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An Empirical Analysis of Children's Thinking and Learning in a Computer Game Context

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ABSTRACT *This study explored ways to analyse gains in children's cognitive skills through playing computer games. Eighty-seven children aged from 7 to 10 years participated in a computer game called 'Find the Flamingo', one of Safari Search series (O'Brien, 1985). The game consisted of a set of rules, given with affirmative and negative if-then statements. Development, individual differences and learning were found in children's inferential game play. It was also found that there were already different play patterns from the beginning of the games between the good problem solvers and the random guessers. Discussions were made on the methods for analysis of computer game activity.*

Introduction

The aim of the study is to develop a framework for analysing children's thinking in computer games. In particular, the focus is on the development of children's ability to make and use inferences in the context of computer games and how this development differs between individuals. Despite the recent upsurge of interest in computer games (see Giacquinta *et al.*, 1993), relatively little is known about educational games, and even less about how to examine the development of thinking in an educational game context (Randel *et al.*, 1992; Walford, 1995).

To build a framework to investigate computer game activity, two points can be made from research on games in general and on problem solving. The first is that decisions have to be made in games (Davis, 1970; Colman, 1982); the second is that processes of decision making and problem solving often involve inference (Manktelow & Over, 1990; Piaget & Garcia, 1991; Thornton, 1995).

The first research question is how to understand children's development in decision-making and choices in a game context. In games, the player finds herself or himself faced with the necessity for making choices at each point. The gain-maximizing strategy and the probability-matching hypothesis explain differently how the player responds to

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happenings in a game situation. A basic assumption of the gain-maximizing strategy is that one can determine the strategies which would best maximize goals in every type of strategic situation (Rapoport, 1990). Seeing games as goal-directed transforms playing games into problem-solving. Developmental changes in problem solving are known to occur along a wide variety of dimensions: planning, encoding of the problem, strategies for solving the problem and systematic use of multiple (more than one) possibility (Acredolo & Holobin, 1987; Anooshian, *et al.*, 1982; Bryant & Roazzi, 1992; Horobin & Acredolo, 1989; Kamiloff-Smith, 1992; Kamiloff-Smith & Inhelder, 1974/75; Siegler, 1989; Wellman *et al.*, 1979). Thus, the gain-maiximising strategy potrays the player as an agent who represents the problem and calculates outcomes of moves. In this view, children's inferential gaming would develop with age.

The probability-matching hypothesis, on the other hand, suggests that a game player generates and holds multiple expectancies that reflect the probability of a particular happening at a particular situation (Kingstone & Klein, 1991). The probability-matching hypothesis envisages that the choices of the player are guided by the likelihood gained through accumulated reinforcements. The assumption is that children learn consciously or not to match their response ratio (the relative frequencies which they predict for each of the events) to the actual probabilities of occurrence of the events. In this view, developmental changes are not expected in a game situation.

The next research question is whether children become more proficient in using a particular form of logical reasoning when it is embedded in a game that they can play over and over again. In this study, unlike some other tasks, children became engaged in a cultural practice, a game, which assumes either the use of inference from the rules or the accumulation of reinforcements. The study investigates whether children continue to perform at the same level of proficiency after many games, or whether they come to use inferences more and more. Two kinds of players were envisaged. The first group was those who played the game with an assumption that the game is a chance event. Their performances were expected to be at chance level. Choices of this group would not correspond to the game rule. The second group was those who made inferences from the game rules. They were expected to perform better. Their choices would be coherent with the game rules.

The third question of the study is whether the computer affects children's game behaviour. Literature on educational computer game has raised the question how the computer game program interfaces with the learner (Greenfield, 1989, 1993; Greenfield *et al.*, 1994; Subrahmanyam & Greenfield, 1994; Sanger *et al.*, 1997; Sedighian, 1997; Littleton *et al.*, 1999). Computers are often perceived as a positive motivational learning tool (Noss & Hoyles, 1996; Light, 1997; Sedigian, 1997). However, there are also growing speculation that computers could give a negative effects on children's reflective thinking (Sanger *et al.*, 1997). This study compared children's inferential game performance between the computer game and a board version of the game.

Methods

Participants

All the children of years 2 and 5 of two inner London schools participated. The number of children was 32 children aged from 6 years 6 months to 8 years 1 month (mean

age = 88.3 months; SD 4.01) and 55 children aged 9 years 10 months to 10 years 10 months (mean age = 124 months; SD 3.45).

The Game

Two criteria for the choice of a computer game for the research were, first, that it can be played by children within a broad age range and, secondly, the problem-solving feature of the educational software. The former criterion is in order to explore whether there are developmental changes in understanding the game structure and inferring the target from information. The latter criterion is in order to examine whether children use logic in playing computer games and what they take into account when making decisions about the next moves.

For the purpose of this research, the chosen game was an inferential problem-solving game called 'Find the Flamingo', one of the 'Safari Search' series (O'Brien, 1985). It is advertised as educational software and one of the goals of this research is to explore the relation of such software to children's thinking. The goal of the game is to find the location of a Flamingo hidden among 25 cards. The instructions appear on the screen as follows:

> Turn over a card to find the Flamingo.
>
> If it's there, you win.
>
> If the Flamingo touches your box sidewise, you are HOT.
>
> If it touches your box cornerwise, you are WARM.
>
> If they don't touch at all, you are COLD (see Fig. 1).

The game looks easy and friendly, since the Flamingo must be underneath one of 25 cards. The Flamingo can be searched for using merely the strategy of random trial and error. However, if the players try to make an effective search, it is cognitively challenging in that information has to be selected in the course of the game, and spatial directions to the Flamingo should be inferred from the information.

Apparatus

The computer and the board game media presented children with the same game structure. Each game apparatus had a 5 × 5 grid to allow 25 items of information to be shown. There was a distinguishing feature between the two media. The computer had a review key that allowed a view of all the moves made in the game. As the player clicked a place on the 5 × 5 grid, a word appeared in the place for a couple of seconds and returned to the original picture. With the board, the player made a choice on the 5 × 5 grid, lifted the top piece in the place and uncovered it until the completion of the game (Fig. 2).

Procedure

Children were taken individually to a quiet room in their school and shown the game. They were randomly assigned to either the computer group or the board group. Each child was given an explanation: that she or he was going to play a game in which she or he had to find a Flamingo. The experimenter said:

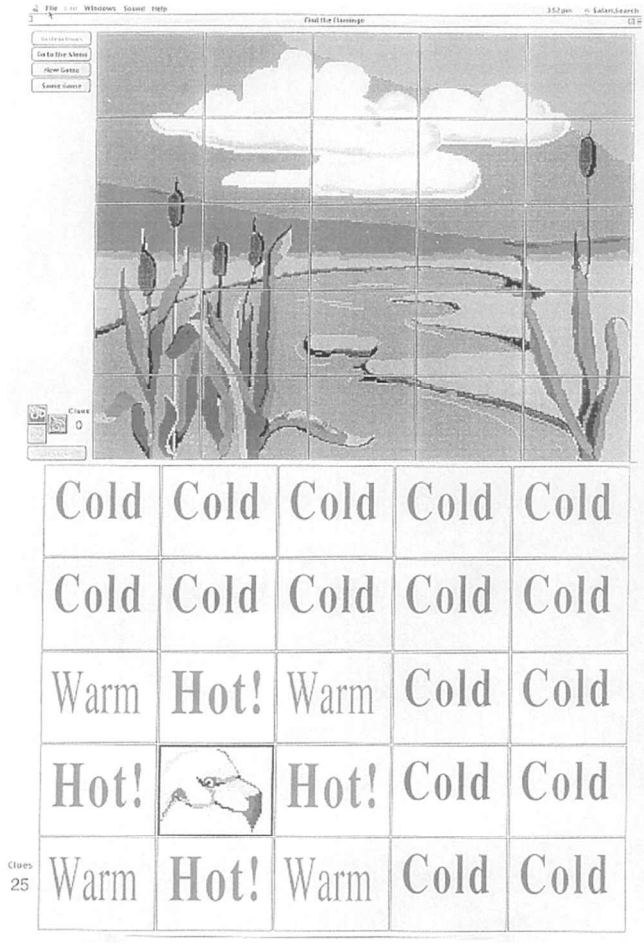

FIG. 1.

If you follow the rules, the job will be much easier. Could you read the rules to me?

The screen that had rules was clicked for the computer group. A sheet on which the following rules was written was introduced to each child in the board group.

> Turn over a card to find the Flamingo.
>
> If it's there, you win.
>
> If the Flamingo touches your box sidewise, you are HOT.
>
> If cornerwise, you are WARM.
>
> If they don't touch at all, you are COLD.

If the child was not a fluent reader, the experimenter helped by reading the instructions.

After reading the rules, the child was asked to explain them to the experimenter. If the child understood the rules properly, she or he started to play the game. If not, the experimenter explained the rules. Each child played the game eight times without any

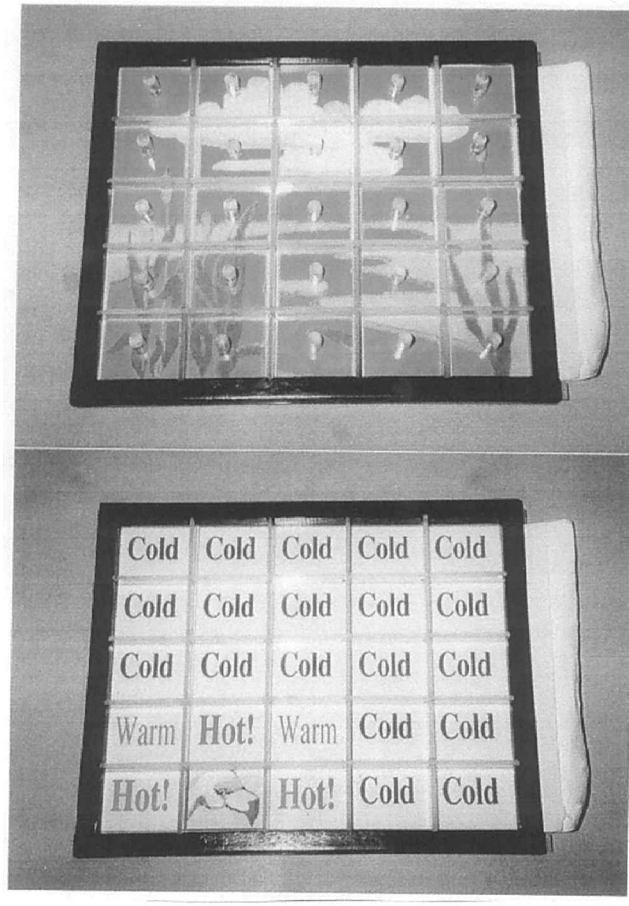

FIG. 2.

more explanation or interruption. In the board game, the piece that had been lifted were not put back in a game.

Measurement

Two quantitative measurements were used:

- Number of moves until the completion of a game was counted for the child's inferential problem-solving ability in the game.
- 'Single information inference' was applied to identify whether a move was an adequate inference from the previous information. The immediately preceding information counts as the base of the inference. Faced with HOT, the choice of the players who made inference from the game rules would be one of the adjacent places that are above, or below, or to the left or right (see Fig. 3). Faced with WARM, it would be a move to one of the diagonally adjacent places (see Fig. 4). Faced with COLD, the next move would be to one of the non-adjacent places (see Fig. 5).

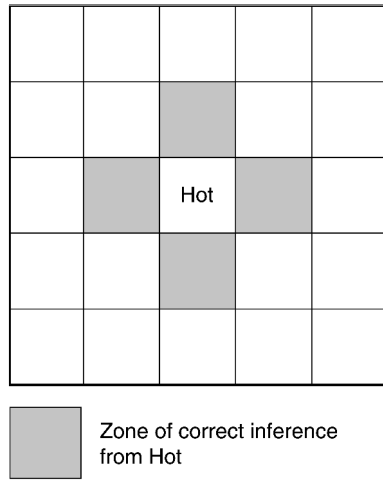

FIG. 3.

Results

The results are given in three sections: analyses of the number of moves, individual differences and learning over games, and choice-patterns.

Analysis of Number of Moves

The questions to be answered in this section were whether the children understood the game rules and used them in their choices. In order to answer the questions, the criterion for success at chance level was needed.

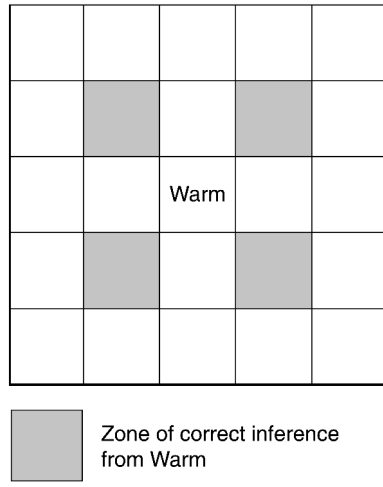

FIG. 4.

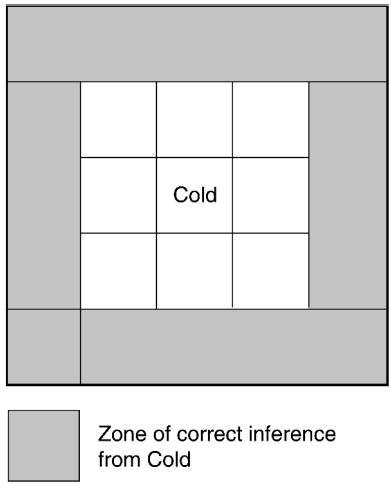

FIG. 5.

The Criterion of Chance Level. In order to know whether the player made inferences from the game rules or just chose the places randomly, the criterion for success by chance was set. It was assumed that, if the player made inferences from the game rules, it would not take as many moves when they were made by chance to find the target. How many moves would it take to find the Flamingo, if the player made random moves? Three mathematical assumptions were made. First, every place in the array has the same probability to be picked. Secondly, the number of places chosen until success follows a discrete uniform distribution over the integers from 1 to 25. Then the calculation for these follows. The mean of this distribution is $(25 + 1)/2$. The variance is calculated through deviance between the square of the mean and the summation of 1 square, 2 square, 3 square ... and 25 square divided by the number of places. Thirdly, it happens that with 8 games, the mean is satisfactorily normally distributed, i.e. it follows the normal distribution with mean 13 and variance $52/8 = 6.5$. In order to set the criterion of chance number, one-tail normal test was carried out with the mean, SD and the number of games. This leads to the criterion of the chance number of 7.07 moves, with 99% confidence or 8.80 moves with 95% confidence. I take 7.07 with 99% of confidence over eight games. If the mean number of moves over 8 games is 7.07 or fewer, I can reject the hypothesis that the player makes moves randomly. There must have been some bias, which is the child's use of the game rules.

Only when the child's mean number of moves in eight games was the same as or less than the criterion, the hypothesis that the child made moves at random was rejected. Each player's mean number of moves in eight games was counted. Sixty-one children out of 88 children made, on average, fewer moves than the chance criterion. Therefore, the majority of the participants inferred the game rules to find the goal. In order to compare rule use between the age groups, the number of participants who made fewer moves than the criterion of 7.07 was counted for each age group. For 13 out of 32 7-year-old children, the mean number of moves in eight games was smaller than the chance criterion, while 48 10-year-old children out of 55 made fewer moves than the criterion. There was a significant difference between the age groups in the number of children whose mean number of moves was less than the chance criterion (Chi-squire $= 4.07$, d.f. $= 1$, $P < 0.05$). In general, the older children did not need as many

TABLE I. Mean number of moves (SD) across age, media, and gender groups

	7 years		10 years		
	Computer $n=16$	Board $n=16$	Computer $n=25$	Board $n=80$	Total $n=87$
Girls	10.55 (4.70)	10.92 (4.70)	6.21 (2.91)	6.00 (3.45)	8.08 (4.35)
Boys	8.29 (4.52)	9.86 (4.40)	5.59 (2.16)	5.03 (2.24)	6.44 (3.52)
Total	9.87 (4.49)		5.58 (2.58)		7.16 (3.97)

moves as the criterion of success by chance while the younger children did. Developmental changes were clearly shown.

Media and Gender Differences in Number of Moves. In order to see whether there were differences between the media groups and between the gender groups, the mean of number of moves was calculated across each group. Table I shows the mean number of moves across the age, media and gender groups.

The distribution of the mean number of moves of all the participants was skewed positively. In order to verify whether there were differences between the game medium groups or between gender groups, Mann–Whitney tests were applied separately with gender variables or with the media variables because data were not normally distributed. There was no significant difference between the computer and board groups ($z = -0.77$, $P > 0.05$) nor between gender groups ($z = -1.27$, $P > 0.05$). The computer group made moves neither more nor less than the board group. The girls and boys performed with more or less the same efficiency in the game.

Reliability of Measurements. To assess the reliability of measurement by counting moves for assessing the child's problem-solving performance, the correlation was calculated between the mean numbers of moves in odd and even sets of games. The correlation between the two means was statistically significant ($r = 0.634$, $P < 0.001$).

Individual Differences and Learning

In order to see whether some children were consistently better than others, and whether the difference existed from the beginning of the game, the study used the method of backward learning curves. The method takes final responses for the selection of groups and traces responses from the first to the last games (Zeaman & House, 1963). The children were divided into two groups—good and poor—based on the mean number of moves in the last four games. The criterion for success at chance level over four games was set as described before (see 3.1.1). The criterion was 7.07 with 95% confidence. Children whose mean number of moves in the last 4 games was smaller than 7.07, the criterion of chance level success over four games, were defined as the good performance group. Those who had a mean number of moves more than or same as 7.07 were placed in the poor performance group. The mean number of moves and the mean scores for the word clue tests of each! of the groups were calculated for the comparison between the groups. Table II shows the number of participants and the mean number of moves for each performance group.

The performances of each group were traced from the first trial to the last. Fig. 6

TABLE II. Number of participants, mean number of moves and mean test scores for each performance group

Age	Performance	No. participants	Mean no (SD)
7 years	Good	13	6.2 (2.48)
	Poor	19	12.4 (3.78)
10 years	Good	48	4.7 (0.96)
	Poor	7	11.4 (2.84)

shows the learning curves of each of the performance groups. In both age groups, the poor game players who performed around the criterion of success by chance level in the later trials were those who started the game badly. On the other hand, the good performers did better from the start. The patterns of responses found in the final games already existed from the beginning. The 7-year-old poor' performance group did not show any improvement within the eight games. The 10-year-old poor' performance group was in overall worse than the 7-year-old good' performance group. The fluctuation of the learning curve of the 10-year-old poor' performance group might have come from the small group size.

One of the questions for the study was whether the children became proficient in inference making in the game that they played over and over. In order to see whether the children performed better as the game went on, games were divided into two blocks (1st–4th and 5–8th). A Wilcox signed-rank test was carried out because the distributions of the mean numbers of moves of the two blocks of games were non-parametric. There was a significant difference in the mean numbers of moves between the two blocks of games ($z = -2.32$, $P < 0.05$). It has been also shown in previous studies that problem solving becomes smooth as practice on the same problem continues (Case, 1986; Ceci, 1991).

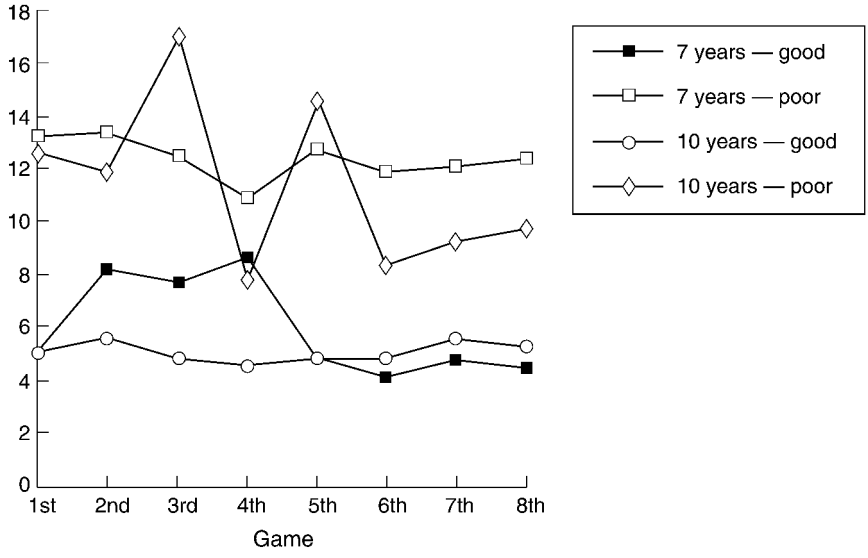

FIG. 6.

TABLE III. Percentages of moves across three areas from single information

	H/V*	Diagonal	No-A ~
HOT	89.1	5.9	5.1
WARM	39.1	51.0	9.7
COLD	25.9	9.2	64.9

□ Percentage of correct inferences.
* H/V: horizontally or vertically adjacent area.
~ No-A: non-adjacent area.

Analyses of Choice Pattern

To assess whether each move (choice) followed from a correct inference from information, 'single information inferences' were counted. For single information inferences, each move was categorized according to three areas that were identical to the three relations of the game rules; the horizontally and vertically adjacent area (H/V adjacent area), the diagonally adjacent area, and the non-adjacent area. The numbers of occurrences of each type of information (HOT, WARM and COLD) and the numbers of correct inferences from the information were calculated over eight games for each of the participants. Because the occurrences of the three types of information varied across each participant, the percentages of correct inferences for the three information types were calculated. Table III presents the percent of moves into the three areas across the information.

Faced with HOT, most of the moves were made to the horizontally or vertically adjacent places. The children were very good at using inferences from HOT in the process of the game. Faced with WARM, most of the moves were made either to the H/V adjacent places or to the diagonally adjacent places. But moves to non-adjacent places were rare with WARM. It seems that the children coded WARM as referring to adjacent places. Faced with COLD, the majority of moves was made to the non-adjacent place.

The distributions of the percentages of correct single information inferences from HOT, WARM or COLD were not normal. It was questioned whether each information was inferred with the same level of correctness statistically. In order to test whether there were significant differences in correct single information inferences between HOT, WARM and COLD, Wilcoxon matched-pair tests were carried out with pairs of HOT and COLD, and of COLD and WARM. There were significant differences between HOT and COLD ($z = -6.34$, $P < 0.01$) and between COLD and WARM ($z = -4.70$, $P < 0.01$). HOT was used more correctly than COLD; COLD was used more correctly than WARM.

To see how the younger and older groups differed in use of each type of information in the game process, the percentages of correct single information inferences were calculated for each age group. Fig. 7 shows the percentages of correct single information inferences from the three kind of information for the two age groups.

In order to verify whether there were differences between the age groups in single information inference from HOT, WARM, or COLD, Mann–Whitney tests were carried separately with HOT, WARM and COLD. There were differences between the age groups in WARM ($z = -4.86$, $P < 0.01$) and COLD ($z = -5.55$, $P < 0.01$) in

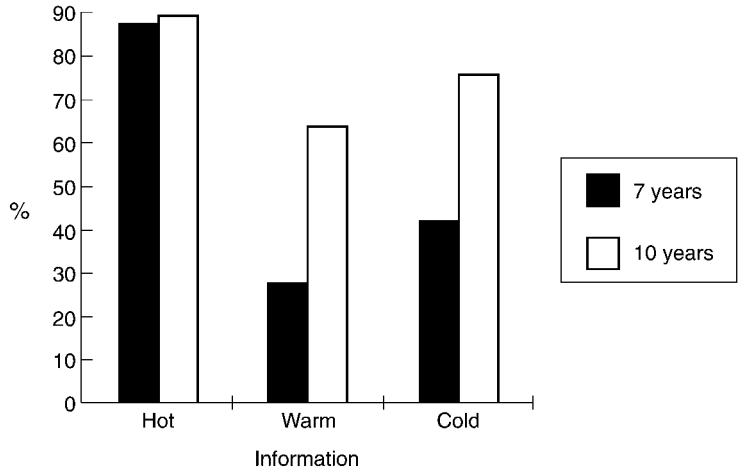

FIG. 7.

favour of the older groups. The younger children made correct use of WARM and COLD on less than half of the occurrences. The older children were better at inferring from WARM and COLD than the younger children, although the correct use of these two items of information was not as high as the use of HOT for both age groups. Why were HOT and WARM used so differently? Spatial information may confuse children about the two kinds of inclusion: the inclusion of horizontally or vertically adjacent places (HOT) and that of diagonally adjacent places (WARM). A directional difference (side versus diagonal) may explain the greater successful use of HOT than WARM.

Discussions and Conclusions

In this part, I will discuss main points of the results and their implication in analysis of children's thinking and learning in the context of computer games. First, developmental change in inferential problem solving was clearly shown. Most of the 10-year-old children made fewer moves than the criterion for success by chance, whereas on average the 7-year-old children could not achieve this. It took as many moves as working at the chance level would need for the younger children to find the Flamingo. The results showed that the ability to understand inferential principles and to use this understanding in planning the search actions developed with age. These findings are consistent with a variety of others that examined the understanding of logical relations in children of roughly the same age range (6–10 years) in other experiments (Pieraut-LeBonniec, 1980; Bynes & Overton, 1988; Markovits *et al.*, 1989; Scholnick & Wing, 1992). It was evident that the children who made fewer moves than the criterion for success by chance did indeed represent the game as problem-solving and infer the goal place form the game rules. Thus, the results support the cognitive decision-making theory, according to which children represent the problem and calculate the outcomes of moves. The cognitive theory explains the children's game behaviour better than the probability matching theory, in which children merely reflect the likelihoods of happenings. There were too many places that the moves could be made to in the Flamingo game to explain the children's choices as a reflection on the likelihood of the target.

Secondly, individual differences have been shown to be quite constant over games.

The good performance group in the later games included those who started the game with much efficiency, while the poor performance group in the later games included those who started the game without much efficiency. Why was the good performance group able to make and use the inferences whereas the poor performance was not able to do so? It was assumed that there was an operative logic of inclusions and exclusions that enabled the more successful child to represent the game structure and to anticipate the results of the moves.

Thirdly, the mean numbers of moves were compared between the blocks of games in order to see whether the children's inferential problem solving improved over the practice of games. The study found significant differences, in favour of the later games. If the games provide children with plenty of opportunities to assimilate, children will learn through doing them. The selection of games, then, is better when the game exceeds a little the child's level of understanding of the concepts and logical structure of the game. The construction of the meaning of the game clues and the planning of the use of inferences will gradually improve over the practice of the game.

Fourthly, neither game media differences, nor gender differences, were found for either the younger or older children. An impressive observation for the experimenter was that all the children were very eager to play the game on the computer. Regardless of whether or not a child managed to play the game properly, she or he reported high satisfaction and joy. This observation supports some claims for the use of technology in education, that is, the positive effects of the strong motivation that computers offer (Silvern, 1986; Cox, 1997). Nonetheless, this study showed that the apparatus used when the children played the game did not have a significant effect on the children's problem solving efficiency. There was no difference in this between the computer and the traditional game tool (the board). In this study, the effects of computer activities on learning did not come from the computer itself, but from the activity.

The findings of the study have implications in ways to analyze children's thinking and learning in computer game play. First, analyses were made in two perspectives on the game play, focusing on the player and the information. One perspective focused on the child who made inferences from the game rules: whether she or he perceived the game as a problem-solving task or a chance event. The other focused on information in the game frame: how correctly each item of information was used to infer the goal places in the game process. These two perspectives depict the inferential game play more comprehensively than either alone.

Secondly, the child's number of moves was observed over the practice of the games. In order to test whether the child used the game rules, the criterion of success at chance level was set. What number of moves would be needed to find the target by chance? This was calculated as approximately the mean number of the places in the game array. If the child used the game rules, she or he would not need as many moves as the mean. In order to decide what number of moves could be confidently judged as showing success beyond the chance level, the criterion of success at chance level was set by using a one-tail t-test with the mean, 13, (because there were 25 places), and the number of games for the degree of freedom. If the mean number of moves was below or the same as the criterion of 7.07, it could be confidently said there was a bias—that the game rules were being used.

Thirdly, two levels of analysis were involved in children's game performance. One concerned the general problem-solving process for different age groups. The other level was the study of intrinsic individual differences, reflecting a fine-grained analysis of the psychological processes in sub-groups of children. Using the backward learning curves

of two performance groups in each age group, this study showed that some 7-year-old children played the game with higher efficiency than some 10-year-old children. Many younger children used the game rules only after the first four games, whereas most of the older children performed the game with high efficiency from the beginning of the games. The grouping offered a means of exploring the diversity of the problem-solving processes of children in a way that would not have been feasible with a reliance on a single mean for the whole group.

Lastly, use of each clue given in the course of the game was examined in relation to the game rules. If the players made inferences from the game rules, their choices would be coherent with inferences from the information that they had. For example, faced with HOT in the Flamingo game, their choice would be one of the 'adjacent up', 'down', 'left' or 'right' places. Faced with WARM, they would move to one of the adjacent diagonal places. Faced with COLD, the next move would be to one of the non-adjacent places. If the players did not have any concept of the game rules, their choices would not correspond to how the game rules define the relations between the goal and the information. Thus, each move can be seen as a result of either a correct or an incorrect inference from the previous information. The method of 'single information inference', in which the immediately preceding information counts as the base of the inference, were applied. However, the method did not include the cases when the children might have gone outside the zone of possible goal places, not because they did not infer from the rules, but because they tried to gather more information with more advanced strategies. Despite this weakness, the methods showed concerning how far the young children made links between the clues and the game rules. While the number of moves measured the child's inferential problem solving in the game, studies of single information inferences identified what concepts and operations children had learned. The methods of counting moves and single information inferences are supported by Piaget, who asserts that an action is evaluated in terms of effectiveness or usefulness in relation to a goal (Piaget & Garcia, 1991, p. 4.).

The study investigated ways to analyse development and individual differences in the inferential game performance, and learning and the construction of the meaning of the clues through play the game. The approach is supported by the view that researchers must measure the promises of providers of high technology systems against our general knowledge of how children think and learn (Squires & McDougall, 1994; Underwood & Brown, 1997; Wood, 1998; Littleton & Light, 1999). Educators should look carefully at games if they intend to make them a central part of the learning environment. More attention should be given to each piece of educational software, with careful consideration of why a specific package would be useful, what activities the child does with it and how, and what concepts are learned through it.

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