present research these techniques are used for data exploration and reduction.

The type of technique for clustering used here is termed an Agglomerative Hierarchical method: the Complete Linkage method. In this method the classes themselves are classified into groups, the process being repeated at different levels to form a tree. It proceeds by a series of successive fusions of the N features (in the present research) into groups.

Groups initially consisting of single individuals are fused according to the distance between their nearest members. The distance between groups is defined as the distance between their most remote pair of individuals (features). Each fusion decreases by one the number of groups. It proceeds until all the features are clustered.

This method can be used with similarity and distance measures. The Complete linkage method is one of the methods suggested in the case only ordinal significance can be attributed to the values to be clustered (Everitt 1974).

Conclusion

All the techniques described in this Appendix are commonly used as exploratory techniques to aid the naked eye of the researcher when dealing with multivariate data.

One of the aims of the exploratory techniques described is to reduce the volume of data by transforming the full data set into a more compact form which preserves its essential characteristics and which provides an accurate summary. Such a reduced data set can then be used as an input for further analysis.

Another aim is to discover whether the data reflects some basic typology , as with a Cluster Analysis, or the presence of latent dimensions, as with a Multidimensional Scaling and a Principal Component Analysis. Latent structure models aim at abstracting from the observed data a hidden pattern or structure based on the latent dimensions.

In the present research these techniques were used with both aims: to summarise and investigate the presence of latent dimensions in the data collected.