

A STUDY OF TRANSFER BETWEEN ISOMORPHS OF THE TOWER OF HANOI PROBLEM

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The study concerns transfer between Tower of Hanoi (TH) isomorphs. The training problem was a Move problem and the transfer problems were three Change of size problems varying according to the type of change evoked in the instructions. There was no transfer effect on the first trial of the transfer problem. A positive transfer effect only developed progressively and was manifest on the third trial. Verbal reports produced after solution show that there was no simple relation between explicit understanding and (1) the problem just solved and (2) performance in the transfer problem. It is suggested that the major progress in learning concerns goal ordering. Subgoal ordering learned in the training problem cannot be transferred immediately to the new problem, perhaps because to do so would involve a very abstract understanding of the structural role of each dimension, which is beyond the reach of participants solving a single problem for a few trials. The appropriate ordering has to be relearned in the new problem, something which requires time and may explain that transfer is based more on implicit learning and less on explicit learning.

Introduction

The nature of transfer is one of the oldest questions in psychology. The first theory of transfer, the theory of identical elements, proposed by Thorndike and Woodworth (1901) in the context of learning, was developed later to explain memorisation of successive lists mainly by Osgood (1962) who introduced the notion of a transfer surface distinguishing stimulus and response similarity. This has recently been revived in the fields of learning complex devices (Kieras & Bovair, 1986) and programming languages (Anderson & Singley, 1993). The common elements are no longer S-R bonds, as in Thorndike and Woodworth's theory: they are production rules, which have both a stimulus side by their conditions and a response side by the action triggered by the conditions. The idea that the degree of transfer between two tasks is proportional to the relative number of productions they have in common (each task being described by a set of productions corresponding to the allowable procedures) has received substantive

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confirmation in tasks like text editing and computer programming (see Anderson & Singley; 1993Kieras & Bovair, 1986).

The common elements theory of transfer has been defended almost exclusively in the field of device learning: we know of only one study which refers to it in the field of problem solving (Kotovsky & Fallside, 1989). This theory relies on the simple idea that common elements are all of the same type and that the similarity between two tasks depends only on the proportion of elements common to both tasks. The success of this theory of transfer is certainly due to the fact that describing a device by means of a set of productions sufficient to operate on it is recognised as a valid description. However, the elements of a problem situation are not so well defined and so easy to describe because they may be subject to multiple interpretations.

For researchers in problem solving, two problems are either isomorphic (if they may be described by the same problem space) or not isomorphic. Regarding their structural features, it is impossible to define an index of similarity: they can be said to be more or less similar only when one considers their irrelevant features. A distinction is commonly made between surface information and structural information (e.g., Holyoak & Koh, 1987; Ross, 1987). Surface information is information which can be changed without changing the solution of the problem. Structural information is information which cannot be changed without changing the solution of the problem and, consequently, the associated procedure. However, this distinction is hardly relevant: the problem solver is as unaware of which information is relevant as he is unaware of whether the new problem is isomorphic to the problem previously solved or not. The only effective factor is the *perceived* relevance of the prior problem with the problem to be solved and the idea of measuring similarity between two problems from an external point of view is unfounded.

Transfer in problem solving has been approached from two theoretical points of view and two paradigms: the point of view of problem space and the point of view of analogy. In the information processing view of problem solving, the central notion is problem space, i.e., the representation of possible states and of their transitions. These are generated by the interpretation a problem solver has of the operator: the type of change allowed and the conditions allowing these changes (the prerequisites). The situations considered are change of state problems, especially isomorphs of the river crossing problems and of the Tower of Hanoi (TH) problem.

In the analogy view of transfer in problem solving, the question which has received the most attention is the mapping of the elements of the target problem onto the elements of the training problem as well as the selection of features which are relevant to succeed in this mapping (e.g., Holyoak & Thagard, 1989). As regards the experimental paradigm, several differences

may be noted between the two approaches. The first difference is that the problems studied in the analogy approach are story problems which are solvable by pure reasoning and do not involve any move making. The solution consists of the statement of a procedure to attain the goal and not of the effective attainment of the goal situation. A second difference is that the semantic content of the problems studied is considerably richer in the analogy approach and the irrelevant features are more numerous, thence the importance of selection for mapping. Thirdly, as the problem is not worked out by the participant and its solution is provided by the instructions, as in a teaching situation, it is likely that what is transferred is declarative rather than procedural knowledge. Lastly, in this paradigm, a problem is given only once, although several isomorphic problems may be given as a source, while in the isomorphs paradigm several trials may be given for the same problem, either with the same beginning and the same goal or with a different beginning or goal. In this way it is possible both to vary the degree of prior training and to observe its effect on successive trials of the transfer problem.

Although there are numerous differences, both theoretical and empirical, in the two paradigms used for the study of transfer in problem solving tasks, the basic question is the same: what conditions are necessary and/or sufficient to generate transfer from one problem to another? We shall successively consider the results obtained in the framework of the two paradigms regarding the role of the main factors invoked: context, including goals, semantic factors and the importance of solution failures experienced in the training problem.

Context

Three cases have to be considered relative to context: (1) the source and the target problem have similar structural information but different surface information, (2) both problems are similar with regards to both surface and structural information or (3) they are similar with regards to surface but not to structural information. In the absence of surface similarity, transfer is seldom observed between the source and the target problem unless the participant is informed of the relevance of the first problem. This has been shown for the tumour problem, the analogous problem being the military problem of the attack of a fortress (Gick & Holyoak, 1980, 1983) as well as for the MC (missionaries and cannibals) problem when preceded by one of its isomorphs, the Jealous Husbands problem (Reed, Ernst & Banerji, 1974). Transfer is not usually observed in Tower of Hanoi isomorphs between move and change of size problems (Kotovsky, Hayes & Simon, 1985). In move problems, three objets of different sizes are transferred between three

persons. In change problems, three objects belonging each to one person may change in size according to the same rules as in move problems.

In contrast, positive spontaneous transfer is obtained when the source and the target problems are similar as regards both content and structure. For instance, Holyoak and Koh (1987) have observed positive transfer on the tumour problem (to be treated with X-rays) with an analog problem involving division and convergence of laser rays. In the same way, positive transfer was obtained from another tumour problem given as a source in which the tumour was in the brain instead of in the stomach (Keane, 1986). Massive transfer has been observed by Luger and Bauer (1978) from the tea ceremony problem, first studied by Hayes and Simon (1974), to the tower of Hanoi problem, the problems involving four tasks and four disks respectively. Time to solution was divided by four and number of moves by two. It must be noted that the tea ceremony problem used by the authors is presented in a device very similar to the TH problem. The three people (a host, an elder and a youth) are represented by three locations forming a triangle and that tasks in ascending order of importance (feeding the fire, serving cakes, serving tea and reading poetry) are represented by blocks of increasing height showing the relative importance of each task. The blocks placed on a given location are arranged from rear to front in order of descending size and the transfer of a block is constrained by a track and moved along a track to another location, so that only the least important task of a person may be transferred, just like the disks in the TH problem. In this way, there is a maximum of similarity between the conditions of application for the operator. However, it is interesting to remark that transfer is more important from the tea ceremony to TH than from TH to the tea ceremony. Transfer is more important when the difficult task (the tea ceremony) is given first: the same result has been observed by Reed, Ernst and Banerji (1974) with an isomorph of the MC problem.

Using TH isomorphs involving move and change of size, Kotovsky and Fallside (1989) obtained a rate of positive transfer proportional to the increased similarity between move isomorphs as well as between change of size isomorphs, although, as said before, no transfer was observed from move to change problems nor vice-versa. In this study, two types of changes could be cumulated in order to vary the similarity of the problems: a change of the beginning state and a change in the rule stating the constraints to be satisfied in move or change making. The rule could be the standard rule (small elements are blocked by larger elements) or the reverse rule (large elements are blocked by smaller elements). Kotovsky, Hayes and Simon (1985) have obtained in a similar situation significant positive transfer only when the rules were the same.

Kotovsky and Fallside (1989) report an interesting result concerning a

situation presented in Kotovsky et al. (1985) but studied from another point of view. Three situations are considered: *peg Move* which is the standard TH situation where the three disks are replaced by three balls. As the balls are stacked, the constraint on taking off a ball is made self-visible, since only the ball on the top of a peg is free to move. In the *Dish move* problem, the situation is the same but without pegs: as the balls are not stacked, the size of the balls has to be explicitly compared in order to decide which is free to move. In the *Dish Change* problem, the situation is physically similar but the interpretation is different. A ball is placed on each dish and behind each dish there is a reserve dish containing the two balls which are different in size from the ball placed in the front dish. It is possible, under certain conditions, to exchange the ball placed in the front dish with a ball of the reserve dish. So the result of an exchange is a change in size of the ball in the front dish. The constraints for exchanging balls are the constraints for changing the size of a globe in a change problem (1) only one ball may be changed at a time, (2) if two balls have the same size, only the ball contained in the larger dish may be changed (the dishes are from left to right: small, medium, large) (3) a ball may not be changed to the same size as a ball placed in a larger dish. Interestingly, there is positive transfer from a *Peg Move* problem to a *Dish Move* problem and vice-versa but not from these two problems to the *Dish change* problem. That means that although change of location and change of size should be conceived as a single operator, since they define the same transitions in the problem graph, the similarity of these operators is not perceived, in spite of the fact that the change of size is obtained by a change of location. This is a case where the physical similarity of the actions is blurred by a difference in the semantic interpretation of these actions.

In the case where both problems are similar regarding the surface features but structurally different, the transfer is negative: the procedure learned first is transferred but is inappropriate to the new problem. This result has been observed in problems of mathematics by Ross (1987, 1989) and by Novick (1988). The surface features are especially important in the first phase of analogy making which is access to the source problem, as it has been shown convincingly by Ross (1989). The most influential theories of analogy, those of Gentner (1983, 1989) and of Holyoak (1985), Holyoak and Thagard (1989) are faced with the difficulty of explaining how structural information may be accessed although it is more abstract than surface information which is more specific and hence more salient.

Gentner's theory (Clement & Gentner, 1991; Gentner 1983, 1989; Gentner et al., 1993) is based on the principle of systematicity. The similarities between the attributes of the object (e.g., form, colour) have to be distinguished from the similarities between the relational properties of objects. The similarities which are privileged in analogy are those which

constitute the richer system of relations between objects: this is the principle of systematicity or structural alignment. In support of this idea, Markman and Gentner (1993) have constructed pairs of scenes where similar objects (having the same attributes) play different roles and then have different relational properties. They have devised a mapping task in which participants are shown an object on a picture and asked to point to the object in the second picture which goes the best with it. In a series of experiments, they show that when participants are first asked to assess the similarity of the two scenes, they tend to prefer the match which is structurally consistent and corresponds to the relational properties. The central claim of the authors is that "similarity comparisons involve a process of structural alignment". When the mapping task is not preceded by a similarity judgement, physical similarity is preferred for matching the objects.

The Role of Goals

Holyoak (1985) stresses the importance of goals in analogy making and insists on the pragmatic character of analogy. Actually goals are related to the structure of the problem, since the structure constrains the allowable procedures for solution. When the procedure is decomposed explicitly into subgoals and the role of each subgoal in the completion of the procedure is made clear, the rate of transfer is higher even in the case where each subgoal has to be completed by a different procedure. This has been shown in a series of studies by Catambrone and Holyoak (1990), Catambrone (1994, 1995, 1996). Similar results have been obtained by Brown, Kane and Echols (1986). In a first phase participants had to study the genie problem (Holyoak, Junn, & Billman, 1984) in which the hero rolls up a carpet and uses it as a tube to transfer his goods from the bottle where he lived to the bottle which is his new home, and were asked to recall the source problem. Thereafter they had to solve a transfer problem in which a rabbit has to transport eggs to the other side of a river. It was shown that participants who had stressed the goal structure of the problem in the recall task of the source problem were more successful in the solution of the transfer problem.

Semantic Factors

Parallel results have been observed in recent studies using the analogy paradigm as well as in the isomorphs paradigm. This suggests that what is crucial for transfer is the way the elements of the problems are encoded and interpreted and the type of semantic structure which is used to encode this

information. Bassok, Wu and Olseth (1995) oppose what they call the *object-mapping hypothesis* with the *interpreted structure hypothesis*. They propose and referred for illustration to a study conducted by Ross (1989). Participants first learned to solve a permutation problem in which cars were randomly assigned to mechanics and had to apply the equation in a transfer problem where scientists were randomly assigned to computers. Although scientists have a similar role as cars (the randomly assigned set), participants erroneously instantiated the value unknown in the equation by matching scientists with mechanics and computers with cars. According to the object-mapping hypothesis, participants remember that one variable was associated with animate objects and the other with inanimate ones and therefore placed the scientists in the role of mechanics, because both are animate, and computers in the role of cars, both being inanimate. Bassok, Wu and Olseth (1995) suggest that it is not the attribute similarity, animate versus inanimate, which is responsible for the erroneous matching but the semantic relation x gets y : Scientists get computers in the same way as mechanics get cars. As the predictions of both hypotheses are confounded, an experiment was devised using three sets of elements: carts, caddies and golfers, the same variable, caddies, being present both in the training and the transfer problem. All participants initially learned to solve the permutation problem in which caddies are randomly assigned to golfers. In the transfer problem, for some participants caddies are randomly assigned to carts, while for the remaining participants carts were randomly assigned to caddies. If the participants match elements as a function of object similarity, as is supposed by the object-mapping hypothesis, they should perform better in the transfer problem where caddies are assigned to carts rather than the reverse, since caddies are the same set in the training and the transfer problem. Instead, the interpreted structure hypothesis predicts the reverse result, because in the training problem the assignment of caddies to golfers is interpreted as "golfers get caddies to carry equipment". With this interpretation, they will place carts in the same role as caddies in the first problem, since they consider that caddies get carts to put equipment in. The results are consistent with the second hypothesis, since participants were highly successful in the problem where carts are randomly assigned to caddies and showed very poor performance when caddies are randomly assigned to carts. In the later work by Holyoak, semantic similarity is taken into account (Holyoak & Thagard, 1995) and is clearly distinguished from surface similarity, goal similarity and structural similarity.

It is interesting to note that in their study on transfer between TH isomorphs, Kotovsky and Fallside (1989) had developed the same point of view: they stressed the idea that what matters in transfer is not the physical similarity between situations but the way the situation is interpreted by the

participant. They devised an experiment using two displays with identical stimulus properties that allowed inferring a different representation from the instructions. An apparent change of size of a disk was presented either as a real change of size of the disk or as a change in distance of the disk, the disk being supposed to move from front to rear and vice-versa. There were four groups who had for the training and the transfer problem respectively the interpretation: size-size, size-distance, distance-size, distance-distance. A marked transfer was observed when both problems pertained to the same representation, but there was no transfer when the representation was different in spite of the fact that the display was the same.

The studies of Bassok et al. (1995) and of Kotovsky and Fallside (1989) converge in showing that it is not the surface or physical similarity which matters but the encoding or interpretation of the elements of the situation, and this is dependent on the semantic structures available that are evoked by the situation and the context, especially the instructions. Therefore it is crucial to determine which encoding is induced by the environmental and semantic context of the problem. Clement and Richard (1997) have shown that the difference in difficulty between the TH isomorphs with a move operator and those with a change of size operator is due to the point of view, induced by the situation, which is adopted in encoding the action. A change (of location, size...) may be considered from two points of view: it may be perceived as a mere change of state, without considering the process which has taken place between the initial and the final state or it may be seen as the process of transition, as the path leading from the initial to the final state, with all its intermediate steps. According to the first interpretation, the change is an all or none process, according to the second one, it is a continuous process. The second interpretation is more specific since it concerns the way the change is made, the first one is more abstract, since it posits only that a change has happened. In TH isomorphs, the adequate interpretation happens to be the perception of a change as an all or none process: it enables interpreting the second rule of the instructions as a condition for leaving a state and the third rule as a condition for entering a new one.

Adult participants faced with a standard TH problem interpret a move as a pure change of location, because of the way it is done on a computer screen following a click: the object was there, now it appears here, and no intermediate state was seen. When faced with a change of size problem they are thinking of the intermediate steps by which the change is made: they perceive the change of size as a continuous process, as a kind of growth process and do not break down the action of changing the size into two sub-actions: taking off a given size, giving a new one. Clément and Richard (1997) have shown that it is possible to devise move problems which induce

a transition interpretation (for instance moving people between floors using a lift) and change of size problems which induce an all or none interpretation. With this new interpretation, a move problem may become more difficult than a change of size problem. Clément (1994) has shown that, in the lift problem, as long as participants do not verbalise the action of moving a person from one floor to another as simply leaving a floor and entering another one, without considering the floors which have been traversed during the path, they are not able to understand the prerequisites of the move and not able to plan their actions.

Solution Failures

A last phenomenon has been brought out by Gick and McGarry (1992) concerning the importance of solution failures experienced in the training problem on the transfer to a later problem. They used as a transfer task the problem of the mutilated checkerboard (Wickelgren, 1974). In this task, two squares have been cut off at diagonal opposite corners of the board, so that they are of the same colour. The question is: is it possible to cover the remaining 62 squares with 31 dominoes? The response is obviously "no" if one thinks of the colour of the dominoes: if two black squares have been cut off, there are 30 remaining black squares and 32 white ones so that it is not possible to match them with the 31 black and 31 white squares of the 31 dominoes. The problem actually is difficult, because participants try to cover the checkerboard. As a training problem participants are given an isomorph of the checkerboard problem which is either easier to solve or more difficult. One of the easy problems is the verbal version of the dinner party problem: "36 people, 18 men and 18 women are at a dinner party. The 36 people are seated. Each table seats only two people, a man and a woman who are sitting immediately next to each other either in the horizontal or vertical direction. If two women leave, as illustrated in the diagram, (the diagram is similar to the mutilated checkerboard, the colours being replaced by the words "man" and "woman", the two women leaving are those seated at opposite corners), can 17 tables be arranged to seat the other 34 people?. The people are not allowed to move. In a first condition the text and diagram are given, in a second condition the diagram is omitted and in a third condition the diagram is given but the text does not call attention on the parity feature of the source problem. The phrase "a man and a woman" was omitted and the phrase "Two women left" was replaced by "Two people left". Participants were given 10 minutes to solve the dinner party problem and afterwards the solution of this problem was administered to them. Then the checkerboard problem was given to solve. A control group had to solve

directly the mutilated checkerboard problem. Participants in the first two conditions did not perform significantly better in the transfer problem than the control participants, even when they were given a hint that the dinner party problem could help them to solve the new problem. In contrast, in the third condition spontaneous transfer was significantly higher as well as total transfer (transfer performance before and after the hint). These results indicate that spontaneous transfer was facilitated by a manipulation of a form of presentation which is more difficult and tends to induce solution failures analogous to those produced in the target problem. The conclusion is that solution failures experienced in the source problem are important for recognizing its similarity with the target problem, because similar solution failures are experienced in the target problem.

The Analogy Paradigm Versus the Isomorphs Paradigm

In our opinion these results have important implications: they suggest that the analogy paradigm lacks an important feature to be quite appropriate for the study of transfer, since in this paradigm participants are given the solution of the source problem, generally without prior attempts to solve it. The analogy paradigm discards the possibility of solution failures and therefore leaves aside an important factor of transfer.

In the present experiment, the isomorphs paradigm of the TH problem has been preferred for the study of transfer for the following reasons. (1) Several trials of the source problem may be given, which provides plenty of experience with the training problem. (2) Several trials may be given in the transfer task, which enables studying transfer effects which are not immediate. (3) It allows a better control of the semantic factors. Indeed in the analogy paradigm the source and target problem vary widely both in physical and semantic context and these aspects are usually correlated. In the isomorphs paradigm what differs is essentially the way the operator is instantiated and it is possible to vary the semantic content of the problem while changing at a minimum the physical appearance of the problem situation, as Kotovsky and Fallside (1989) did. This dissociation between physical similarity and semantic similarity has not been attempted in the framework of the analogy paradigm and we do not see how it could be possible.

Hypotheses

We want to test two hypotheses. The first one is that the extent of transfer depends on the distance between the appropriate interpretation of the operator as a change in the form of an all or nothing process and the interpretation induced by the environmental and semantic context of the problem. More specifically, extent of transfer will depend on the time taken to change from the spontaneous interpretation to the interpretation which is required. We consider that the moment when the participant hits upon the correct interpretation is the moment when he becomes able to manifest some planning of his action and that this moment corresponds to what Kotovsky et al. (1985) and Kotovsky and Fallside (1989) have called the final path. We agree with these authors in considering that the effect of transfer takes place in the exploratory phase which precedes the final path. We will compare transfer problems with a change of size operator given after a training problem with a move operator. We shall compare transfer problems which differ by the semantic interpretation of the change of size induced by the context, which may refer either to an action which looks like a continuous process or to an action which is closer to an all or nothing process.

The second hypothesis to be tested is that the transfer may not be immediate, i.e., is not necessarily manifest on the first trial of the transfer problem and may appear during a later trial. This hypothesis is motivated by the effect of solution failures shown by Gick and McGarry (1992). If the recognition of the similarity of failures (mainly impasses) experienced in the training and the transfer problem is important to recognize the similarity of the two problems, we may expect that this recognition takes several trials to take place: an impasse has to be encountered in several places in the problem space to be identified as being the same as a previous one, the only differences being due to the peculiarities of the states visited. For instance, a common structural property which may become manifest in impasses is the fact that the desired change is blocked by the presence of a larger element. So we expect that transfer may not be present on the first trial but become manifest on the second or third trial.

A third hypothesis we want to test is the idea that transfer consists in elaborating a representation of the operator in the form of an all or nothing process. In order to test this hypothesis, we shall be interested in verbalisation.

Experiment

Method

Participants. The participants were 60 students of Rwanda: 50 of them belonged to the Training College for Priesthood of Kabgayi and 10 to the National University of Rwanda. They were randomly assigned to the six conditions (see Design), 10 per condition.

Materials. Four problems were used, one Move problem for the training phase and three Change of size problems for the transfer phase. The training problem was a Move problem similar to the Monster Problem (Hayes & Simon, 1974) and very close in its material presentation to the Dish Problem studied by Kotovsky et al. (1985) and referred to previously. The participants were given sheets of paper on which a series of three squares of equal size were drawn representing the monsters, which were identified by their positions (instead of size as in Hayes & Simon, 1974). The first line was meant to represent the state on the initial trial (see Figure 1) and the following lines the state on each successive trial. Inside each square, the participants had to draw the globe (or globes) held by each monster at this state. They were free to choose any representation they liked: as a matter of fact they chose either circles of different sizes or the initial letter of "Petit" (Small), "Moyen" (Medium) or "Grand" (Large).

This presentation of the problem was chosen rather than the classical TH, because in the TH version there is a clear indication of the ordering of the disks. As there is no physical information about which element has to be given its definite size first in the change of size problem, the Dish version is more comparable.

The first two changes of size problems, named Globes and Balls, had identical conditions of presentation which were similar to those of the Move problem. Participants received the same sheets of paper: there were three squares on each line representing the monsters and inside each square the participants had to draw the size of the element held by the monster in that position. The only difference was the fact that in the instructions the elements were named differently (Globes or Balls) and that more specific information was given regarding the way a change of size was to be carried out. For globes nothing was said about the mode of change, while it was said that balls changed their size by inflation and deflation. The third variant was a change of size by substitution problem and was quite similar to the Dish Change problem studied by Kotovsky et al. (1985). For this problem the squares were drawn on a piece of cardboard and to the rear of each square was a reserve dish. The tokens were coins of different sizes (5, 20 and

50 FRW). The coin held by a monster in a given position was placed in the front dish and the two other coins of differing sizes were placed in the reserve dish. Changing the size of a given monster's globe was done by exchanging the coin placed in the square representing the monster with a coin of another size from the reserve dish. For this variant of the problem, concrete objects that could be manipulated were preferred to drawings because it would have been unmanageable, due to the complexity of the situation, to represent the exchange of coins with drawings. However the result of the exchange appeared on the cardboard in the same form as in the other change of size problems: a coin of a given size inside each square.

The material chosen made the situations as similar as possible except for the semantic differences. Two dimensions were involved which played different roles: (1) position (right-left dimension), which was variable in Move problems (objects changed locations) and fixed in Change of size problems (2) size, which was fixed in Move problems (each object had a given size and was identified by this size: for example the large disk) and variable in Change of size problems.

The choice of size and left-right dimension allowed having physical displays which were as similar as possible in the two types of problems. The physical differences that remained were those which were inseparable from the semantic differences: in Change of size problems there was always exactly one circle inside each square, whereas in a Move problem this number could have varied from 0 to 3. However, in order to make the Move problem more similar to a Change of size problem, in the problems proposed each monster held one globe in the initial and in the final state.

A paper and pencil version was chosen rather than a version in which physical objects were manipulated (except for the substitution problem for which it was impossible) because it was expected that this presentation would suggest to the participants that the problem was a matter of reflection and reasoning and would discourage them to try random moves.

In the Move Problem the instructions were:

Three monsters are in three locations: left, middle, right. Each of them is holding a globe which is small, medium or large. The monster on the left is holding the large globe, the monster in the middle is holding the small globe, the monster on the right is holding the medium globe. We want the monster on the left to hold the small globe, the monster in the middle to hold the medium globe and the monster on the right to hold the large globe. The globes have to be transferred with the following constraints:

1. Only one globe may be transferred at a time
2. If a monster is holding several globes only the largest may be transferred
3. A globe may not be transferred to a monster holding a larger globe.

Change problems (Globes)



Change problems (Balls)



Move problems (globes)



Exchange problems (with reserve dishes)

reserve dishes



front dishes



Figure 1. Representation of the initial state of each type of problem. Each square represents a monster and each circle represents a globe. Remark that in a Move problem several circles may be in the same square, while in the Change of size problem there is only one circle of a given size in each square. 1, *p* or ○ = Small (Petit) ; 2, *m* or ○ = Medium (Moyen); 3, *g* or ○ = Large (Grand).

For the Change of size problems we gave the version for the Globe variant and show in parentheses the differences when there were any.

Three monsters are in three locations: left, middle, right. Each of them holds a globe (ball) which is sized small, medium or large. The monster on the left is holding a medium sized globe (ball), the monster in the middle is holding a large globe (ball), the monster on the right is holding a small globe (ball). We want the monster on the left to hold a small globe (ball), the monster in the middle, a medium globe (ball) and the monster on the right, a large globe (ball).

The size of the globes (balls) has to be changed with the following constraints:

1. Only one globe (ball) may be changed in size (replaced) at a time
2. If two globes (balls) are of the same size, only the one which is held by the monster who is more to the right may be changed in size (replaced)
3. It is not possible for a globe (ball) to get the same size (to be replaced by a globe of the same size) as a globe (ball) held by a monster who is more to the right.

Design. The participants in the experimental groups first had to solve the move problem for three trials and then were given one of the three size problems (Globe Change, Balls Change or Globes Exchange) for three successive trials. The participants in control groups were given directly one of the three size problems.

In this design the participants are imbedded into groups which are defined by the Cartesian product of two factors, Training and Context, and are crossed with trials. The design is summarized by the formula:

$$\text{Participants}_{10} < \text{Training}_2 * \text{Context}_3 > * \text{Trials}_3$$

where $< >$ means an embedding relation, $*$ means a Cartesian product. The subscripts mean the number of modalities of each factor, Participants_{10} means that there are 10 participants in each group.

Procedure. After he or she had received the instructions, the participant was invited to draw the globe(s) held by each monster in each position at the initial and final state in the appropriate squares. In case of error he was invited to reread the instructions. After this he was invited to solve the problem: he was asked to report verbally the action he decided to do on each trial and to draw the globe (or globes) held by each monster following this action. At the end of the first trial, after the problem had been solved, the participant was invited to state verbally how he understood the instructions and to explain what to do in order to solve the problem. He was then given a second trial and after completion he was invited again to report his

understanding of the problem and finally he was given a third trial in the same conditions.

Results

We shall analyse successively the solution time, the number of trials and the verbal data.

Solution time. The relevant data are presented in Table 1. We have completed an analysis of variance involving the three factors Training, Context and Learning as systematic factors and participants as the random factor. There was a very significant effect of Context [$F(2,54) = 12,94$, $p < .0005$] and of Learning [$F(2,108) = 169.37$, $p < .0001$] but no significant effect of Training [$F(1,54) = 0.06$]. As regards the effect of context, it was due, as it may be seen in Table 1, to the fact that the solution time was much shorter in the Exchange (Dish Change) version. As this version involves manipulation, instead of pure drawing, this result has no particular implication: as it could be expected, making a concrete exchange was faster than drawing the effect of a move or of a change of size. The positive effect of learning was also expected: the improvement from the first to the third trial was very significant and also important in size. As regards transfer, the difference between the experimental and the control group was slight and was in the reverse direction (control: 224.96 sec.; experimental: 230.61 sec.). These results accord with the results presented in Kotovsky and Fallside (1989).

Table 1. *Effect of Transfer as Measured by Solution Time in Seconds for Each Version and Each Trial*

Version	Trial	Control group	Experimental group
Globes	1	398,2	574,5
	2	223,2	196,4
	3	89,0	62,5
Balls	1	626,3	520,7
	2	160,0	213,9
	3	67,7	94,0
Exchange	1	247,6	278,0
	2	163,8	110,5
	3	48,8	25,0

If we consider the first-order interactions, the only one which was significant was the interaction of Context with Learning [$F(4,108)=9.18, p<.0005$]. As can be seen in Table 1, the improvement from the first to the second trial was lower in the Exchange version than in the other version, while it was the opposite from the second to the third trial. Although there was no first order interaction between Training and Context nor between Training and Learning, there was a significant second-order interaction between Training, Context and Learning [$F(4,108) = 3.98, p<.005$]. As can be seen from Table 1, the Globe version and the Exchange version present a similar pattern over trials: negative transfer on the first trial and positive transfer on subsequent trials. The Balls version presents the reverse pattern: positive on the first trial and negative on the others.

Number of moves. The number of moves necessary to solve the problem diminished significantly from the first to the third trial [$F(2,108) = 30.80, p<.0005$], (see Table 2). The effect of training was positive (control group: 7.74 moves; experimental group: 6.98 moves) and was marginally significant [$F(1,54) = 3.46, p<.10$]. The effect of context was not significant [$F(2,54) = 0.55$]. The mean number of moves was respectively for the Globes, Balls and Exchange versions: 7.06, 7.43 and 7.58 moves. There was no indication of interaction between Training and Context [$F(2,54) = 0.32$], nor of Training and Learning [$F(2,108) = 0.06$], but there was a marginally significant interaction between Context and Learning [$F(2,108) = 2.57, p<.10$] and between Training, Context and Learning [$F(2,108) = 2.29, p<.10$].

Table 2. *Effect of Transfer as Measured by Number of Moves for Each Version and Each Trial*

Version	Trial	Control group	Experimental group
Globes	1	7,6	8,6
	2	7,8	6,6
	3	6,3	5,7
Balls	1	11,9	8,5
	2	6,5	6,7
	3	5,6	5,4
Exchange	1	9,3	9,1
	2	8,4	7,3
	3	6,3	5,1

In order to take a closer look at the meaning of this interaction, we have completed a separate analysis for each trial. The result is that on the first two trials there was no significant effect of Training nor of Context nor of the interaction. On the third trial, on the other hand, there was a significant effect of training [$F(1,54) = 5.81, p < .01$]. Table 2 shows that in the training groups the number of moves on the third trial was close to the minimum required (5): the transfer effect was empirically larger in the Exchange version, however the interaction of training with Context was not significant [$F(2,54) = 1.10, p > .05$].

Verbal data. The verbal data obtained after the solution of the problem on each trial were analysed from the point of view of the understanding of the allowable actions and were coded into the following categories:

0. Mere repetition of the instructions or information irrelevant or no verbal report at all
1. Presence of an expression stressing the all or nothing character of the change. For instance, for a move problem "It is necessary to know when a globe can leave and where it is allowed to go" and for a Change of size problem "I got rid of this size..." That means that the action resulting in the change was broken down into two subactions.
2. Expression of the all or nothing character of the change plus an expression evoking the idea that a desired change is hindered by the presence of an element. For instance: "a globe is not allowed to leave if it is hindered by a larger one at the same location"
3. The same as 2 with a metaphor: "when he is with the master or with the director, the pupil may not leave before they have left"
4. Expression of the all or nothing character of the change plus an expression of the prerequisite of the action, i.e., the conditions which have to be realized so that the action may take place. In this case the rule is expressed in the positive form (it may leave when...) instead of the negative form (it is not allowed to leave when...) which is characteristic of cases 2 and 3, as well as of the instructions. Examples of category 4 are: "a globe may leave only when it is freed from a larger one and it may only occupy a location freed by a larger one" or "a globe may change only if on the right I have got rid of the size I want to give to it".
5. The same as 4 plus a metaphor "the adult and the old one have to free the child so that he may leave".

Category 1 was never observed, i.e., the breaking down of the change into two subactions never appeared alone but always with the expression of a prerequisite of this subaction or at least with the idea that this subaction is

blocked by the presence of an element. At the end of trial 1 either there was no verbal report or it belonged to category 0. Categories 2 to 5 appeared only on trials 2 and 3, so we shall pool trial 2 and trial 3 for the following analysis. Table 3 presents the number of participants falling into categories 2 to 5 for each version of each problem type and for each group (experimental or control), i. e. the complement of the number of participants falling into category 0.

Table 3. *Proportion of Participants Faling into Categories 2 to 5*

	Globes	Balls	Exchange	Move
Control	2/10	4/10	5/10	14/30
Experimental	3/10	1/10	4/10	

At the descriptive level, there is no indication of a difference between the experimental and the control group. Moreover, it is remarkable that none of the 14 participants falling into categories 2 to 5 in the Move problem presented such a level in their verbal report when they were transferred to the Change of size problem. We will discuss this point later.

The proportion of participants presenting a high level in their verbal reports was somewhat larger in the Exchange condition and was similar to the proportion observed in the Move problem, but these differences are not significant even when grouping Move and Exchange problems against Globes and Balls problems ($\chi^2(1)_{\text{corr}}=1.73$, 1 df). If we consider only the verbal reports stating a prerequisite (categories 4 and 5) we also observe a higher proportion in the Exchange problem (.45) than in the Globes (.20) or Balls (.20) problem, but again the difference is not significant ($\chi^2(1)_{\text{corr}}=2.96$, 1 df).

It is interesting to note that the use of a metaphor is observed quasi exclusively in the Move problem: 9 out 14 verbal reports involve a metaphor for this problem against 3 out of 19 in Change of size problems. For most of the cases in the Move problem the circles (globes) are seen as persons with a given level of dignity depending of the size of the circle and these persons enter places or sit down on seats. According to another less frequent metaphor circles are similar to persons tied by larger ones. In Change of size problems, the metaphors are of the same type: the squares (monsters) are seen as persons more or less important and what they change is their salary or the degree in alcohol of the wine they drink.

Verbal data and performance. We may compare the contents of verbal reports with performance by first considering the number of moves observed in the trial for which the verbal report was coded in categories 2 to 5. The mean number of moves for these was 5.27: out of 33 participants, 26 made the minimum number of moves (5) and 6 made an extra move. So a perfect or near perfect performance was necessary to be able to produce a verbal report which was relevant to the problem. When the verbal report produced at the end of trial 2 fell into categories 2 to 5, the performance on trial 3 was optimal or quasi optimal: out of 11 such cases, the third trial was completed in 5 moves for 8 participants and 6 moves for 2 (mean: 5.64). However these participants did not perform better than the participants who completed the second trial in 5 moves but produced verbal reports belonging to category 0. If we consider the participants who completed the second trial in 5 moves, those who manifested an explicit understanding of the task on that trial had a mean number of moves of 5.50 on trial 3, as compared to 5.66 for the participants who manifested no understanding in their verbal report.

In summary, it is necessary to have a high level of performance to show explicit understanding. Nonetheless, explicit understanding is not predictive of high performance on the following trial. And regardless of whether the verbal report was relevant, a high degree of performance on the second trial predicted a high level of performance on the next trial.

Let us now examine whether participants showing a high level of explicit understanding at the end of the training problem showed better performance on the transfer problem. We will compare the three experimental groups taken as a whole. Regarding solution time, it may be seen from Table 4 that there is no reliable difference between the participants who produce relevant verbal reports and the others, the trend being in favour of the last ones. As for the number of moves, a high level in verbal report involves a decrement in performance which is significant on trial 1 and marginally significant on trial 2: only on trial 3 did performance become equivalent. It is the same

Table 4. *Solution Time and Number of Move in the Transfer problem as a Function of the Verbal Report Produced in the Training Problem*

Category	Solution time			Number of moves		
	1	2	3	1	2	3
0	447,9	153,9	66,2	7,44	6,31	5,13
2, 3, 4 or 5	468,9	196,1	54,0	10,07	7,50	5,50
t 1,28	0,27	1,06	0,63	2,53 <.02	2,01 <.10	0,75

pattern of results which was observed for solution time. There is a clear indication that an explicit understanding of the operator of change of location makes the Change of size problem given in the transfer phase more difficult to solve, at least on the first trial and perhaps on the second one. This is an unexpected result which requires discussion.

Discussion

As regards transfer, our results are consistent with previous ones: there is no positive transfer on the first trial, as shown by Kotovsky and Fallside (1989) in their reanalysis of the data of Kotovsky et al. (1985). What is new is that transfer may appear on later trials. This is shown both for solution time where a significant interaction between Training, Context and Learning was observed as well as for the number of moves, since there is a reliable effect of training on trial 3. So the hypothesis that transfer may not appear immediately is clearly supported.

We expected a difference between the different versions of the Change of size problems, the Exchange problem being assumed to produce a larger positive effect, since the semantic context of an exchange makes the situation more similar to a change of location. Indeed there are some indications at the descriptive level which are favourable to this hypothesis: the number of moves on trial 3 is somewhat smaller in the Exchange condition, being very close to the minimum required and the explicit understanding of the operator is better in this condition, but as the interaction between Training and Context is not significant and as the level of understanding shown in the verbal reports are not predictive of the performance, the hypothesis cannot be considered as supported. Moreover we have to explain why, in spite of the fact that this condition leads to an explicit understanding of the situation which is comparable to what is observed in the Move problem of the training phase, there is no significant difference in performance.

As regards our third hypothesis, the analysis of verbal data clearly supports the idea that the understanding of the problem implies the encoding of the change as an all or nothing process. All verbal reports which provide relevant information concerning the comprehension of the operator involve this type of encoding which breaks the action down into two subgoals. When this coding is adopted, it leads generally to the conception of the prerequisites of these subgoals or less often to only the recognition of impediments to their completion. This result is in agreement with those obtained by Clément (1994) and Clément and Richard (1997). The verbal reports for the majority of participants do not reveal such an understanding:

it is observed in about half the cases in the Move and Exchange problems but only in a fourth of cases for the other problems. The important result is that this understanding is not related to performance in a simple way. When it appears, it is sufficient for perfect or near perfect performance but is not necessary. Moreover not only does this understanding not facilitate transfer, but it actually makes it more difficult.

This result has to be combined with the fact that none of the 14 subjects who had manifested an explicit understanding of the operator in the training problem were able to show such an understanding in the transfer problem. Moreover out of the 16 participants whose verbal reports were very poor (Category 0) in the training problem, 8 were able to report relevant information (Category 2 to 5) in the transfer problem, a result which is highly improbable at random. We stressed the fact that in the Move problem the situation was in most cases translated into a metaphor, something which is certainly a help for processing. We shall examine the idea that the use of a metaphor in a Move problem is an impediment to solving a size problem. Consider indeed the metaphors used. The globes are usually interpreted as persons and their size reflects their hierarchical rank and the monsters, represented by squares, are seen as mere locations to which the persons may move. The position in the hierarchy is analogous to the position of a disk in a pile as a function of its relative size in the classical TH problem. Such a metaphor produces an affordance, like position in the TH problem (Richard & Tijus, 1998; Zang & Norman, 1994): therefore it is quite relevant.

When the participant is faced with a change of size problem, we may expect that he or she will try to transfer the metaphor which helped him/her to solve the Move problem. If so, the participant will try to interpret size as a position in a hierarchy, but such an interpretation will not work, because size does not play the same role: it is the position on the left-right dimension which generates the impediments to a change. The transfer may be negative for this reason, but there is another possible reason. A hierarchy is a quite appropriate metaphor for a TH isomorph: actually every participant who produced a metaphor produced a metaphor of this type. It is very difficult indeed to map a hierarchy into a left-right dimension, while it is very easy to map it into a size dimension. In fact very few participants were able to do so in the Change of size problem. The fact that the same lack of metaphors was observed also in the control group suggests that the second reason is quite plausible.

Actually the type of conception which is necessary to map a change of size onto a change in location problem is much more abstract. In order to have a workable representation, it is necessary to exchange the role of the dimensions. Changing sizes is like changing places, you leave a place or a size to go to another place or size. In the same way as a globe of a given size

blocks all the globes of smaller size which are at the same place, a globe at a given position blocks all the globes placed more to the left from losing the size held by this globe or from taking this size. The structure of the problem involves two ordered dimensions and the left-right dimension is not spontaneously ordered: the positions are perceived as absolute values rather than as relative (for instance middle is not immediately perceived as being on the right of the left).

Since we have got evidence of transfer, the question is: What is transferred? The analysis of verbal data has shown that it is not what has been explicitly learned which is transferred: the transfer is more probably imputable to implicit learning. We are faced with a case of dissociation between implicit and explicit learning well known in problem solving and demonstrated initially by Berry and Broadbent (1984). The hypothesis that the basis for transfer is implicit learning is consistent with the fact that transfer takes time to develop, since it requires sufficient experience of the new task.

The question is: What does this implicit learning consist of? We have no direct evidence from the results of the present experiment but we may put forward some hypotheses. First, we may assume, considering Gick and McGarry's (1992) results, that what has been learned is based on solution failures. In the TH isomorphs impasses occur when a subgoal is completed before the completion of a subgoal of higher priority: in such a case, because it is impossible to complete the other goals, it is necessary to undo what has been done and to destroy the goal which has just been completed. Such an impasse provides some information about goal ordering.

In a five moves problem, what is crucial is discovering which object is the most constrained. In the problem chosen, the most constrained change concerns the size of the globe of the monster who is the farthest to the left. Two moves are necessary to change this size from medium to small. The first of these is that the size of the globe held by the monster the farthest to the right must be changed from small to large and then the size of the globe held by the monster to the left needs to be changed from medium to small. As soon as the first subgoal is completed, the ordering of the two other subgoals is easy. As a matter of fact, in the situation obtained by completing the first subgoal, the third subgoal seems to have been met (the globe on the right is large) but the second subgoal is not and cannot be so since the size of the globe in the middle cannot be changed, because it is the same size as the rightmost globe. So the only move possible is changing the size of the globe on the right from large to a size other than middle, i.e., small. At this step, the second and the third goal may be completed. It is obvious that as soon it has been discovered that the subgoals have to be ordered and which subgoal has the highest priority, major progress in learning has been made and this

progress ensures a quick solution.

As in a Change of size problem, the goal ordering is no longer based on the size of the globes, as in a Move problem, but on the position of the globes, it is therefore comprehensible that when the participants are shifted from the Move problem to the Change of size problem, they have to relearn the appropriate ordering by experience. Deducing the new ordering from the ordering discovered in the Move problem would require a very abstract understanding about the role of each dimension. One dimension is constant and the other is variable: the constant dimension induces constraints on the change of the variable dimension when the object to be changed has to lose or to get a value already possessed by another object. Such an abstract understanding is not necessary to solve the Move problem and manifestly no participant got it. When the subgoal ordering of the new problem is recognized, the similarity with the training problem may appear, since the direction of the goal ordering may be put into relation with the direction of the constraints and then the strategy based on the recognition of prerequisites may take place: this will produce transfer but takes time to develop.

As a final remark, it must be stressed that the transfer from a Move problem to a Change of size problem involves a very deep semantic change. It is no wonder that it requires several trials to take place. What is important is that it does in fact take place and that it does so without any hints concerning problem similarity having been given. The transfer is effective provided sufficient experience is provided both in the training and in the transfer problem. It is likely that transfer requiring a deep semantic change requires the implicit learning acquired during the exploratory phase of problem solving. It is our guess that the analogy paradigm allows only explicit learning and deliberate transfer. This would explain why the cases of positive spontaneous transfer obtained in the analogy paradigm do not involve such deep semantic changes as the ones we have observed in the present experiment.

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