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Externalizing the Latent Structure of Computer Games: Effect on game play, reasoning and implication for design

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Externalizing the Latent Structure of Computer Games: Effect on game play, reasoning and implication for design

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Abstract

Computer games have initially and primarily been used for entertainment purposes. Recently, however, computer games have gained popularity in the educational and training arena. Epistemic computer games require players to think hard while entertaining them at the same time. Designing good epistemic computer games is complex and difficult. This thesis aims to further our understanding of how to design good epistemic computer games.

Super Maze is a puzzle game that requires players to navigate through a maze picking up things on the way. At each junction, players can move either up, down, left or right. Four different versions of Super Maze were created. These versions differ from each other with respect to the representation of the maze and the way players interact with the maze to move through and finish it. The alternative representation to the traditional maze representation externalizes the internal structure of the maze as a tree diagram.

An exploratory usability study was conducted to investigate how externalizing the internal structure of the game affects thinking and reasoning and if and how externalizing the internal structure of the game affects the gaming experience.

Keywords: Epistemic computer games, External Representations (ERs), Representation, Interaction, Usability studies.

Dedication

I dedicate this thesis to Dr. Mohammad Dadash Zadeh, my dear friend and husband, whose love and constant encouragement enabled me to realize my aspirations.

Acknowledgements

First, profound and special thanks are due to my supervisor, Dr. Kamran Sedig, for his patient help and supervision and for being a constant source of advice. He is owed my thanks and gratitude for helping bring this thesis to its conclusion.

Secondly, I would like to thank my work colleague in the Cognitive lab, Robert Haworth for innumerable stimulating discussions. I also acknowledge the invaluable assistance that Robert gave me with programming.

Finally, I am indebted to my parents, Ebrahim and Sharareh, the two most special persons in my life. They, not only gave me life, but also fill it with all the love and affection one can wish for.

I hope that this achievement will complete the dream that you had for me all those many years. Thank you.

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Chapter 1

1. Introduction

1.1 Meaningful Play

Playing does not come just from games; rather it comes from the way that players interact with the games in order to play them. None of the board, the pieces, and even the rules of Chess can alone constitute play. The game environment and the method of interaction between players and the system of the game are foundations for the emergence of meaningful play [Salen K., and Zimmerman E., 2004].

Meaningful game play, in its general form, is attached to enjoyment and having fun. However, a game can be designed and developed as a system that not only engages players in meaningful play but also facilitates and supports desired thought processes for players.

1.2 Playing and Cognitive Development

Playing games constitutes a significant part of children's cognitive and social development [Csikszentmihaly M., 1990; Provost J.A., 1990; Rogoff B., 1993]. "In the context of cognitive development, playing is considered fundamental to the stabilizing processes that are essential for the development of cognitive structures" [Rosasa R. et al., 2002, page 72]. Playing is a natural approach for children to practice basic cognitive operations such as conservation, classification, and reversibility [Piaget J., 1951].

Children's play is a privileged learning experience [Rosas R. et al., 2002]. As Vigotsky L. [1979] states, children enhance their learning process through playing since playing often consists of activities that are more complicated than the regular day-to-day activities of children. Bruner's [1986] findings also support this idea. He found that the grammatical structure used by children while they are playing is more complex than what they use in real life situations. Consequently, playing provides children with the cognitive supports required to develop higher order mental processes such as reasoning.

Playing is considered the first form of symbolization because it initiates the symbolic use of objects [Piaget J., 1951]. Therefore, playing composes the first step towards abstract thinking [Vigotsky L., 1976].

Games are one of the most common forms of playing. All games have properties, rules, and procedures that must be mastered in order to become a player. The understanding of the underlying structure and components of games plays an important role in the development of cognition [Schank R.C., 1990] as it needs a mental framework consisting of goals, conditions, players, and resolutions.

1.3 Computer Games

Computer games are quite popular among children these days. One of the main uses of personal computers, particularly for younger users, is computer games. The time children spend playing computer games recommends that more attention should be paid to the role of games. Moreover, "Playing computer games can enhance visual processing skills, including visual attention, and the ability to manipulate objects or mental images through space. Players discover strategies for overcoming obstacles, and construct understanding of complex systems through experimentation in natural ways" [Dormann C., et al. 2005, page 246].

The game industry was very successful in recent years. For instance, the Entertainment Software Association (ESA) in 2007 stated that total sales were $18.85 billion, with $9.5 billion of that spent on games (both PC and console) and $9.35 billion on consoles. [Bangeman E., 2008]. "The average American child aged 2–17 years plays video games for 7 hours a week" [Douglas A. et al., 2004, page 6]. Accordingly, "Playing computer games is an important social and cultural activity for many school-aged children." [Young J. and Upitis R., 1999, page 397]. Additionally, computer games are powerful tools for challenging users thinking and reasoning with representations.

One way of understanding and learning about particular concepts and ideas is through social interaction while playing computer games. Computer games can be engaging and powerful tools for challenging children's thinking and for learning various concepts, whether concrete or abstract [Young J. and Upitis R., 1999]. Consequently, computer games are a significant test bed for our research for two main reasons:

1. Games are associated closely with leisure and entertainment
2. The subjects of our study are children.

This study is an attempt to design better games. The main purpose of this thesis is to investigate how we can develop games that improve reasoning and thinking skills but are still fun and entertaining. To this end we designed a puzzle game called Super Maze (SM) in four different versions. Children played the different versions and the results of playing these games are compared. The entire experiment process is explained in Chapter 4, the results are presented in Chapter 5, and the final conclusion is given in Chapter 6.

1.4 Cognitive Abilities and Computer Games

Interaction with computer games can develop the complex thinking skills related to problem solving [Keller S., 1992] and strategic planning [Jenkins H., 2002; Keller S., 1992; Mandinach E., 1987; McFarlane A. et al., 2002].

Children are attracted to computer games since they are challenging and interesting and give control over what is happening in game to the players [Jenkins H., 2002; Lepper M. and Malone T., 1987]. Furthermore, they reduce the verbalized errors since computer games normally correct mistakes without highlighting them [Institute for Learning Sciences, 1994].

Baltra suggests that it is possible to create appropriate tools for better reasoning, learning, and motivation for children by merging instructional elements with the intrinsic interest that children and students have in video games [Baltra A., 1990]. Computer games motivate children and this motivation is directly related to their attention and concentration [McFarlane A. et al., 2002].

According to [Rosasa R. et al., 2002, page 75] to design an effective video game the following attributes should be met:

1. "A clear goal: almost all video games are goal-oriented; that is, they have a clear and specific goal that children must try to reach (e.g. capturing the princess, or reaching a destination).
2. Adequate level of complexity, not too low but not too high; well-designed games are highly challenging and are rarely totally mastered.

3. High speed: most video games have a much faster speed than traditional mechanical games.
4. Incorporated instructions: in most video games, children understand instructions while playing the game and do not need to read all the instructions beforehand.
5. Independence from physical laws: video games normally do not follow the physical laws of the universe; objects can fly, spin, and change shape or color as they please.
6. Holding power: they capture players' attention and continue to do so as the game builds a micro-world with its own rules and regulations [Malone F., 1980; Provenzo E., 1991; Turkle S., 1984]."

Nevertheless, there are negative aspects of video games such as aggression, gender biases, and immersion effects as well. Most video games are at least aggressive, if not explicitly violent [Rosasa R. et al., 2002]. This aggression is usually verbal or physical among the main characters. These aggressive actions and behaviors are said to provoke aggressive behavior in children who play them. Studies on the effect of video game use related to aggression confirm noteworthy correlations between the use of video games and aggressive behavior on the short and intermediate term. Recent research suggests that exposure to violent video games does lead to an increase in aggressive behavior. Some research indicates that children exposed to violent video games show more hostile conduct than those exposed to non-violent video games, and these in turn show more hostile conduct than children not exposed to video games [Ballard M. and Wiest R., 1995; Cesarone B., 1994; Kirsh S., 1997].

1.5 Epistemic Games

"The word epistemology comes from the Greek root words episteme, meaning knowledge or understanding, and logos, meaning thought or study. Thus epistemology is the study of knowledge and what it means to know something." [http://epistemicgames.org/eg/].

Sets of rules, moves, conditions and strategies form epistemic games, allowing users to organize information into a target form or structure. Epistemic games are similar to analysis techniques in that they are reflective, knowledge generating activities. Nevertheless, they are more general and can be applied in various fields with various kinds of data. [Sherry L., 1995].

Playing epistemic games teach players how to construct and organize their own knowledge. By creating epistemic forms, players are analyzing the material and building new structures showing the relationships within the material. Fluency in pattern recognition, which is a skill related to expert behavior and creativity, is enhanced by observing how information can be classified into various structures.

The learning experience is also enhanced by game playing through supporting users to visually organize new material and through activating participants in the learning process. Games provide a thoughtful activity, which can be performed in person or in collaborative groups [Sherry L. and Trigg M., 1996].

The term, cognitive artifact, was invented by Norman D.A. [1993] to express any external representation of an abstract concept. Cognitive artifacts help us restructure knowledge, which is the most complex part of learning and reasoning.

1.6 External Representations

Advances in computer technology in the past few years have given us the power to create tools that can display representations and allow users to interact with them [Sedig K. et al., 2005].

Problem solving can be aided through graphical representations by supporting perceptual judgments since they are easier to understand and can act as aids to retrieval [Larkin J.H. and Simon A.H., 1987]. External graphical representations have to be well-constructed in order to become capable of representing the necessary information in a problem [Cox R. and Brna P., 1995].

In contrast with internal representations, rather little research has been performed on the nature of ERs in cognition. This might be due to the idea that very little knowledge about the internal mind can be gained by studying ERs, or due to the view that external representations are nothing but inputs and stimuli to the internal mind, or simply due to the lack of a suitable methodology for studying external representations [Zhang J., 1997].

1.6.1 Theoretical Background of ERs and its Important Rules

Zhang argued that external representations could be transformed into internal representations by memorization. However, when external representations (ERs) are available, these internalizations are not essential and may even be impossible when ERs are very complex. Internal representations can also be transformed into external representations by externalization. The externalization process is costly, thus it would be favorable only when applying ERs offsets the cost related to this process. [Zhang J., 1997].

There are various ideas regarding the differences between internal and external representations. One view is that external representations are just inputs and stimuli to the internal mind. In this view, even if it is the case that many cognitive tasks involve interactions with the environment, all cognitive processing only occurs in the internal model of the external environment. Thus, when a user (agent) encounters a task requiring interactions with the environment, the user first has to create an internal model of the environment through some encoding processes. Then, he/she performs mental computations on the contents (symbols, sub-symbols, or other forms) in this constructed internal model. After that, he/she externalizes the products of the internal processing to the environment through some decoding processes. This is a common view in traditional Artificial Intelligence (AI) and other fields of cognitive science [Newell A., 1990, page 57].

In the studies of the relationship between mental images and external pictures, Chambers and Reisberg showed that external pictures can give people access to knowledge and skills that are unavailable from internal representations [Reisberg D., 1987].

In the studies of logical reasoning with diagrams, Stenning [Stenning K. and Oberlander J., 1995] argues that diagrammatic representations such as Euler circles limit abstraction. Hence, by limiting the degree of abstraction in general forms, graphical representations are able to make some information transparent and interpretable.

Zhang stated that, “Different forms of graphic displays have different representational efficiencies for different tasks and can cause different cognitive behaviors.” [Zhang J., 1997, page 3]. Accordingly, [Kleinmuntz D.N. and Schkade D.A., 1993] showed that different representations of the same information such as tables, lists and graphs are able to significantly affect decision making strategies.

In a study of the representational properties of distributed cognitive tasks, [Zhang J. and Norman D.A., 1994] also identified several properties of External Representations (ERs):

1. ERs present directly perceivable information that does not need to be formulated and that can be interpreted explicitly.
2. The physical structures of ERs limit the variety of possible cognitive actions by permitting or prohibiting different actions. Thus, ERs are potentially able to anchor cognitive behavior.
3. ERs change the nature of tasks: tasks with and without ERs are totally different from a user's viewpoint, even if the abstract structures of the tasks are the same (see also [Norman D.A., 1991]).

All the studies mentioned above have revealed that external representations are not simply inputs and stimuli to the internal mind, and they are much more than memory aids. For many tasks, external representations are so intrinsic to the tasks that they guide, constrain, and even determine the pattern of cognitive behavior and the way the mind functions. Given that external representations are so important, they need to be considered seriously, not as something trivial; and they need to be studied on their own right, not as something peripheral to internal representations.

The present study is an attempt to improve epistemic games through investigating whether and how children's reasoning skills and the entertainment value of games are affected by externalizing the underlying structure of a game. A particular game is designed in various versions, as the test bed. This study explores the functions of external representations, using reasoning as the task domain. It takes the position that much can be learned about the internal mind by studying external representations, because much of the structure of the internal mind is a reflection of the structure of the external environment [Anderson J.R., 1993; Shepard R.N., 1984; Simon H., 1981].

Given that games are associated closely with leisure and entertainment for children, Super Maze is developed as a game for children. Super Maze (SM), as an epistemic game, is designed and developed to study the effects of ERs on children's reasoning

1.7 Problem Statement

Gee J.P. [2003] points out that computer games today are mostly coined as entertainment and that the other applications of them may be alien to many. This thesis is an attempt to crystallize the role of computer games on reasoning and thinking. By developing a computer game as a paradigm, this study intends to explore how to design games that lead to more systematic thinking while remaining pleasurable and entertaining.

"It is the interwoven processing of internal and external information that generates much of a person's intelligent behaviour." [Zhang J. and Norman D.A. 1994, page 87] Analyzing the interaction between internal and external representations is a requirement within cognitive science, and research has been performed to promote this need [Scaife M., Rogers Y., 1996].

Norman D.A. [1988 and 1993] has for several years been describing cognition in terms of knowledge in the head and knowledge in the world. Larkin J.H. [1989] has also shifted her thinking from Larkin and Simon's [1987] earlier computational model of diagram use that focused primarily on internal representations to considering the role played by external displays in cognitive problem-solving. Other researchers have been also examining specifically the cognitive effects of external representations in reasoning tasks.

Internal and external representations are two indispensable parts of the representational system of any cognitive task [Zhang J. and Norman D.A., 1994]. By using externalizations we can support creativity and reflection processes, foster synchronized communication, and introduce structure into the problem solving process [Engel D., Bertel S. and Barkowsky T., 2005]. It is not easy to develop an apt tool to investigate whether and how the externalization of the inner structure can impact children's reasoning. Engagement with, and enjoyment of, computer games provide the motivation needed to obtain the cooperation of children. Therefore, we decided to develop Super Maze in order to use it for further investigations.

Super Maze is a tool for observing the effects of the presence or absence of the visible latent structure of the game on the user's reasoning and performance. For this purpose, four different versions of the software were developed. Different interaction methods are used in the four versions of Super Maze, which are explained in the next chapter. There has been much research prior to my study about the role of computer games on children's learning and other related concepts. There has also been research about the role of external representations and the importance of them. Nevertheless, our research is the first study of its kind that investigates the roles of ERs in the context of a game to actually see the effects of them on children's reasoning. The purpose of this study is to discover how we can develop better games in terms of thinking and reasoning without devastating the enjoyable game play. For the purpose of this thesis, the following questions need to be answered:

- How does externalizing the internal structure of a game affect children's reasoning?
- Does the externalization have negative effects on game play and enjoyment of the game?
- Does it have positive effects on improving thinking and reasoning skills of children?
- When can children have both the enjoyment of the game and enhancement of reasoning and thinking simultaneously?

In order to address the above questions, four different versions of the game were designed. The method of interaction with each version is different from the others, as is shown in Table 1-1.

Table 1-1. Method of interaction and shown representation

<table>
<tr><th>Versions</th><th>1</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td rowspan="2">Method of interaction</td><td rowspan="2">Internal Structure</td><td rowspan="2">Main Puzzle</td><td>Main Puzzle and</td><td rowspan="2">Main Puzzle</td></tr>
<tr><td>Internal Structure</td></tr>
<tr><td rowspan="2">Shown representations</td><td>Main Puzzle
And</td><td>Main Puzzle
And</td><td>Main Puzzle
and</td><td rowspan="2">Main Puzzle</td></tr>
<tr><td>Internal Structure</td><td>Internal Structure</td><td>Internal Structure</td></tr>
</table>

Moreover, to develop a better game, designing the game interactions plays an essential role. How to achieve an appropriate design is a complex task and less studied. Therefore, the next focus of my thesis is on the design of interactions. To assess the quality of design and the usability of the game, the following questions should be addressed:

1. How does the design of interaction affect game play and enjoyment of the game?
2. What are the effects of design on children's thinking and reasoning? What are the children's ideas and suggestions regarding the designing of the game?

As Bauer M.I. and Johnson-Laird P.N. [1993] discovered, facilitation of problem-solving depends on the kind of graphical representation being used [Scaife M., Rogers Y., 1996]. There are numerous factors associated with the design of ERs. An extensive literature review has revealed two main related design disciplines. First is interaction design and second is representation design. These disciplines determine how users interact with the software and how the software itself is structured and organized.

Several questions arise on the above-mentioned design disciplines, which must be investigated further in order to get a better understanding about how to devise ERs:

1) Is the chosen representation suitable for describing the internal structure of the game?
2) Which version of the software is more interesting for children? Why?
3) What version of Super Maze is the most successful one according to the study's intention, which is to find out whether and how the externalization of the internal structure of the game affects reasoning and game-play?
4) Are the chosen colors attractive for children?
5) Do they actually interact with the panning panel at the side of the game to have a full vision to the structure tree?

To answer all these questions, an empirical exploratory study is devised to determine the effects of externalizing the underlying structure of the game on children`s reasoning skills and enjoyment of the game. The study will also investigate the influences of design disciplines on the usability of the software.

1.8 Approaches

The purpose of this pilot study is to obtain preliminary results about the usefulness and usability of the 4 different versions of Super Maze, to determine how to develop better epistemic games. The study of Super Maze is one study in a broader series of investigations to discover how to design effective visual computer interfaces to support reasoning and thinking in serious games. Designing visual computer interfaces is not an easy task, and much research is needed to determine how to design effective interfaces [Sedig K. et al., 2001]. The visual computer interface of Super Maze is designed in the context of research in Human-Computer Interaction (HCI). From the perspective of HCI design, users need to interact with the interface to determine its usefulness and usability [Gould J.D., 1995]. It is necessary to involve users in the study because the designers of an interface are usually not the end-users and cannot predict how real users will react to the interface. Designers need to validate their design conceptions through testing with end-users [Gould J.D., 1995]. We compared the 4 different versions of Super Maze to find out how the different representations and interactions affect reasoning and thinking. Each version of SM has a different interface but all of them have a common part, which is the main puzzle screen.

1.9 Research Objectives

There are two main concerns regarding SM that shape the objectives of the thesis.

- First, how children reason with the underlying structure of the game and how different interfaces affect the user's experience of the game. Experiencing the game means that one can interact with the game in various ways depending on the version of the game. Each interface has a unique method for interaction. These methods are explained in next section.
- Second, to evaluate the overall quality of design according to information visualization disciplines in all of the four interfaces. This is done by comparing the similar and different features of the versions such as game components, colors, how much the children enjoyed playing the game, and so on.

These two concerns form the main objectives of this thesis as follows.

- The first purpose of this research is to investigate whether and how the externalization of internal structure of a game can influence children's reasoning skills and the enjoyment of playing the game. The proposed strategy to investigate effects on reasoning is to engage children with four different versions of the developed software (SM) and analyze the different experiences of the game.
- The next component of this thesis is to evaluate the quality of design with respect to design disciplines. Designing an analytical tool such as SM is important in terms of how to design it in an effective and appropriate manner. There are several features associated with this design. This thesis focuses on two main design disciplines:

1) Interaction design

2) Design of Representations

Different interfaces of SM have been developed. Subsequently, a usability study has been designed to compare these interfaces and to investigate the feasibility and effectiveness of the design.

1.10 Thesis Outline

This thesis is organized in six chapters and an appendix.

In the first chapter, an introduction to the research is presented along with the importance of the computer games for children. In the second chapter, fundamentals of the developed software are described and the four different versions of the game are introduced.

In Chapter 3, a general description of representations and theoretical background involved in representations are presented. The role of design and particularly the interaction design are discussed. The literature review and background on current research in external representations, interaction design, representation design, and usability are introduced.

Chapter 4 provides the method of investigation for the thesis and presents the process of experiment. The objectives and protocols of the study are also explained in this chapter. In Chapter 5, the results of the pilot study as well as the findings of the qualitative observations and analysis is reported. The qualitative results for each group of subjects including their anecdotal remarks are also discussed and presented individually in this chapter.

The thesis is summarized and concluded in Chapter 6. Evaluation of different versions of the developed software is also highlighted.

Appendix A. presents the letter of consent for participated children on this study and their parents.

1.11 Summary

This chapter provides a brief introduction to cognitive abilities and computer games. A general description of playing and cognitive development is presented. The applications and importance of computer games for young generations are discussed. Theoretical background and the important rules of external representations are also described. Finally, the problem statement is proposed and the approaches to this study are presented. In the following chapter, the developed software Super Maze (SM) for the experiment will be described.

Chapter 2

2. Super Maze Development Descriptions

Super Maze was developed using the C# programming language. C# was chosen for its portability with the Microsoft .NET Framework, its object-oriented characteristics, as well as its ease of use. It was also easier to find a supportive graphical engine for C# as compared to other languages such as Java. Flat Red Ball (FRB) was chosen as the graphical engine for Super Maze, which provided a useful and straight-forward framework for graphics, sound, and overall game structure.

The design of meaningful play requires an understanding of how rules ramify into play. To have better games, players should experience the rules of the game in motion. Rules are the raw materials with which games are created [Salen K. and Zimmerman E., 2004]. Super Maze has operational rules for it has some degree of abstraction. SM has multiple levels to describe these operational rules. The game is played in a maze-like environment made of 21 levels. Each level contains an Exit, obstacles, Stand blocks, and may contain a different layout of objects.

- The player directs an object through each level.
- The player may need to collect other objects as they progress through the maze before they reach the exit.
- A level is complete once the player collects all the necessary objects and reaches the exit.

- The game ends when the player completes every level.

2.1 Operational Rules of SM

Operational rules provide the necessary information for the formal game system, the representational sub-system and the interactional sub-system [Sedig K., 2009, Lecture notes].The operational rules for the SM are as follows:

2.1.1 First Set of Operational Rules of SM

- The game contains multiple levels, each composed of various types of blocks in different arrangements.
- The player directs an avatar to move in some direction, continuing in a straight line until it collides with other blocks.
- Stand blocks will stop the bolt.
- Arrow blocks will change the avatar's direction.
- Walls will destroy the avatar.
- The exit block leads to the next level in case of completing the current level.

2.1.2 Second Set of Operational Rules of SM

- The player must collect a set of collectables scattered throughout each level before the avatar reaches the exit.
- Before collecting each collectable the avatar must pass through the changing circles in order to gain the match color.

- If the player has collected all the collectables on the level and reaches the exit, the game proceeds to the next level.
- The game ends when the player completes the final level.

2.2 The Objects of SM

Any system is comprised of four things: Objects, attributes, internal relations and environment [Sedig K., 2009, Lecture notes]. The following are the objects and attributes of SM.

- Player's avatar (see Figure 2-1)
- Various types of blocks and their attributes are:
  - ➢ Stand blocks which stop the avatar from moving (see Figure 2-2)
  - ➢ Wall blocks which destroy the avatar. (see Figure 2-4)
  - ➢ Arrow blocks which move the avatar in a certain direction. (see Figure 2-3)
  - ➢ Rotating blocks which rotate the avatar in a certain spinning direction. (see Figure 2-5)
- Collectables. (see Figure 2-8)
- Coloured Circles. (see Figure 2-7)
- The level exit. (see Figure 2-6)
- Top tree nodes. (see Figure 2-9)
- Symbolic collectables on the top tree branches. (see Figure 2-12)
- Direction arrows on top of each node which show the chosen movement direction. (see Figure 2-13)
- Symbolic exit on the top tree. (see Figure 2-11)

- Symbolic walls on the top tree. (see Figure 2-11)
- Continuous dots to avoid repetitions on the top tree branches. (see Figure 2-14)
- Side tree which contains a panning glass to allow users to see the entire tree. (see Figure 2-24)

2.3 Representational Sub-System

Representational system of a game can be comprised of one or more of the following representations: Symbols, icons, pictures, text, plots, maps, diagram, and tables [Sedig K., 2009, Lecture notes]. Here you can illustrate the representational sub-system of the SM.

- Icons used for various objects of the Super Maze

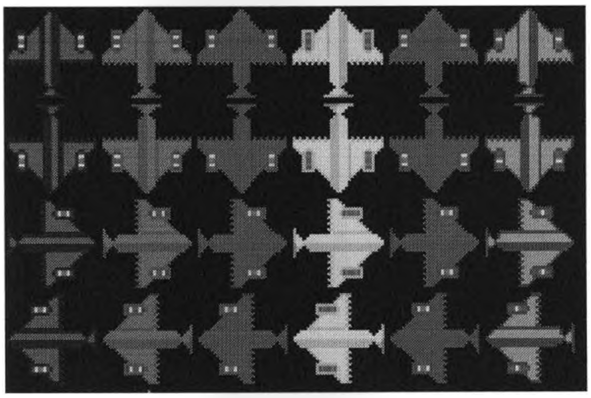

Figure 2-1. Avatars' icons in different directions.

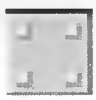

Figure 2-2. Stand block.

Figure 2-3. Arrow blocks in different directions.

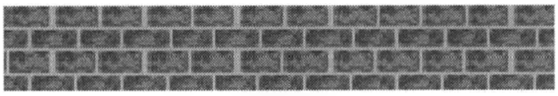

Figure 2-4. Wall.

Figure 2-5. Rotating blocks.

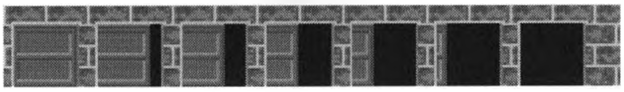

Figure 2-6. Exit.

Figure 2-7. Colored circles to change the avatar's color.

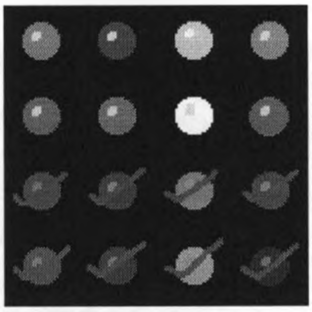

Figure 2-8. Collectables before and after being collected.

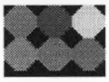

Figure 2-9. Tree nodes (their colors depends on the avatar's color.)

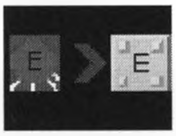

Figure 2-10. There are similar letters on top of the tree nods and the stand blocks of the puzzle.

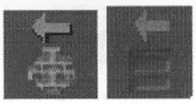

Figure 2-11. Symbolic walls and exit on the top tree.

Figure 2-12. The blue and red dots are symbolic collectables on the top tree.

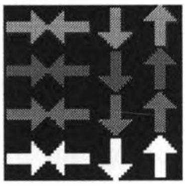

Figure 2-13. Direction arrows on top of the tree nods.

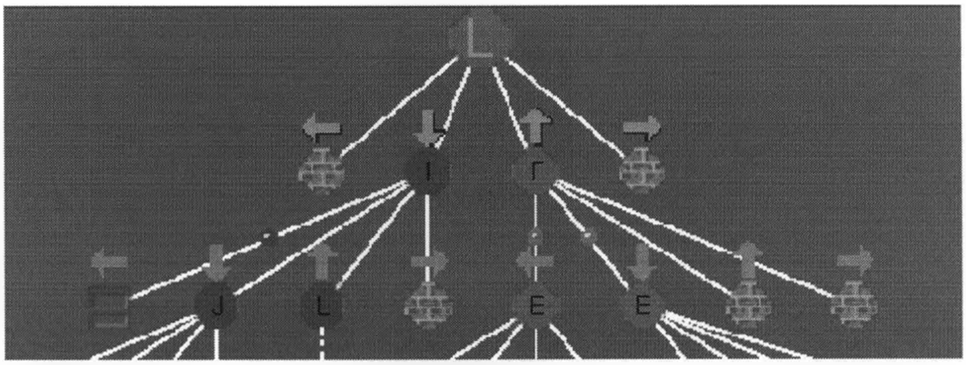

Figure 2-14. When there are repetitions on the tree branches, continues dots are replaced with the actual braches e.g. "L –node" in this figure.

- Display of level information is textual.

Figure 2-15. Level's information.

- Background

Background is a picture as shown below.

Figure 2-16. Background.

- Story boards

The following storyboards depicted in Figure 2-17, Figure 2-18 and Figure 2-19 show the movement between the main screens of the game, internal relations and environment of the Super Maze.

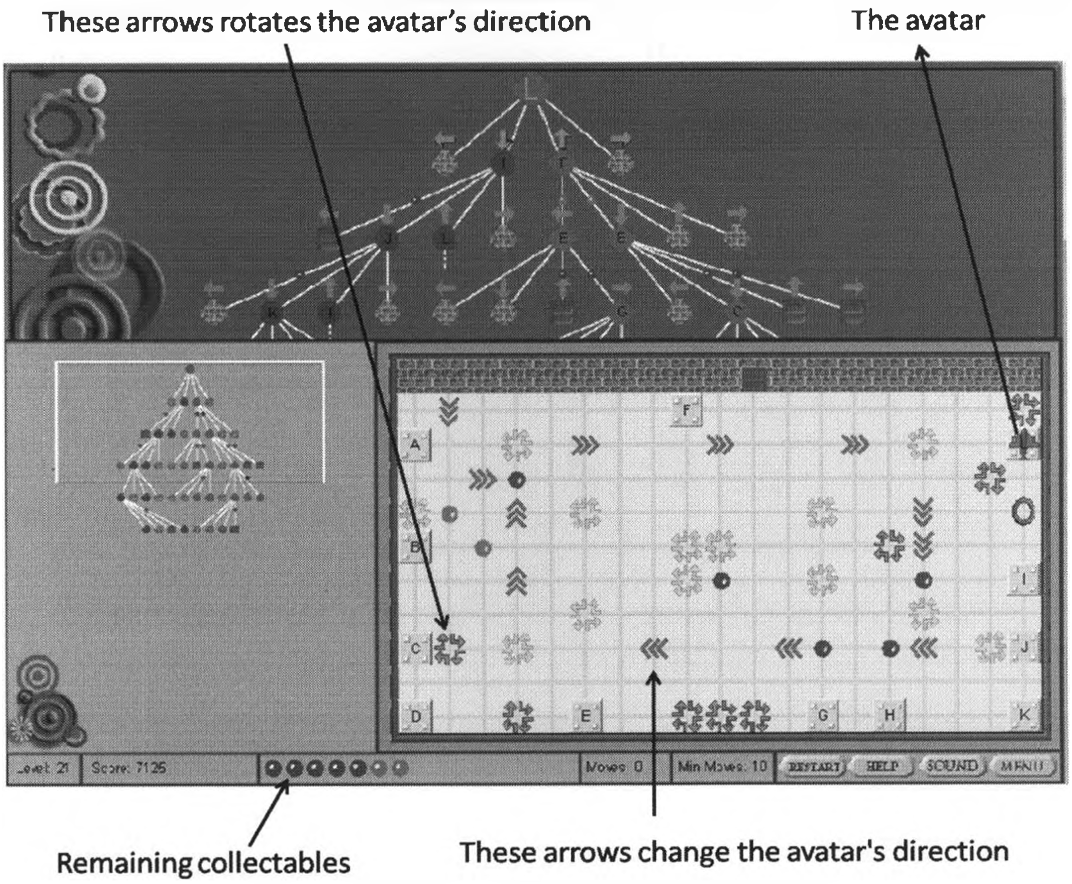

Figure 2-17. Elements of the game in the main puzzle.

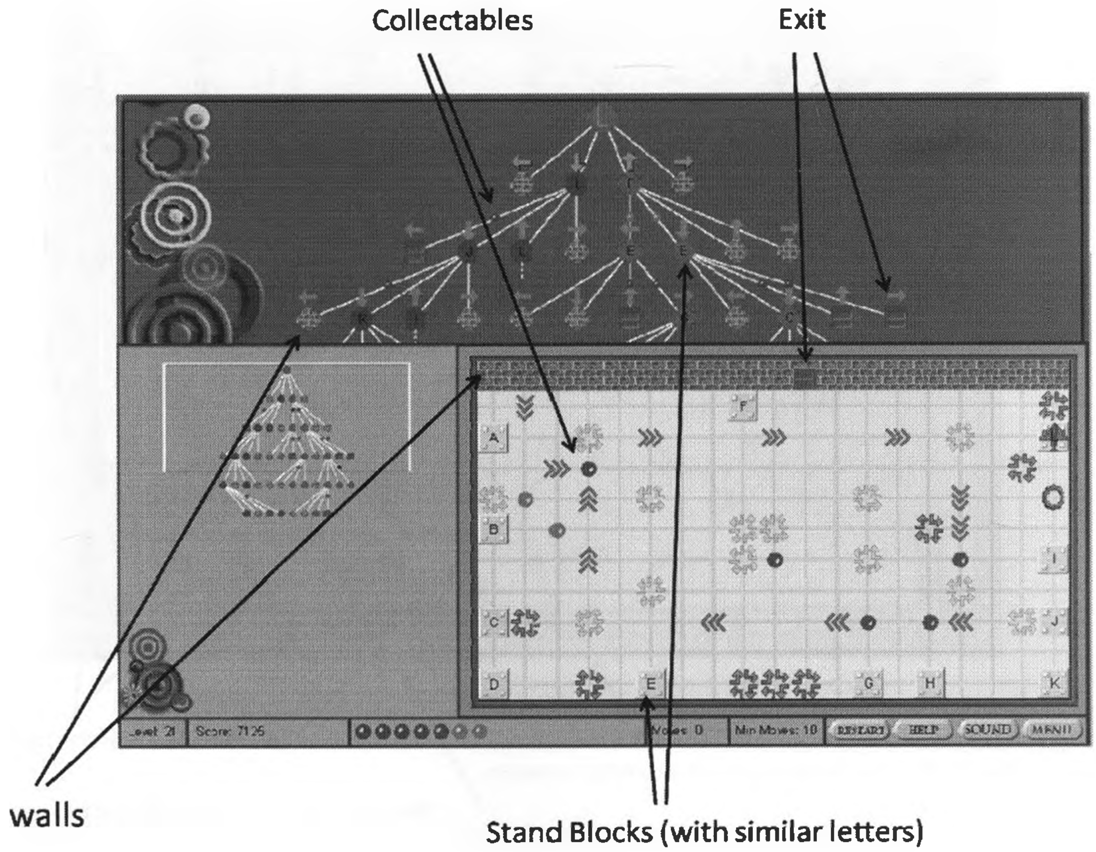

Figure 2-18. Similar icons in the tree and the puzzle.

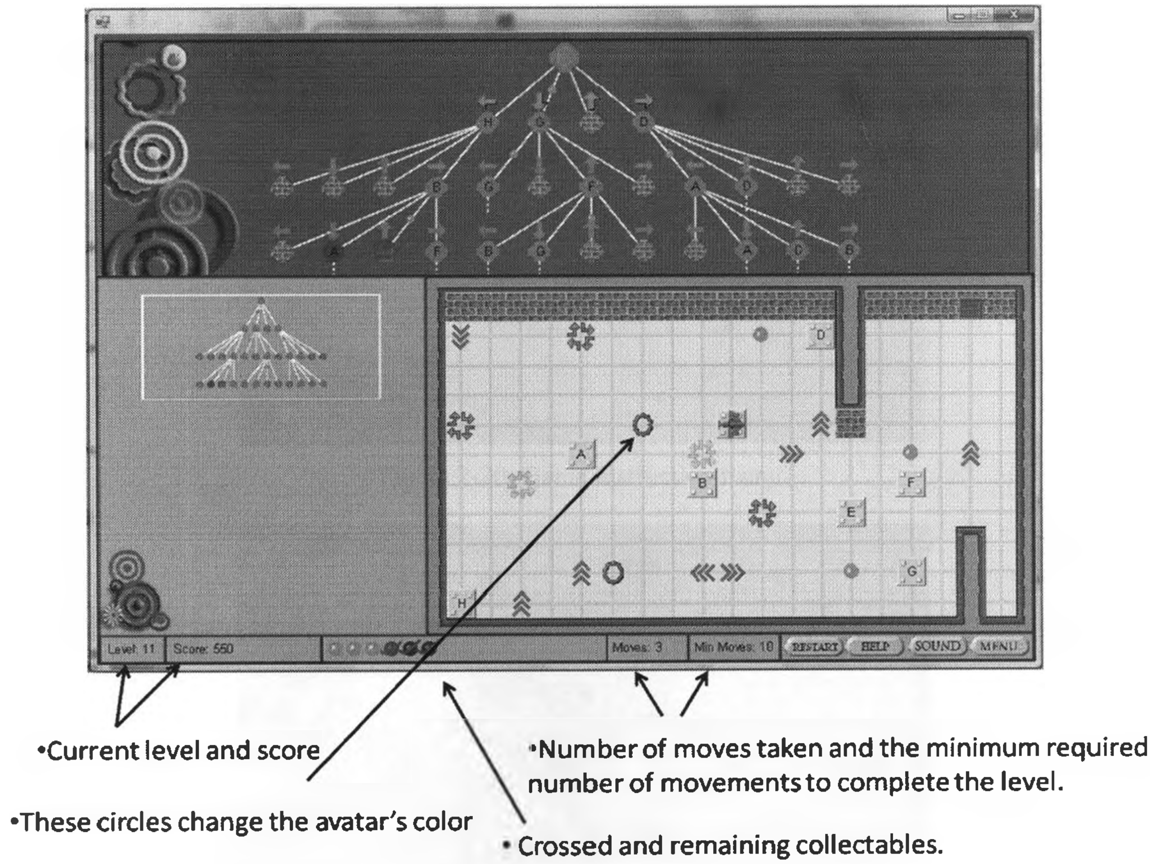

Figure 2-19. Textual and iconic elements of SM.

2.4 Game Description

Before beginning the game, as shown in Figure 2-20, players can refer to the help button to learn the how to play. After completing each level the screen shown in Figure 2-21 will appear to report the acquired points and the total number of their movement along with the minimum possible number of movements to complete the level.

different versions are conducive to enhancing thinking and reasoning. Our hypothesis is that the four versions differ in the way they support thinking. We anticipate that Version 1 is superior to the other versions since it requires more careful thought before committing to an action.

The difference between the four versions of Super Maze lies in how users can interact with the representations in the game. Version 1 presents a tree structure of the puzzle and requires users to click on nodes of the tree to solve the puzzle. Whereas, Version 2 presents users with the tree structure, but requires them to use the arrow keys to solve the puzzle. Version 3 allows users to use both the arrow keys and click on nodes of the tree to solve the puzzle, and Version 4 requires users to use the arrow keys to move things on the screen to solve the puzzle. Different parts of each version and their interaction methods are explained in more detail in following sections.

2.5 Version 1

In the first version, the internal structure of the game is externalized as a tree to observe the impact of externalization on children's play. The purpose of the externalization is to determine what interaction techniques support children's reasoning better and consequently lead us to a better epistemic design of computer games. The internal structure of Super Maze is a search tree. As shown in Figure 2-22, this version has four main windows. The most top window is showing a search tree with all the possible paths through the level.

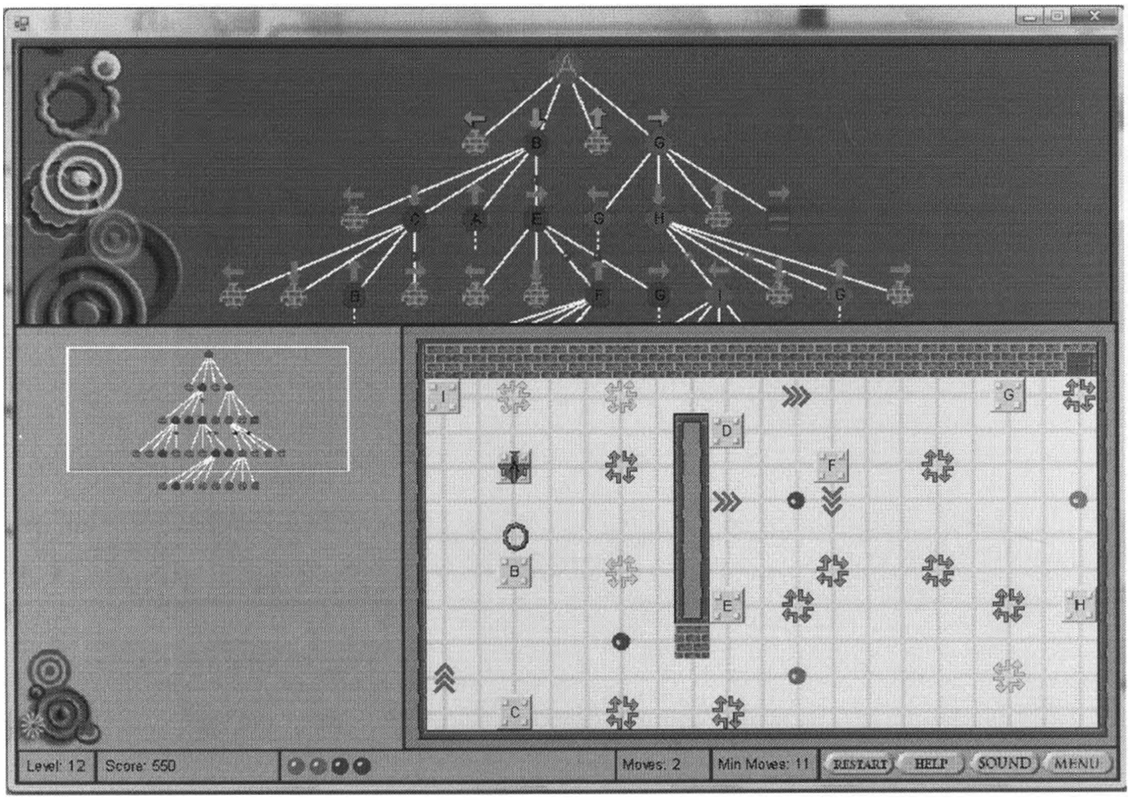

Figure 2-22. Shot screen of SM for level 12.

As depicted in Figure 2-22, all the directions are signified with small arrows on top of each node. There are alphabetic letters on each node, which designate the similar position of the stand blocks in the main puzzle. In the top tree window, all the possible steps are shown; however, the repeating branches are ignored. Instead, these repetitions are shown with continuous dots. In this version, children can only play the game through the externalization. In other words, the interaction is through the tree representation by clicking on the direction arrows as illustrated in Figure 2-23.

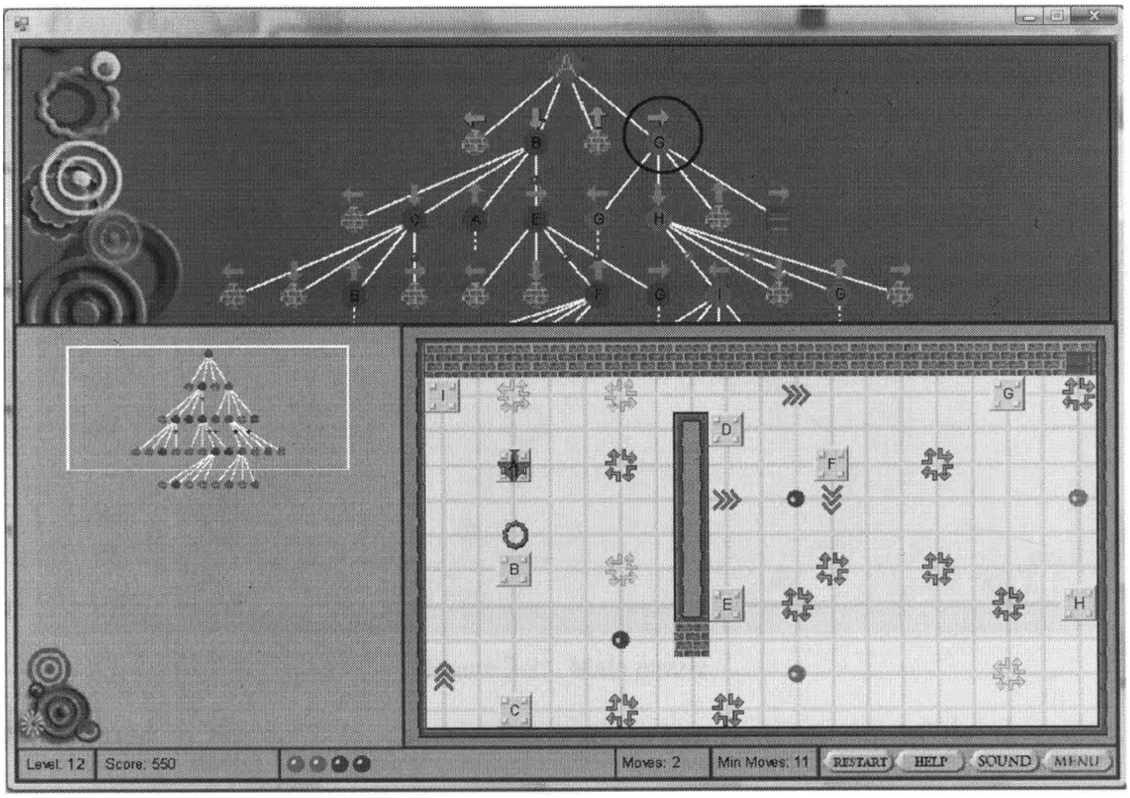

Figure 2-23. To play the game in Version 1, user must click on the direction arrows of the tree.

As shown in Figure 2-24, next component of this interface is the left side tree, which is actually the entire tree in a smaller size. There is a panning glass on top of the side tree. Interaction with this panning glass allows users to see different parts of the tree both in the side and the top tree.

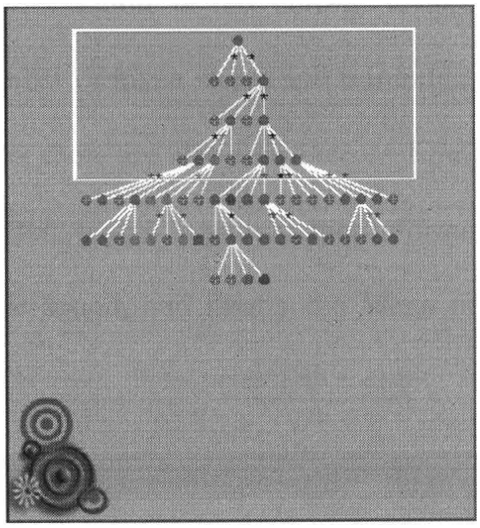

Figure 2-24. By moving the panning glass of the side tree, users can see the entire tree in the top tree.

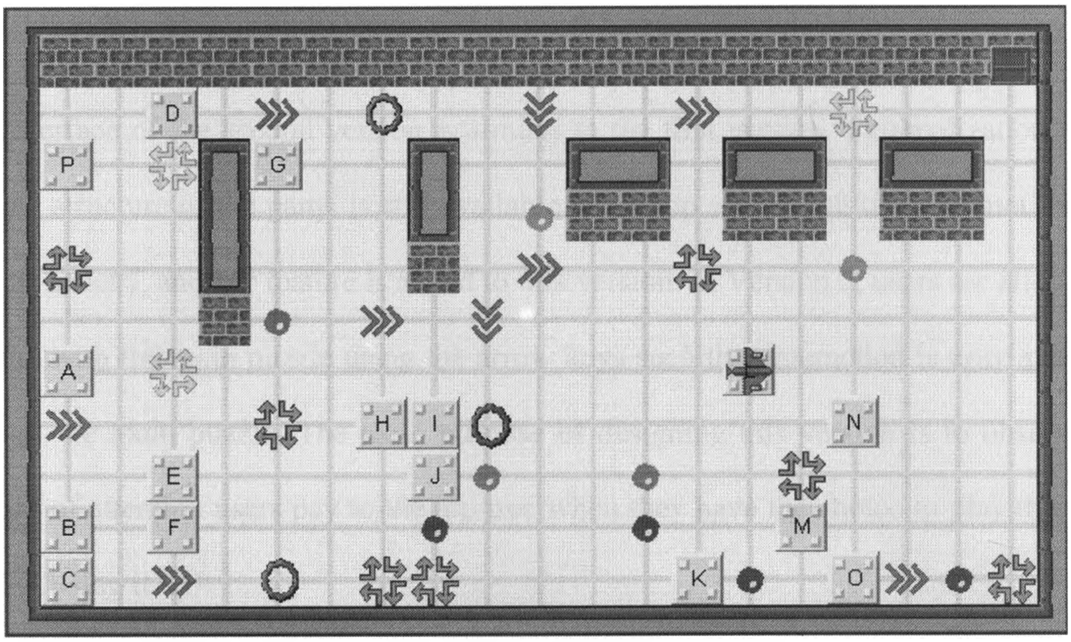

Figure 2-25. Main puzzle.

As illustrated in Figure 2-25, the main screen on the right bottom of the screen is the main puzzle. Children have no direct access to this screen in this version. They can interact with the top tree and observe the consequences of their actions on the main puzzle. The main puzzle contains several elements, such as walls, stand blocks, exit block, directing arrows, rotating arrows, collectables, pre-collectables and the game avatar. There are several information boxes on bottom of the screen, which contain the game information. This information is the current level, total score, collected and remaining collectables, number of taken steps, and minimum steps required to finish the current level. In Figure 2-26, there are also four buttons from left to right: Restart button to restart the current level, Help button to gain further information about the game, Sound option button to control the sound, and finally the Menu button to return to the main menu.

Figure 2-26. Textual information.

2.6 Version 2

The interface of the second version is similar to the first version. Externalization of the internal structure of the game is still available at the top screen, but users cannot interact with it. Instead, another feature is added to this version. In Version 2, users are allowed to interact with the main puzzle using the arrow keys such that interaction is only available through the main puzzle. The main purpose of designing this version is to observe the amount of attention users pay to the top tree when they have the choice to play the game without using it.

2.7 Version 3

The interface of the third version is similar to Versions 2 and 1. This version is a combination of the first and second versions. Users can perform their movements either through the tree structure or the main puzzle. This version is a good indicator for designers to recognize the most preferred method of interaction from the users.

2.8 Version 4

Last Version of Super Maze contains only two main parts. First, the main puzzle and second, the information boxes in bottom of the screen. In this version the externalization of the internal structure is removed as shown in Figure 2-27. This version is similar to available puzzle games in the market, which are entertaining and persuasive. This version was designed to observe and study the user's reaction based on their interest to such games compared with other versions.

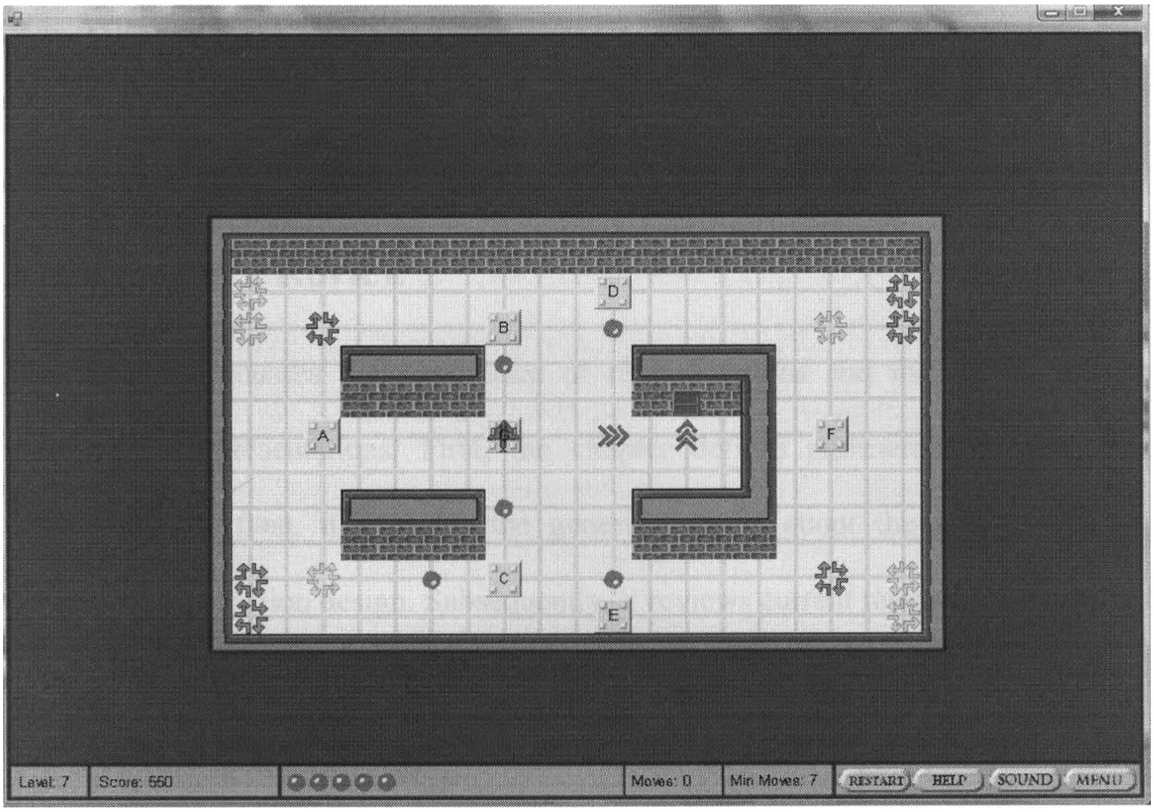

Figure 2-27.In Version 4 users interact with the main puzzle through the arrow keys.

In this version, children can only interact with the main puzzle and the interaction is performed through the arrow keys.

2.9 Summary

This chapter described the game named "Super Maze". The operational rules, objects, and representational sub-system of SM were introduced and the entire game with its four different versions was described. Chapter 3 will present the literature review and background on current research in external representations, interaction design, representation design and usability.

Chapter 3

3. Literature Review

This chapter discusses the importance of representations and theoretical background involved in representations. First, the chapter defines representations and external representations; then, it provides the general context about the role of design and particularly interaction design. Subsequently, it reviews current research in representation design, interaction design, and usability.

3.1 Representation Design

Davis R.B., Young S. and McLoughlin P. have proposed a definition of representation: "A representation may be a combination of something written on paper, something existing in the form of physical objects and a carefully constructed arrangement of idea in one's mind" [Davis R.B., Young S. and McLoughlin P., 1982, page 23]. Good representations enable users to perform a task more efficiently. By using representations, identifying characteristics and patterns are easier and information that might normally be ignored is more effortless to find.

The presented definition includes both internal and external representations. A significant feature of the Davis et al. definition is that it highlights the relationship between internal and external representations in reasoning [Cox R. and Brna P., 1995]. A different description of representation is presented by [Mason J., 1987]: "...it is not clear that `representation' is a sensible or consistent way to describe what goes on inside a person, because their inner experiences are their world and not merely a representation of the world, whatever that may be .... It is more sensible to speak of inner experiences as a person's world, and to speak of their manifestations in terms of pictures, diagrams, words, and symbols as a `presentation' of their world." [Cox, R. and Brna P., 1995, pages 239-302].

Virtual reality and visualization, as means of representing and interacting with information, are very much at the forefront of technological development. It is now more feasible for people to interact with information in innovative approaches due to advancements in graphical technologies [Scaife M., Rogers Y., 1996].

Visual representations can represent thoughts, concepts, and structures. Thus, we can encode knowledge as well as generate new knowledge by finding patterns in the visual representation that could not easily be noticed in the world [Norman D.A., 1993]. We assume that one can actually see and understand the underlying structure of the game by interacting with both the main puzzle and the search tree. This statement however is to be discovered during this thesis experiment. A search tree or tree diagram is an advanced mathematical concept that many children are not exposed to before a university education. Tree diagrams have various applications in several disciplines such as [http://en.wikipedia.org/wiki/Tree_diagram]:

- In mathematics and statistical methods, a tree diagram is used to determine the probability of achieving specific results where the possibilities are nested.

- In physics, a tree diagram is an acyclic connected Feynman diagram which is an intuitive graphical representation of a contribution to the transition amplitude or correlation function of a quantum mechanical or statistical field theory.
- In linguistics, a parse tree is one way to visually represent the structure of a sentence, a syllable, or phonological feature geometry.
- In biology, particularly in phylogenetics, tree diagrams are used to study the evolutionary relatedness among various groups of organisms e.g. species and populations as discovered through molecular sequencing data.
- In Artificial Intelligence, a game tree is a tree diagram used to find and analyze potential moves in a game.
- In information visualization, a Hyperbolic Tree is a visualization method for a graph inspired by hyperbolic geometry.

The final goal for children is actually to become familiar with the search tree. However, this objective is outside of the scope of this thesis. By developing the epistemic game i.e. SM we want to see and evaluate the role of externalization on the reasoning process. Super Maze has a "Tree diagram" representation to externalize the internal abstract structure of the game.

Visual representations can be defined as a collection of graphical symbols that visually encode causal, functional, structural, and semantic properties and relationships of a represented world, either abstract or concrete [Sedig K. et al., 2003]. Appropriate representations enable users to perform tasks more efficiently. Norman states, "The power of the unaided mind is highly overrated. Without external aids, memory, thought, and reasoning are all constrained." [Norman D.A., 1993, page 43].

Appropriate representations can facilitate many cognitive activities such as understanding, problem solving, calculation, and the growth of knowledge [Peterson D., 1996; Norman D.A., 1993]. Peterson D. [1996, page 8] defines a representation as "a notation together with an interpretation of the notation." However, Norman D.A. [1993] simplifies the concept of representation by stating that representations stand for (or refer to) objects, things, or concepts. These definitions indicate that representations are abstractions of entities, such as objects, things, or concepts, which may or may not have an associated set of operators. Furthermore, the interpretation of the properties of an abstraction is associated with, but is not the same as, the properties of what the abstraction represents.

Representations can be internal or external. Internal representations cannot be expressed with any media, for they are mental images. Internal representations are not available to others. An internal representation can be defined as a mental model. On the other hand, external representations can be expressed with media. Visual representations are external representations expressed using a medium that allows others to see and interact with them. Thus, external representation can be used as an external aid to help people reason [Peterson D.A., 1996; Norman D.A., 1993]. Norman argues that without external aids, memory, thought, and reasoning are all constrained [Norman D.A., 1993, page 43].

Internal models have a crucial role in problem solving [Qin Y. and Simon H.A., 1995]. Users must interpret a visual in order to understand what it represents. Their interpretations depend for the most part on mental models. The mental images of users are continually modified because of the users' interactions with the visual. The users continue to modify their mental models of the visual in order to obtain a workable result. This result may be neither technically accurate nor complete.

The results of a study on imagery in problem-solving show that among other factors, organization and structure can help create mental images [Qin Y. and Simon H.A. 1990; 1995]. The activity that the organization and structure of a problem afford affects the mental images created. However, it is noteworthy that the average person's working memory, where the mental images are formed, is limited [Simon H., 1981]. Therefore, an appropriate visual representation of our problem needs to be highly structured and organized. It also needs to be divorced from ambiguity to allow for consistent interpretations.

Norman discusses the two essential ingredients of a representational system [Norman D.A., 1993]:

1. The represented world: that which is to be represented.
2. The representing world: a set of symbols, each standing for something, representing something in the represented world.

The above implies that the information captured by the representing world is a subset of the information in the represented world. It also implies that the information captured by the representing world is encoded. This captured and encoded information results in a cognitive artifact, a tool that can be used for reasoning. For example, the information needed to represent the unused space of a hard drive can be encoded with the use of a coloring scheme, a numbering scheme, or a drawing scheme. Each encoding scheme produces a different representation or cognitive artifact that can be used to make inferences about the capacity of the hard drive. The choice of which representation to select depends on the task to be performed.

Explicit representation of important information has been shown by a number of researchers to improve the performance of users [Norman D.A., 1993; Sedig K. et al., 2001]. For example, the research of [Sedig K., et al. 2001] with concept-centered applications shows, among other things, that what users interact with is important since it can affect their performance.

Psychologists and AI researchers have collected much evidence on the significance of good representations for users [MacEachren A. M. et al., 1999; Norman D.A., 1993; Newell A., 1990 and Simon H.A., 1972]. Norman states that [Norman D.A., 1993, page 49]: "a good representation captures the essential elements of the event, deliberately leaving out the rest". Therefore, a representation of a problem should ignore irrelevant information and focus on the important features of the problem presented to the user. Consequently, an inappropriate representation of an entity can make tasks using that representation surprisingly difficult [Tabachneck-Schijf H. J. M., Simon H. A., 1996].

The representation and the manipulation afforded by the environment do not however always provide the desired insight, as certain factors can constrain or influence this insight [MacEachren A. M. et al., 1999]. The abstraction, therefore, becomes the difficult thing to develop [Norman D.A., 1993].

Although one representation may be better suited than another for a certain task, there is no perfect representation for all tasks. A representation of the problem determines the kind and level of task required by the user to find a solution. Representations can turn the task into an experiential task where the solution is easy to spot or into a reflective task where careful and deliberate thinking is needed to make sense of what is being experienced.

The same task may be easy or difficult to perform depending on the way it is represented [Tweedie L. et al., 1996]. The efficiency and ease with which users perform a task depend crucially on the representation of the problem.

As it mentioned above, visual representations are external aids that can help users in their problem solving and reasoning processes. In this research, the proposed environment presents alternative representations in such a way that it allows users to find relevant information easily, and helps them to capture important and essential features of the represented. Super Maze has been designed to observe the effects of epistemic utilities on children's reasoning. Epistemic utility in context of games refers to a game mediating proper reasoning, problem solving, and effortful thinking.

Interacting with visual representations is an important aspect of Super Maze. Additional efforts have been made into developing a good representation for the underlying structure of the game. The following section presents literature review on external representation.

3.2 External Representations

Skilled reasoning usually involves re-representing the problem in a way that makes the solution salient [Simon H.A., 1981].

The term External Representation (ER) refers to a wide variety of representations. Lohse G.L. et al. [1994] identify 11 basic categories for ERs: graphs, tables, graphical tables, time charts, networks, structure diagrams, process diagrams, maps, cartograms, icons and pictures.

Graphical ERs such as freehand idea sketches are an important support for creativity in design disciplines such as architecture [Goldschmidt G., 1991]. ERs are also an everyday phenomenon. For instance, if we need to communicate the directions to a party to our friends, we draw a map. We take shopping lists to the supermarket. All these are examples of the use of ERs in problem solving or related activities. In addition to everyday examples, it is well known that ERs are effective aids to problem solving for a range of more formal problem types. Cognitive and semantic properties are two main attributes of ERs that are responsible for their effectiveness in reasoning.

3.3 Interaction Design

Researchers during the 1980s worked to develop tools and methods for user interface design. The research arose from the belated recognition by computer scientists that the user interface is as vital a component of computing systems as an operating system or database [Badrel A.N., 2002].

Interaction means two or more entities acting upon one another. In the context of human computer interaction, the term interaction is intended to convey the way in which users relate to the computer and the way the computer affects users. That is to say, interaction is concerned with the communication between users and the computer [Shedroff N., 1999]. “Interaction design is the discipline of defining the behavior of products and systems that a user can interact with”. “Interaction design focuses on how the user interacts with an application or product. It follows a task centered design approach ensuring the flow of the interaction as the central goal." [Norman, D.A., 1988].

In 1999, Raskin J., the creator of The Apple's Macintosh computers, emphasized that external representations can play an important role in supporting interaction by discussing the need to develop novel approaches to interaction. Following paragraphs look at the limitations of the interaction and current interface techniques that allow interaction.

Norman refers to interaction in terms of action [Norman D.A., 1993]. The users have a plan i.e. something they want to do with a system. Thus, the users form goals in psychological terms. However, because the system presents its current state in visual terms, the users have to determine how to interact with the system to accomplish their plan and then interpret the visual state of the system to determine if their plan was successful. This can create epistemic conflict for it determines the amount of cognitive effort needed to use a system. This conflict creates two gulfs: the Gulf of Execution and the Gulf of Evaluation [Norman D.A. and Draper S., 1986; Norman D.A., 1991].

These gulfs are between the user and the computer system. The Gulf of Execution refers to the difficulty of acting upon the environment and how well the artifact supports these actions; i.e. the user trying to do something. The Gulf of Evaluation refers to the difficulty of interpreting the state of the environment and how well the artifact supports those interpretations; i.e. the user trying to understand the current state of the system. Interaction design is concerned with bridging these gulfs. "The gulfs can be bridged by bringing either the system closer to the user or the user closer to the system" [Sedig K., 2001, page 34].

Raskin J. [1999] argues that a primary goal for interaction designers is to allow users to develop automaticity across all tasks. That is to say, the effectiveness of an interaction is reduced if a feature forces users to stop thinking about their task and begin paying attention to the feature. This prevents users from entering the automatic phase with respect to that feature.

Hence, the effectiveness of an interaction is determined by the ease of use, the time taken to perform a task, and the amount of effort needed to perform a task [Sedig K. et al., 2001]. Therefore, minimal cognitive effort is needed to bridge the gulfs of execution and evaluation. That is, little mental effort is required to translate a goal into actions and then evaluate the effect.

One prevalent way to bridge the gulfs is through Direct Manipulation (DM) interfaces. "DM refers to systems which allow users to see graphical representations of objects and directly manipulate them on the computer screen with some kind of pointing device" [Sedig K. et al., 2001, page 35]. Stary C. and Peschl M.F. [1998, page 341] maintain that we should design interfaces such that "the intended task(s) can be accomplished with minimal cognitive effort".

Hence, the interaction design for cognitive tools necessitates great care. The designer needs to choose a suitable representation and augment it with appropriate interaction techniques. Several empirical studies have demonstrated that interaction can enhance the benefits that visual representations provide [Sedig K. et al., 2006; Otero N. et al., 2001; Sedig K. et al., 2001; Gonzalez-Lopez M., 2001; Arcavi & Hadas, 2000; Olive J., 2000; Matsuda N. and Toshio O., 1998].

Interaction in our case is defined as the communication between the user and a Visual Representation (VR) via a human-computer interface. The interaction method varies in different versions of SM. Through our experiment we aim to determine the most effective interaction approach for enhancing children's reasoning. Our system, described in Chapters 2, provides users with different interfaces and levels of interaction. Each interface affords users an interactive visual representation that they can explore for themselves. However, the level of interaction and the types of representations help highlight the different aspects of the structure under consideration.

3.4 Usability

Equivalent to the investigations and academic growth of HCI, the software industry has focused on designing user-compatible interfaces and making software systems ever more usable. "Starting in the mid-1980s and gaining strength in the 1990s, the interface development community employed usability engineering methods to design and test software systems for ease of use, ease of learning, memorability, lack of errors, and satisfaction" [Badrel A.N., 2002, page 5] .

An application with high usability can make the user more effective and in less need of support and education. The risk of users making mistakes will be reduced and a system with high usability will provide a less stressful environment for the users [Goransson B., Lif M., Gulliksen J., 2003]. In the International organization for Standardization (ISO), usability is defined as "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use." [ISO 9241-11, 1998, page 6]. The effectiveness of a system relates to the work objectives (goals). The efficiency relates to effectiveness in relation to the resources needed to perform the tasks. Satisfaction, according to ISO 9241, concerns acceptability and comfort.

Usability practitioners of the 1990s considered two factors as measures of usability. **Ease of Learning:** One can measure usability by comparing the time it takes users to learn to do a task when working with new software to the time it takes them to learn to do the same task in another way.

Ease of Use: The minimum number of actions required to complete a task successfully. This becomes an invaluable measure of usability for more experienced operators [Badrel A.N., 2002].

Well-designed tools can greatly assist users in their thinking and reasoning, but these tools are challenging to be designed [Hollan J.D., Bederson B.B., Helfman J.I., 1997]. To evaluate the usability of a system, "Ease of use" is one of the main indicators. SM shows and records the steps taken with the user and the minimum steps required to complete each level. As a result, this information can be used as valuable indicators for comparing the usability of different versions. In other words, the closer the number of steps taken during a game is to the minimum steps, the more efficient usability is provided.

It is desirable to measure the usability and effectiveness of design for different components of SM. These components are the magnifying glass, colours, icons and position of each element, etc. For this reason, it has been decided to use the following strategies:

1) Direct observations

2) Structured interviews

To obtain accurate information, our test subjects were videotaped while playing the game and they were interviewed after completing the game. Findings and results of the interviews are provided in Chapter 4. The following are some sample questions of the interview:

1. Do you enjoy the game?
2. Do you consider this game as a good game?
3. Is the concept clear to you or are there confusing points regarding SM?
4. Do you like the colours?
5. What do you generally feel about the game?
6. Do you have any suggestions about how to improve the game?

3.5 Summary

A brief literature review about representation design, external representation, interaction design and usability was presented in this chapter. The two main gulfs between the user and the computer system, the gulf of execution and the gulf of evaluation and the approach to bridge these gulfs were also discussed in this chapter. The main strategies to examine the usability of Super Maze were also explained. In the following chapter, the method of investigation will be discussed.

Chapter 4

4. Method of Investigation

The purpose of this pilot study is to obtain preliminary evaluations of the four different versions of SM and to observe which version best supports children's thinking and reasoning as well as enjoyable game play. The differences between the four versions lie in how users can interact with the representations in the game. Version 1 presents a tree structure of the puzzle and requires users to click on nodes of the tree to solve the puzzle. Version 2 presents users with the tree structure, but requires them to use the arrow keys to solve the puzzle. Version 3 allows users to use either the arrow keys or click on nodes of the tree to solve the puzzle. Version 4 requires users to use the arrow keys to move things on the screen to solve the puzzle, and the tree is absent in this version.

Research has shown that different ways of interacting with representations of the same concept can support thinking, reasoning, and learning in different ways [Sedig K. et al., 2001; 2003; 2005]. We would like to understand which aspects of the interfaces of the different versions are conducive to enhancing thinking and reasoning while at the same time not detracting from the general game-play and enjoyment of the game.

The study involves children 9 to 13 years of age. The letter of information and the consent form (Appendix A) was given to the participants and they were asked to read it. An advanced consent form with more details was also available for their parents/guardians to read and sign. Both the child and one parent/guardian were requested to sign the consent form, which was then returned to the researchers. Children were allowed to participate only after both consent forms were signed and returned to the researchers. A brief summary letter was given to all participants and their parents/guardians upon completion of the study.

To investigate the effects of externalization on reasoning and game-play we used an exploratory research method including a number of types of data collection approaches (video transcripts, interviews, and direct observations). In this exploratory study, we gave the Super Maze game to 13 children to play and collected a number of observations. We wanted to actually see the children's reactions to each version of SM, and to explore how they reason with any version of the game. The results and some anecdotes from the experiment are presented in Chapter 5.

This study compares the representational effects of the different versions of SM on children's reasoning and their general enjoyment of the game-play. "Representational effects refers to a phenomenon that different isomorphic representations of a common formal structure can cause dramatically different cognitive behaviours." [Zhang J. and Norman D.A., 1994, page 88]. The intent of this thesis is to discover the most successful interfaces (version) in terms of reinforcing reasoning in an entertaining approach.

Moreover, this study investigates the usability of SM and the role of design on user's impressions. For this investigation, we placed particularly attention on the HCI concepts of interaction design and representation design.

We chose the co-discovery learning method because research has shown that the conversation between the two subjects makes it easier for designers to understand the subjects' interaction with the system so as to pinpoint usability problems [Kennedy S., 1995]. This is especially true for younger participants. Through interaction with another person, subjects are encouraged to express their thoughts in a more natural way. In the case of sole subjects, of which there was only three, the co-investigators asked them to think aloud and they played the role of the accompanying person for the sole subjects by continually asking them what they are thinking at each movement.

Videotaping the subject during their interaction with the system allows us to estimate how much time was spent on each puzzle and which aspects of the interface were particularly easy or difficult to interact with. Two types of data collection were employed:

1. Direct observation
2. Individual interviews

The subjects were videotaped as they were interacting with the system, and the co-investigators observed their behaviour and took notes. Special attention was paid to the areas of design that attracted the attention of the subjects, when the subjects lost interest in the game, how the subjects approached the material presented in Super Maze, and how much time the subjects spent on each level.

All of the subjects were interviewed after the completion of the experimental session. This session was also videotaped. The purpose of the interview was to acquire information about why subjects chose to solve puzzles in a certain way and to elicit the subjects' impressions of the design of the game. Moreover, the interview was an enormous support for a better understanding of the subjects' reasoning with the game and the amount of fun and enjoyment that they experienced during the game. The co-investigators watched the videotapes of the interviews and transcribed them.

This study was a pilot study and based on its results, a comprehensive usability study will be conducted in future. The nature of this pilot study is qualitative. The sample size for qualitative research according to [McMillan J.H. and Schumacher S., 1993] does not have to be as large as required for quantitative research. The sample size for the interviews is therefore much smaller and more focused i.e. three to four subjects per each game version.

It is anticipated that the subjects will benefit from interacting with Super Maze by learning how to navigate through a search tree. Search trees and tree diagrams are higher-level mathematical concepts that the most students are not exposed to before high school. As discussed in more details before, tree diagrams have various applications in several disciplines such as mathematics, economics, statistics, physics, biology, and AI. The educational goal of Super Maze was for users to become familiar with search trees. Super Maze employs tree diagrams to externalize the internal abstract structure of the game.

4.1 The Experiment

After the subjects agreed to participate in the study, by reading the information letter and signing the consent form, the subjects were randomly assigned to interact with one of the four versions of the game.

Each one of the eight resulting groups was asked to complete one version of the game. The participants were reminded that the purpose of this study is to evaluate the usability and usefulness of Super Maze and not to test them or their knowledge of any concept. The estimated duration of each study was 150 minutes.

Initially, the subjects received a brief introduction to Super Maze and then they were asked to familiarize themselves with the game for five to ten minutes. Subjects were then asked to play the game and complete it. The time allotted was approximately 90 minutes. After 45 minutes there was a short break before the second 45 minute session.

Most of the subjects worked in pairs and only three subjects did the experiment individually, and these lone subjects were accompanied and encouraged by one of the co-investigators to think aloud and articulate their next decision throughout the game. This usability testing method is called co-discovery learning [Kennedy S., 1995]. The subjects were reminded that their interaction with each other and with the game would be videotaped.

After they played the game, the participants were asked to answer a few questions. The co-investigator conducted open-ended interviews with the subjects to gather further information about their interactions with the game.

Questions of the interview were anchored in their interactions with the game, for example:

- Did you learn anything from this game? Please explain.
- When you played the puzzle in the fifth level you did not use the panning glass. Why?

After the completion of the study, all subjects were given the opportunity to interact with the other 3 versions of Super Maze and were asked which version they preferred and why. Subjects were also invited to give suggestions as to how to improve the game.

4.1.1 Version 1

In the first version of SM, where interaction is with the externalization, interaction is possible via manipulating the "Tree" by clicking on the direction arrows on top of the tree branches. The user only has an indirect control of their game avatar. By choosing a route to take, SM moves the player's avatar around. Users determine which path to follow amongst four possible movements (right, left, up and down) by looking at the tree branches and considering the new routes through the tree that each decision provides. They can achieve good performance in the game depending on which path they choose to follow.

4.1.2 Version 2

In the second version, the tree structure is available, but in order to play, players have to direct their avatar via arrow keys only. The player can actually see the consequences of each action on the tree but he or she can not directly manipulate through the tree.

4.1.3 Version 3

In the third version of the game, the tree diagram again shows the possible routes that player can choose, but users can interact with their avatar by using the arrow keys on the main puzzle screen or by manipulating the tree.

4.1.4 Version 4

The forth version of SM used for this study offers users just the functionality of the main screen. Users are able to interact with the avatar of the puzzle and the tree is absent in this interface.

4.2 Objective

The objective for this study is to observe the role of externalization on children's reasoning, and to investigate what version of SM supports user's reasoning in an entertaining and motivating approach. The differences between the four versions lie in the representations and interaction methods with the tree diagram and the main puzzle as described above.

Research has shown that different representations of the same concept support thinking and learning in different ways [Norman D.A., 1993]. We would like to study how people reason while they interact with different interfaces of the same structure. Furthermore, we would like to understand which aspects of each representation/interaction model are conducive to thinking about and discovering the underlying structure of different representations and creating a mental model based on that. Our hypothesis is that the first version is the most effective to support users on the formation of their mental model for understanding the underlying structure and, consequently, enhancing the process of reasoning when dealing with different representations of the same concept.

The possible assumption for Version 2 is that it will be less effective for supporting the formation of user's mental models for understanding the underlying structure of the game than the first version. The reason for this assumption is that, since children have this option to play with the puzzle directly, it is possible that they do not interact with the representation of the tree. Compared to the first version, where interaction is only through the externalization, in the second version users will not realize the relationship between the tree diagram and the underlying structure of the game.

In the fourth version, users can only interact with the puzzle, and there is no externalization representation. We think that this version is similar to so many other games in the market and it does not have any significant effect on the users' reasoning. However, this version is invaluable for our study since we can use it as an apt indicator to compare other versions with this one to realize whether the presence of the externalization in the second version is effectual or not. Besides, this assessment is possible by comparing and observing the users' behaviors and results in Versions 2 and Versions 3. They may also show that these versions are more interesting and entertaining for children though this is not our main goal.

4.3 Protocols

We planned to conduct an exploratory study with approximately 13 subjects to see the role of externalization of the underlying structure of the game on user's reasoning, as well as the quality of design on motivation. Subjects were randomly assigned to one of the four groups. All groups were asked to play all levels of the SM. The participants assured that the purpose of this study is to evaluate the role of externalization on their enjoyment of the game play as well as usability and usefulness of the software and not to test them on their knowledge.

4.4 Analysis

The method we planned to use for analyzing this study is an exploratory-quantitative research method. By this, we mean to record the interactions of the users with the tool including their visual and auditory responses. From these responses, we analyzed their emotional reactions as well as their responses to the internal structure of the game. Finally, these results were analyzed to determine if there was any significant difference between the four versions in terms of reasoning and perception.

Qualitative Analysis: The participants' interaction with the software has been videotaped. The subjects' interaction with the software has been studied to determine which areas of the design support reasoning and which ones confuse the subjects. Additionally, the co-investigators asked the subjects questions during their interaction with the software to gather further information about the usability and usefulness of the features of the game.

The qualitative data in a narrative manner has been studied and analyzed to cross-validate and provide explanation for the results. To accomplish this aim, we asked different questions from each group. The following are some sample questions that we used:

- "While using SM, did you feel comfortable interacting with it?"
- "Was there anything you would have liked to do in SM that was not available to you? Explain your answer."
- "Can you think of any features that were missing from the program that would have helped you complete the game?"
- "What was the most difficult part of the program?"

- "What feature of the interface did you find the most useful? Why?"
- "What features did you find the least helpful? Why? "
- "Were there any features that distracted you?"

4.5 Summary

This chapter presented the method of investigation, and the process of experiments. The objectives and protocols of the study were described. As explained in this chapter, an exploratory-qualitative research method was chosen as the analyzing method for the study. In the following chapter, the findings and results of the experiment will be discussed.

Chapter 5

5. Results and Findings

This chapter reports the results of the pilot study as well as the findings of the qualitative observations and analysis. Since this study has four different versions, the subjects were also divided into two sets of four or eight different groups with each group containing either one or two subjects. The qualitative results for each group of subjects including their anecdotes are presented individually in this chapter.

5.1 Pilot Study Results

The total number of subjects participated on this exploratory study is 13 including 7 girls and 6 boys, aged between 9 to13. Table 5-1 presents the total number of subjects participated in each version. It also shows the number of girls and boys in each group.

Table 5-2 indicates the time children spent and the total score achieved by each group. As it is shown, the average total score of Groups 1 and 2 who played the first version is higher than the average total scores of the other groups. Table 5-2 also shows that Group 2 followed by Group 1, who both played the first version, took the least amount of time to complete all of the levels in the study.

Table 5-1 Subject basic information for each version.

Group Number	Subject's Gender	Ages	Total Number of Subjects
Group – 1 and 2 (Version 1)	Boys: 2 Girls: 2	9 and 10 13 and 13	4
Group – 3 and 4 (Version 2)	Boys: 1 Girls: 2	10 12 and 13	3
Group – 5 and 6 (Version 3)	Boys: 1 Girls: 2	11 11 and 13	3
Group – 7 and 8 (Version 4)	Boys: 3 Girls: 0	12, 11 and 10	3

Table 5-2. The time children spent and their score for each version

Version	Group Number	Total Time	Total Score	Average Total Score for each Version
Version 1	Group 1:	78 minutes	8750	(G1+G2)/2 = 9812.5
	Group 2:	67 minutes	10875	
Version 2	Group 3:	107 minutes	-825	(G3+G4)/2 = 7212.5
	Group 4:	94 minutes	15250	
Version 3	Group 5:	149 minutes	13125	(G5+G6)/2 = 5337.5
	Group 6:	134 minutes	-2450	
Version 4	Group 7:	101 minutes	9875	(G7+G8)/2 = 9087.5
	Group 8:	84 minutes	8300	

Following figures show the average amount of time in minutes that each group spent on each version. It also shows the average total time that each group spent for each level. As it is shown in Figure 5-1 and Figure 5-2 and also according to Table 5-2, the total spent time on the experiment for both groups of the first version is the lowest among the eight groups. Besides, the subjects of this version gained the highest total score amongst all other groups of participants.

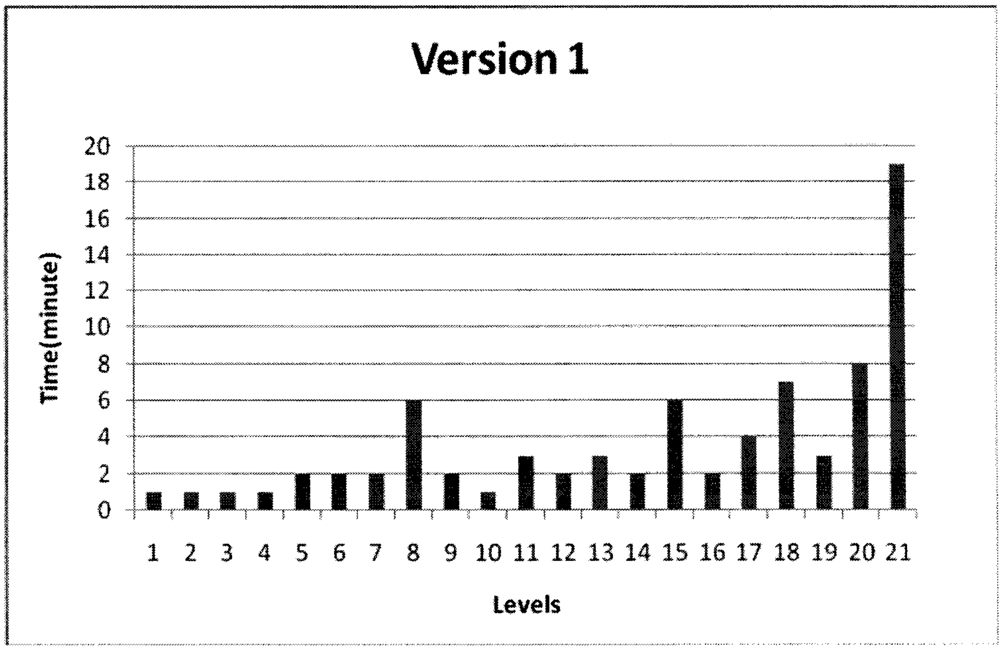

Figure 5-1 (Group 1-Version 1)

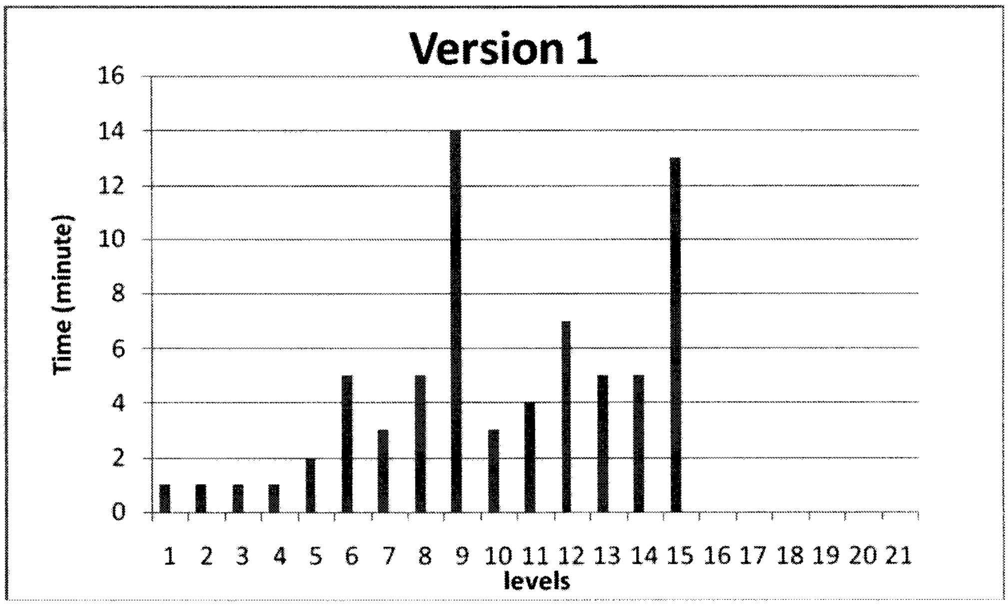

Figure 5-2 (Group 2-Version 1)

Figure 5-3, Figure 5-4 and Table 5-2 indicates that the participants who played Version 2 are in the third place after the participants who played the first and the fourth version regarding the total spent time to complete the experiment and the total score.

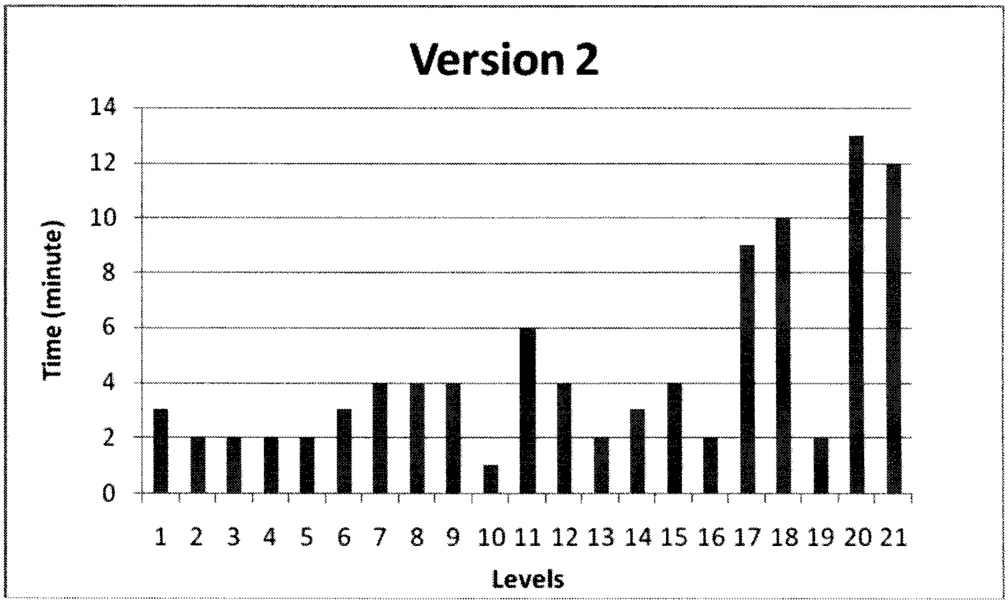

Figure 5-3 (Group 3-Version 2)

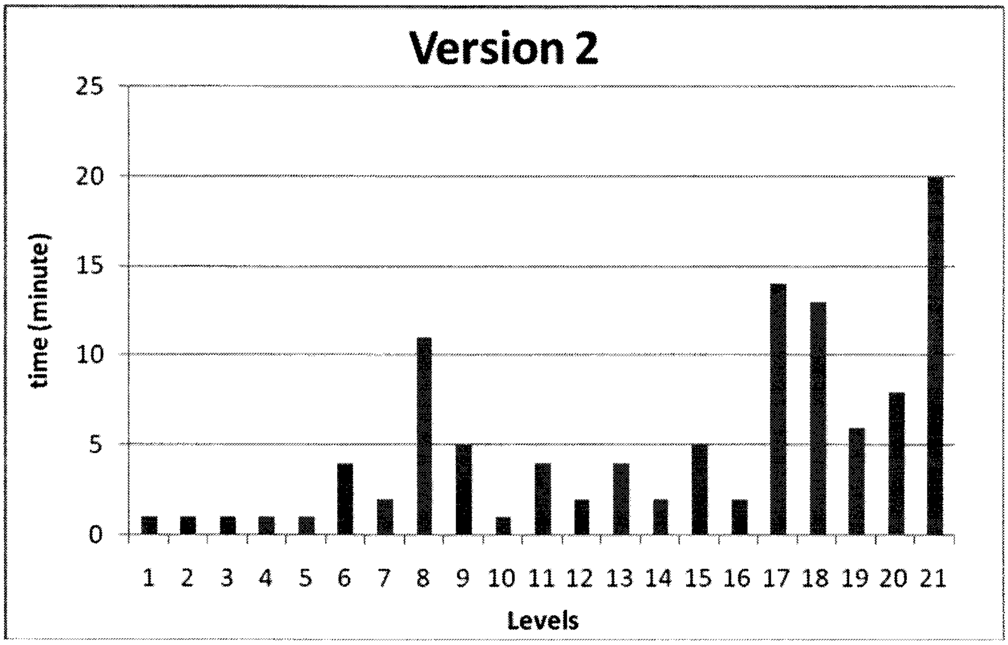

Figure 5-4 (Group 4- Version 2)

Considering both the total spent time and acquired score during the experiment and according to Figure 5-5, Figure 5-6 and Table 5-2, the subjects who played Version 3 reached the last position among all the other groups.

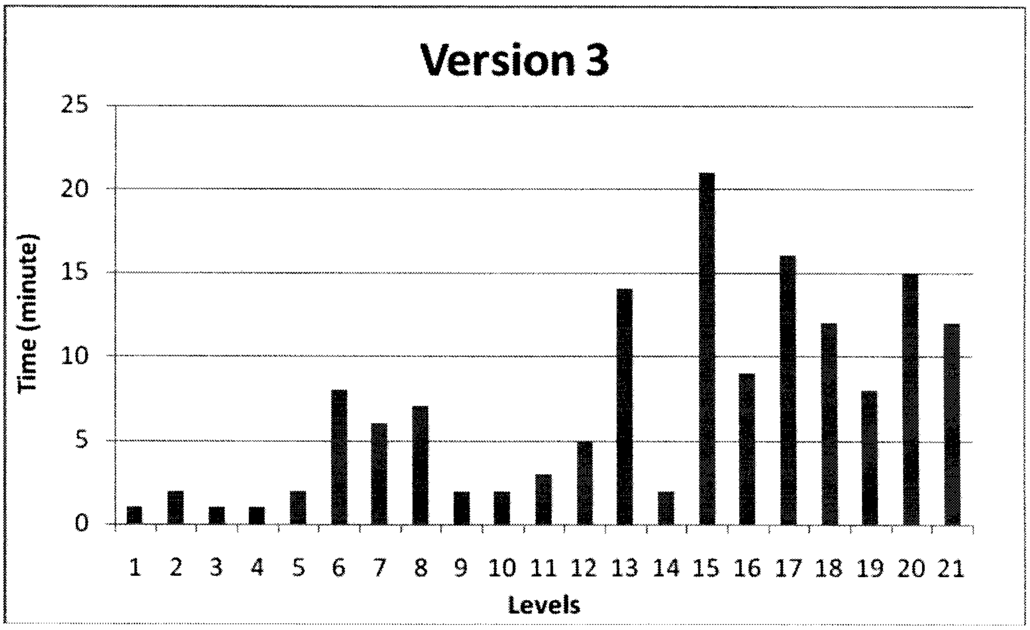

Figure 5-5 (Group 5- Version 3)

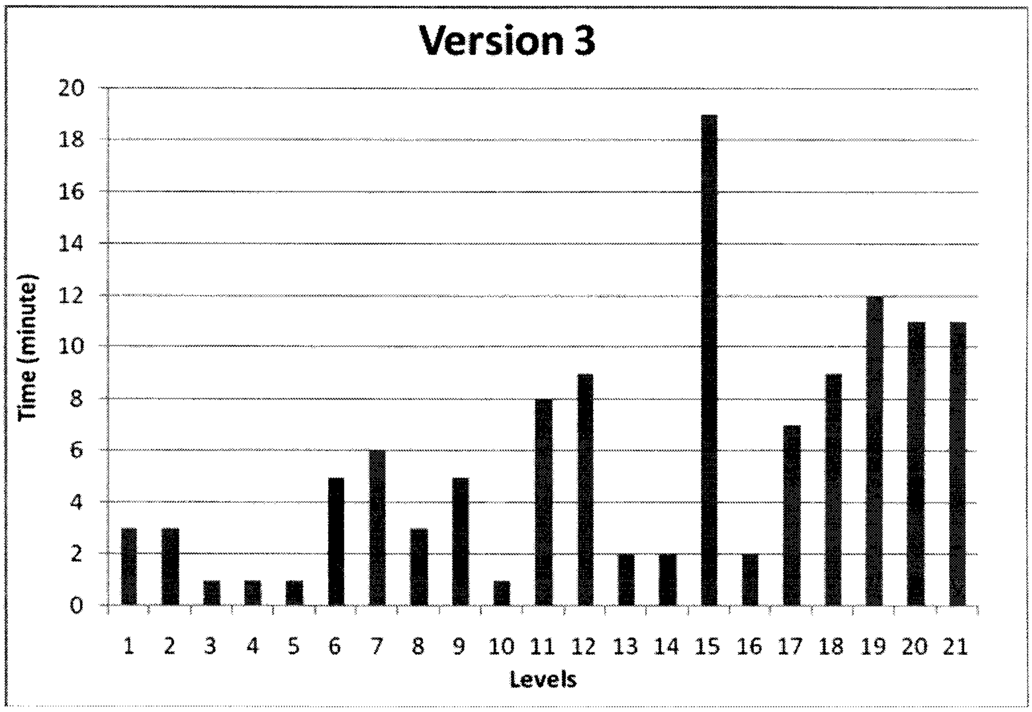

Figure 5-6 (Group 6 –Version 3)

As it is shown in Figure 5-7, Figure 5-8 and Table 5-2, the subjects of Version 4, according to their spent time to complete the experiment as well as their total score, achieved the second place after Groups 1 and 2 who played Version 1.

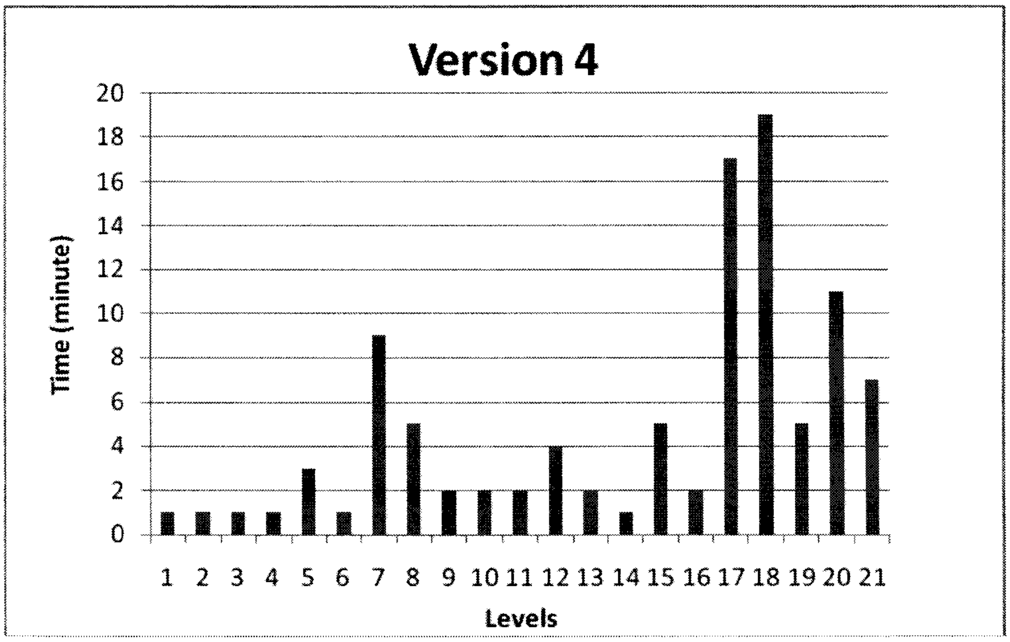

Figure 5-7 (Group 7- Version 4)

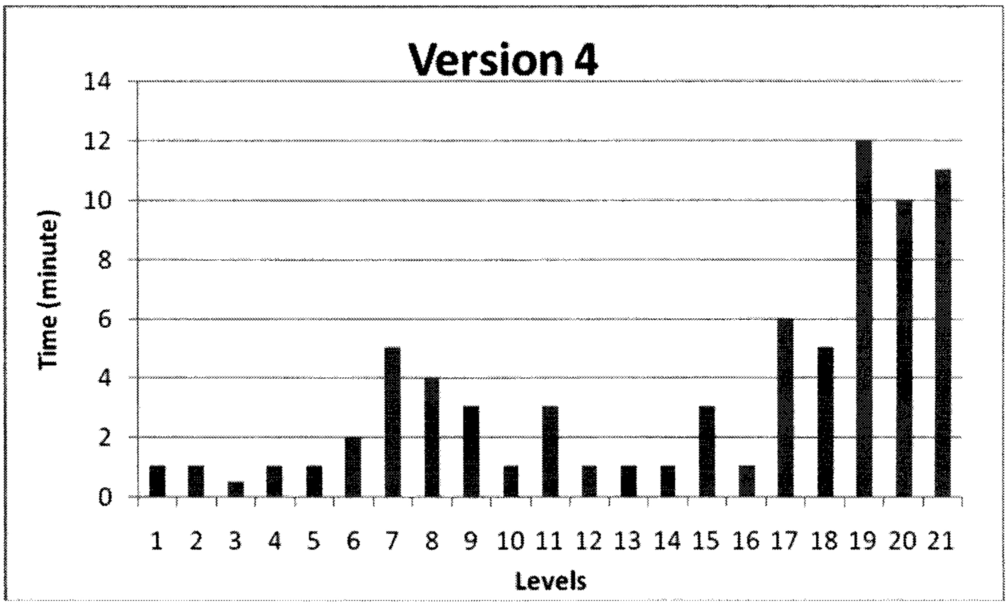

Figure 5-8 (Group 8- Version 4)

5.2 Qualitative Results

Each group demonstrated a distinct pattern of exploration indicating that indeed the interaction model and available underlying representation limit the reasoning capabilities of the participants.

From two different points of view, spent time and total score, the rankings of all versions are in the same order. Version 1, which was concentrated on the tree-externalization, outperformed all the other versions followed by Version 4, Version 2, and finally Version 3. As it is shown in Table 5-2, Version 3 involves the maximum spent time and the minimum score. According to the interviews, Version 3 is their most favourite version.

5.2.1 Version 1

5.2.1.1 Group 1

The subjects of this group were required to complete the tasks by interacting with the latent structure of the game by clicking on the tree externalization nodes. Initially, the subjects of this group spent time "getting to know" the Super Maze. It seemed that the subjects of this group were using the playing field area of the game for local reasoning, but used the tree for some long-term planning. Since only the first few levels of the tree are shown in the top tree representation, the subjects only seemed to care about those levels and used only that much for their reasoning. Generally, this pattern of behavior suggests that the subjects used the tree to validate their own moves. They used it to make sure they did not get stuck. Also, they used the tree to see where they could change color and how to get there.

The subjects of this group would alternate between tracing a path on the playing field and looking at the tree, either for validation or to choose their next action. They did not take moves that would go to a wall, no matter how well obscured the path was because the tree showed them that it would collide to a wall. The subjects became more confused about where to go next by around level 8.

The tree was mainly used to find how to reach the next set of dots. The complete tree was not searched often, as the subjects usually just did a quick scan of what was immediately visible.

Aside from the last level, the subjects only restarted when they knew they were stuck. Otherwise, they just kept going ignoring how many moves it would take. When the tree showed the limit of their available moves, they noticed things such as:

> "*Get blues* [blue collectables] *first, there's no ring on the screen to turn us back to blue*" and "*oh, we should restart we can't go anywhere else now.*"

During the interview when the subjects were asked "What was the most difficult part of the game?" They responded with the following:

> *A: I think it got more difficult as the levels increased because the navigation was more complex. So, you had to navigate your way through all the arrows, stops and those things.*
>
> *B: I think level 21 is really hard. Because it has lots of different directions that you will go and it's hard to decide which way to go, so you have to think for a long time.*

When they were shown the other versions, the subjects stated their ideas about the other versions as follows.

When they were shown the Version 2, they stated:

> *A: I prefer Version 2 (rather than Ver.1) because you can keep looking at those (Tree nodes) but still moving.*
>
> *B: I prefer this version, in this graphic you can keep going. You don't need to be like this (looking at both, main puzzle and the tree) to see where your clicks are going.*

However, when they interacted with Version 3, they changed their mind to:

> *A: I like this version is even better. If then somebody likes one of them* [Clicking or arrow keys] *it won't be hard for them to play, because they can use one or the other.*
>
> *B: I would prefer this too.*

And in response to the fourth version, they declared:

> *A: No...I think the third version was better because that tree structure shows you the possibilities but this version is just bunch of supers and it just jumbled.*
>
> *B: This one looks much harder. There is nothing to tell you these are the possibilities and you are in danger. In this version you just have to keep doing it to see what will happen but in other versions, you can actually see this leads there. We used the tree to see how to go to somewhere in the hard situations.*

5.2.1.2 Group 2

The subjects of this group only played the first 15 levels of the game due to their personal reasons. The main strategy that was often used with this group was to explore each level by trying different paths and then restart the level to find the path needed.

The subjects of Group 2 tried a certain direction by looking at the main screen; however, it seemed that they could not notice the changes in the direction. For instance, they were not sure how the tree showed how they arrived to a certain node when looking at the stated direction. It did not seem like they could reach the node by following it on the main screen.

According to the observations, subjects of this group did not pay attention to the tree despite having to interact with it. For example, subject A used it solely to direct the avatar, and only made very short distance plans on the screen while subject B did match up the tree with the screen to check if a direction would crash into a wall. None of the subjects seemed to use the side panel, or to use the colors of the nodes to know when they would change the colors.

When they were asked “What was the most difficult part of the game?” the subjects answered as follows:

> *A: Umm... I would say finding your way around.*

> *B: Finding your way from the rotating blocks.*

And their answers to the question: “Did you find the tree helpful?” was:

> *A: Yeah, Obviously it was showing me all the shortcuts and possibilities.*

B: I technically agree with that.

When they were asked "Did you learn anything from this game", they answered:

A: I learnt about the navigation and path finding.

B: I learnt about making a good decision, although it was just a game.

And when they were shown the other versions, they both enjoyed the second version better than the Version 1 and said:

A: It is defiantly better...Basically I like this version better. It is easier than clicking.

B: I think this is better. Wow, it is so easier. What is useful about the version that we played is, that you can click and see where you want to go.

Later on when they were shown the third version, they changed their mind to:

A: I like just the arrow keys.

B: I like to have a choice, so actually I like this version better.

And finally, they were shown the last version and their opinions regarding this version were as follows:

A: I like this version and the Version 2.

B: I like Version 2 better because it let you see what really happens.

5.2.2 Version 2

5.2.2.1 Group 3

The subjects of this group were required to complete the tasks by interacting with the main screen through the arrow-keys. The tree externalization was also available on this version to show them the potential possibilities although the subjects were not able to interact with it.

Subjects of this group traced the path in the main puzzle window and not in the tree window. They also tracked the path in the main puzzle window with their fingers. Interestingly, they did not move until a path had been traced. Then after few levels, they started moving the avatar without tracing the path. In Level 7, they talked to each other as follows:

A: I still don't understand the tree.

B: It is not exactly that helpful.

They restarted levels several times to achieve the minimum steps (best score) unless the level was hard. Then, they just tried to reach close to the minimum number of movements.

Subjects of Group 3 immediately noticed the lack of color rings indicating which collectable bolts to collect first. They looked at the last collectable bolt before the exit to determine what color to be at the end.

In addition, they always first eliminated which directions they could not go before looking at which directions they could go. As one of them mentioned in Level 15:

B: First of all we have to illuminate which way we can go.

A: There...there & there &...then we die.

And in Level 17 they said:

B: We have to illuminate all we can do. It's fun; let's see which way it will take us.

A: Undo is a good option then we don't need to restart.

To the subjects of this group, the long travel times of some moves in some levels were fun at first, but then became boring.

In Level 17, the subjects looked at the tree to find the destination spot without noticing the path. Then, they found the path from the present place to the destination point by just looking at the main puzzle window. In Level 20, as could not find it by just looking at the main puzzle window, the subjects again used the tree to verify their plans and to check for how to collect the last ball. Finally, in Level 21, they used the tree to see what would happen in the big circular path, shown in Figure 5-9 by thick red lines, since it was too complicated for them to find it simply by looking at the main puzzle window.

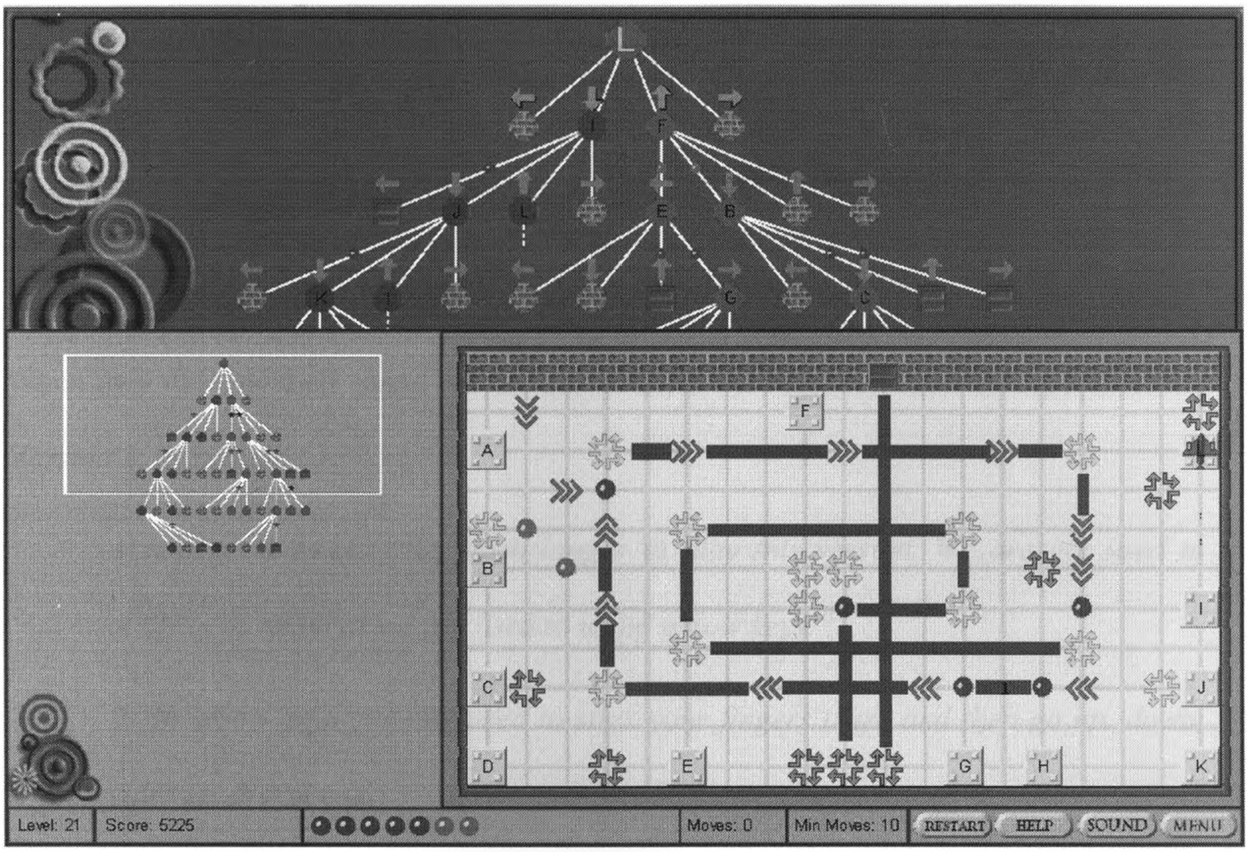

Figure 5-9. Shot screen of SM showing the big circular path of level 21.

Since the main strategy for them was trial and error, in the very last level after 12 minutes trying without any progress, one of the subjects declared:

A: let's do something different this time. We are crashing every time.

Their answer to the question "Were there any part of the game that you found confusing?" was:

A: No.

B: I think it was the tree. We used the tree because it was easier compared to following all those arrows.

And their answer to this question: "What was the most difficult part of the game?" was:

A: Looking after all those arrows to find the correct path.

B: The last level.

Their reply to this question: "What features of the game did you find least helpful?" was quite interesting:

A: First I thought the tree but at the end I got quite used to it.

When they finished their game, we had shown them the other versions. In response to the Version 1, they said:

A: I think it would take much longer to play this version. We are not used to clicking as much as we are used to using arrow keys.

B: In arrow keys you just need to stick your fingers there and then go up, down, sides so, that is easy.

And when we showed them Version 3 and asked them what version they prefer the best, they replied:

A: So, here you can do both [clicking and using arrow keys]. *So this means that there are two ways to play this game and you can choose the way you like the most.*

B: It depends on people. Some people prefer this, some that.

After interacting with Version 4, they thought:

A: I think this might be a bit more confusing.

B: Trees are turns off since we had seen enough trees at math class, but it doesn't really distract me from playing the game. It was helpful from time to time. So you don't have to look at all the way to find a path. But the arrows are more fun.

5.2.2.2 Group 4

The subject of this group had no accompany; instead one of the co-investigators played the role of the next subject by constantly talking to him and asking him to think aloud to describe his decisions.

The subject of the fourth group did not start a level with a plan. He just tried a random direction. Then, after he had explored the level, he tried to create a plan. The subject followed the maze layout backwards by looking at the collectable bolts and tried to figure out which midway stand blocks he would need to reach first before arriving to the collectable balls. For stand blocks that were not close or obvious how to reach, the subject used the tree to determine his path. The subject only did this after the co-investigators suggested it a few times.

The subject of this group did have difficulty understanding how the nodes were connected in the tree. Also, he looked at a wrong node with the same name (see Figure 5-10 showing node "L" in two different part of the tree) as the current node name instead of looking at the blinking node at the top of the tree window which was showing the current place of the avatar. Yet, he continued to use the tree despite these issues and he only used the side tree to scroll.

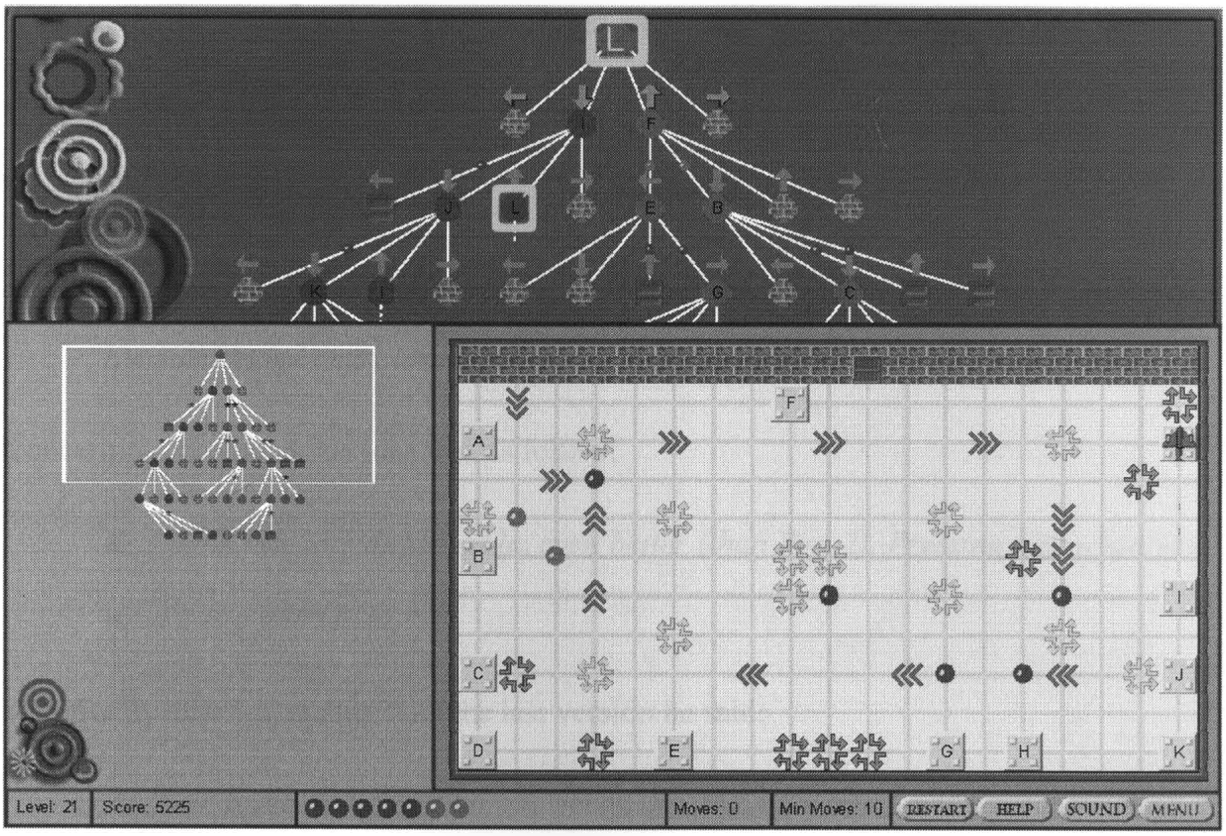

Figure 5-10 Shot screen of SM showing similar nodes in different parts of the tree.

The subject had constant attention to the tree through the entire game and the subject was not too concerned about the number of moves used in a level.

During the interview, the subject was asked "Would you consider this game as a good game compared to other sorts of games that you played?" and his answer to this question was notable:

> *A: Yes, because I don't like fun games, I like mind games that makes you think.*

Later on, he was asked "Did you find the tree helpful?" and the subject replied:

> *A: Yes, first I didn't know what it is, but when I found it, it was really helpful.*

And when he was asked "Did you learn anything from this game?" he said:

> *A: Yes, it helped me to learn how to find a way.*

After he finished the second version, other versions were shown to him and his idea regarding the other versions was asked.

Regarding Version 1, he said:

> *A: I still think these arrow keys are better to play. Clicking is kind of hard to play but some people may like it better.*

Concerning Version 3, his idea was as follow:

> *A: I think this version would be even better (than Ver. 2). Pressing tree when you need it is a good idea.*

And finally after interacting with the last version he said:

> *A: That is really difficult I think, because without the tree, I will be stuck a lot.*

5.2.3 Version 3

5.2.3.1 Group 5

Subjects of this group were supposed to play the third version which was a combination of Versions 1 and 2 thus they had both the options of clicking on the tree nodes and using the arrow keys to complete the game. Initially, they had a trouble with the four possible directional movements (up, down, right and left) as they were planning to use movements in diagonal directions. However, after the first couple levels, they were able to plan using four possible directions.

Subjects of Group 5 looked ahead for their future steps to form a plan. The co-investigator's initial suggestions of using the tree were ignored, but when they really had trouble finding a certain stand block, they did use it.

They had some difficulties in interpreting the tree to understand what collectable bolts were remained to be collected, and whether an stand block was reachable or not. They also used the tree to plan more than a few steps ahead. However, they rarely used the tree to see what directions were useful i.e. one that did not lead to a wall. Even though there were constantly checking the tree for their moves, they still looked at the main puzzle screen window as verification as if the tree might be wrong. They also did not use the side tree except for scrolling. The subjects of this group would restart a level if they thought they were stuck; however, they did not restart to achieve a better score.

During the interview they were asked "What was the most difficult part of the game?" and the subjects answered:

A: Probably figuring out what color to pick up first.

B: For me picking which arrow not to take me to the wall was the most difficult part of the game.

They were also asked: "What features of the game did you find least helpful?"

A: Not really but a little those little arrow above the nodes [in tree].

B: I think the rotating blocks made the game trickier.

And "Did you find the tree helpful?"

A: It was really helpful especially when you were stuck somewhere it was giving you all your options.

B: Looking at the tree it tells you if you are going to wall or where.

Also they were asked "Did you learn anything from this game?" and they replied:

A: Yes, It helped my mind for problem solving, like if you want to go to some point you have to look what other points are there.

B: Yeah, I pretty much agree.

After they finished their game we had shown them the other versions. In response to Version 1, they said:

A: I prefer using arrow keys. It is kind of easier for me. So, this version might be easier but I like the arrow keys better.

B: Yeah me too. Because all the other games are using arrow keys so we are kind of used to it and I think, this version is more challenging.

After they played this version, they said: *"When you are using the mouse, you pay more attention to the tree so it is trickier".* This sentence can suggest that the enjoyment of "Game play" is lower in this version compared to the Version 3 where they had both options to play the puzzle through tree via mouse and the main puzzle window via arrow keys.

Regarding Version 2, the subjects mentioned:

A: I like this version because using arrow keys make it more fun.

B: I think having both options is more fun.

And after they were shown the last version, the subjects stated:

A: This one is harder because we used to look at the tree whole time.

B: I still prefer the version that I played. Having the tree up there is kind of better because when you are stuck it really helps.

5.2.3.2 Group 6

The subject of this group had no accompany; instead one of the co-investigators played the role of the next subject by constantly talking to him and asking him to think aloud to describe his decisions. At the first few levels, the subject tried the game elements to see what they did and then restarted to get a better score.

The subject of this group first planed out the route and then executed it. He followed all the arrows in the main puzzle to find out where they were going. The subject had local reasoning and he analyzed all the possibilities in the main screen to choose a path.

If a route did not reach the proper conclusion, the subject would restart the level and try to collect all the collectables of a different color this time to see if that was the right way to start.

In Level 15, the subject after spending 15 minutes on this level he said:

> *A: I am doing the same things that I did before.*

Thus, the co-investigator provided him with a hint to pay more attention to the tree. Consequently, he finished this level after a couple of minutes after the hint had been given.

In Level 20, he was encouraged to use the tree to capture the last green ball (as he was having some difficulties trying to collect it). However, he only used the tree to remember the route to that ball afterwards. He did not use the tree for anything else in this level, and did not use it initially in the following level.

When he was asked "Would you consider this game as a good game compared to other sorts of games that you played?" during the interview, he said:

A: Yes, I guess this game was supposed to teach you something I guess at least this one looks fun because of all the interesting things that you could do on this. Unlike other games were they just tell you and show you all the stuffs that happen.

And his answer to this question "Did you find the tree helpful?" was:

A: First I didn't understand it but then I kind of get used to it.

After he finished his version to play, the other versions were shown to him. Regarding the Version 1, he said:

A: Ah.....I don't like that; it's kind of distracting. There are too many arrows around you where you want to click so it's kind of distracting.

Concerning the second version, the subject's idea was as follow:

A: I don't mind if I can't click on the tree. I like this version.

And finally, about the last version, he stated that:

A: Oh it does not have a tree! ...I don't mind if there is no tree but it seems to be just a bit harder. I used the tree for some parts so it might be a bit harder otherwise I will do the same way.

5.2.4 Version 4

5.2.4.1 Group 7

Version 4 was the last version of the experiment which did not externalize the latent tree structure. The subjects of Group 7 and group 8 played this version. The subject of Group 7 had no accompany; instead one of the co-investigators played the role of the next subject by constantly talking to him and asking him to think aloud to describe his decisions.

The subject of this group planned his path in short steps and tried them out before planning further. In some levels, he did not even plan, just started taking a route and it ended up working for him.

In this game, the color of the last collectable bolt which is usually in the path to the exit indicates the last color to collect. The subject of this group occasionally looked at the last collectable bolt. Generally, this subject used a trial and error strategy for certain paths through all the levels. The subject tried a variety of paths in each level even if one seemed good to begin with. This subject often tried the same path that resulted in a failure because he did not look ahead before moving.

When he was asked “What was the most difficult part of the game?” the subject replied as:

> *A: Figuring out the proper way to go around and finding the best way to the door. You have to think before you move.*

Also, when he was asked “What features of the game did you find least helpful?” he said:

> *A: Not really. Actually one thing: the letters on the blocks. It wasn’t necessary! It was nice for speaking and remembering for example go from A to J.*

Once the subject finished the fourth version, the other versions were shown to him. Regarding the Version 1, he said:

> *A: actually I think it is a little bit harder, because you have to concentrate on the tree instead of the puzzle....It makes the game more difficult and less joy-able.*

When he was shown the Version 2, he stated:

> *A: That will be a little bit more different. I think this version is kind of the same thing as the fourth version, but that tree up there is to show you if you've gone hit the wall or not. I still don't know if the tree is really necessary. It really doesn't help much. It would be good to have a button to click on it when you want to see the tree. Because some people like my sister are very -very visual so I think if you could put it up and down would be better to show and hide whenever you want it.*

And finally, regarding the Version 3, his idea was as follow:

> *A: I think the fourth version is still better.*

5.2.4.2 Group 8

Subjects of this group normally just played the game like any other action game without focusing on any plan. As such, during the interview, when they were asked: "Do you have any suggestions about how we can improve the game?" they answered:

> *A: Maybe you can add some cheat codes or some rockets.*
>
> *B: Or you can add shopping item to it.*

Both the subjects just performed local movements. They did not seem to plan too far ahead. Usually, their movements were made without concern for the result. Thus, in several cases they had difficulty figuring out where the plane would end up; nevertheless, they went that way.

They also played without much concern for score. If a level was taking too long (usually 5 or 6 minutes) they wanted to move on. They found it annoying to keep trying the level.

Once finished Version 4 and were interviewed, they were shown the three other versions. Regarding Version 1, they suggested:

A: I like this version because it tells you your options and it's easier. I think it is less challenging.

B: This version is pretty confusing because it has lots of lines.

Concerning Version 2, they said:

A: I like it better than Version 1.

B: Me too.

And, finally about the third version, they stated as follows:

A: I prefer to use arrow keys.

B: Me too, I like the arrow keys better.

5.3 Results Analysis

The main purpose of this exploratory study is to further our understanding of how to design good epistemic computer games. Thus, the stated four versions of the SM were designed and tested to obtain preliminary evaluations regarding children's reasoning as well as enjoyment of the game.

Reasoning is defined as the cognitive process of looking for reasons for beliefs, conclusions, actions or feelings [Kirwin, Christopher. 1995]. Accordingly, the reasoning of all the participated groups of this study is ranked in correspondence to the subject's attention to the latent structure of the game or the tree externalization. Version 4 of the SM, which does not contain the tree externalization, is used as an indicator to compare and evaluate the other three versions with this version to actually see the effects of the presence of the tree externalization.

Table 5-3. Study findings in summary

SUPPORTS	VERSION-1	VERSION-2	VERSION-3	VERSION-4
REASONING **RANKED:**	✓ 1	✓ 2	- 3	N/A 4
GAME PLAY **RANKED:**	✓ 1	✓ 3	✓ 4	✓ 2
INSTANCE (For Reasoning with Tree Externalization)	Pros: Both groups used the tree to validate their - own moves.	Pros: (Group 4) Constant attention to the tree through the entire game. Cons: (Group 3) traced a path along the main puzzle window rather than the tree externalization.	Cons: (Group-5) looked at the main puzzle screen to verify their movements (Group-6) stated: *"I used the tree for some parts only."*	N/A
INSTANCE (For Game play or Enjoyment of the Game) Note: The indicated Time and Scores are the average time and score for the participated groups on each version.	Pros: Obtaining the highest score in minimum spent time. **Score: 9.81** **Time: 72.5** And positive answers to interview regarding enjoying the game.	Pros: Obtaining the second high score in the second minimum spent time. (Except for Version 4, that had not the tree externalization.) **Score: 7.21** **Time: 100.5** And positive answers to interview regarding enjoying the game.	Pros: All the subjects of this version stated that they enjoyed the game and prefer this version over other versions also positive answers to interview regarding enjoying the game. Cons: Obtaining minimum score in maximum time. **Score: 5.33** **Time: 141.5** Note: Based on interviews this version is the most favorite version for the participants.	Pros: Users score and spent time to complete the game. **Score: 9.08** **Time: 92.5** And positive answers to interview regarding enjoying the game. Note: Participants of other versions did not prefer this version over the version that they played and they find it more complicated and confusing to play.

It is noteworthy to state once again that all the findings and conclusions of this study are based on our preliminary study and more studies are required to arrive to accurate and reliable conclusions.

According to the stated findings in Table 5-3, it was observed that Version 1 best supports children's thinking and reasoning as well as enjoyment of the game-play. For instance, the subjects of group 1 used the tree to validate their own moves. This emphasizes their reasoning using the tree externalization. They could also obtain the highest score in minimum time, which highlights their enjoyment of the game play.

According to Table 5-3, Version 4 is in the second position after the first version based on users score and spent time to complete the game when assessing the enjoyment of the game. This version is similar to the available entertaining games which are based on puzzle concept. However, it clarifies whether or not the subjects of other versions, rather than Version 4, are showing the same pattern of play or not. Furthermore, when this version was shown to the participants of other versions, it appeared that they did not prefer this version over the version that they had played and they found it more complicated and confusing to play.

Version 2 can be ranked as the second position concerning the users reasoning since one of the participated groups on this version (Group 4) had constant attention to the tree through the entire game while the other group (Group 3) traced a path along the level and not the tree and tracked the path in the main puzzle with their finger.

Also regarding the tree externalization, the subject of Group 4 stated:

"First I didn't know what is it [tree], *but when I found it, it was really helpful. Without the tree, I would be stuck a lot."*

While the subjects of the other group (Group 3) stated:

A: I still don't understand the tree.

B: It is not exactly that helpful.

But, finally they got used to the tree and said:

"First I thought the tree is the least helpful feature of the game but at the end I got quite used to it and I found it quite useful."

As shown in Table 5-3, Version 2 is in the third position in term of enjoyment of the game after the Versions 1 and 4 based on the participants anecdotes. It is also evident by their higher scores compared to the Version 3's score.

According to Table 5-3, Version 3 was considered as the most favorite version for the participants. Almost all of the subjects of different groups voted to this version as the most preferred version since it had both options of clicking on the tree externalization and using the arrow keys to perform the game.

Despite the children's interest on this version, according to data of the preliminary study, this version had the least amount of thinking and reasoning with the latent structure of the game for the participants. For instance, the subjects of Group 5 only looked at each level layout to verify their movements. Also, the participants of Group 6 stated:

"I don't mind if there is no tree but it seems to be just a bit harder. I used the tree for some parts only."

The subjects of this version also gained the minimum score in maximum time. However, all the subjects of this version stated that they enjoyed the game and prefer this version over other versions.

Based on the presented results, we are able to have a preliminary evaluation on this epistemic game. As it is shown in Table 5-3 and discussed above, Version 1 is assessed as the most successful version considering the main purpose of this research, which is developing better epistemic games. This version not only enhances reasoning but also entertains the player.

There are number of suggestions based on the current study to improve SM as an epistemic game. These ideas have been found only after completing this pilot study by observing the children's reactions to different versions and interviewing them. For instance:

1) It would be a good idea to have a pop-out tree externalization instead of a fixed one, that users can view any time they need to check the tree.
2) Giving the option to users to be able to click on nodes of the tree at any level, and the avatar moves to that point automatically. Currently users can only click on nodes of the second level.
3) Making a better graphic, changing the background color, and changing the music of the game were also suggested by different subjects of this study. However, further investigations will be required to evaluate the effectiveness of these changes.

The Current study was an attempt to design better epistemic games that can enhance reasoning while entertaining. The findings of this research have shown that improving reasoning and thinking does not have negative effects on enjoyment of the game play in the studied cases.

It has been observed that the direct interaction with the externalization of latent structure of the game may affect subjects' reasoning. This is very noticeable when comparing the performance of different groups.

Groups 1 and 2 who played Version 1 outperformed the other groups, thus one can argue that direct interaction with the latent structure of the game facilitates children's decision making and supports them when thinking ahead of their actions. As a result, they can have thoughtful moves instead of making trial and error decisions. In other words, interacting with the latent structure of the game can support children's mental process or cognitive process for better decision-making.

Moreover, interaction design for an epistemic game such as SM should also be highlighted since design of an epistemic game can affect thinking, reasoning, game-play, and enjoyment for the subjects. The interface of Super Maze was designed considering the HCI main goals:

1) Improving the interaction between users and computers
2) Making computers more usable and user friendly

Since each group performed differently in the evaluation process, various conclusions could be obtained as follows:

1. Different representations and interaction methods modify users' thinking and reasoning about any subject. Therefore, it is necessary to examine and investigate different interaction approaches for developing an apt epistemic game. To support children's reasoning, an epistemic game such as SM can offer alternative representations of the same structure and attempt to show the relationships between them. It can also allow children to directly interact with the hidden structure of the games to enhance their reasoning.

2. Based on this preliminary study, we can argue that an indirect interaction with the underlying structure of an epistemic game, e.g. Version 2 and Version 4, is not adequate to support user`s reasoning while direct interaction, e.g. Version 1, is observed to be more helpful.

3. An apt interaction design for epistemic games has an essential role since it can directly affect children's reasoning and/or enjoyment of the game. Hence, it would be a good idea to create different versions of a game and test it with children before finalizing it.

5.4 Summary

The results of this pilot study as well as the findings of the qualitative observations and their analysis were argued in this chapter. The qualitative results for each group of subjects including their anecdotes were presented and discussed individually. All the collected data for this research was also compared to help understand the weaknesses and strengths of each version. Based on this analysis, some ideas were suggested for future research. The next chapter will present a summary and conclusion of the thesis and a brief overview of future works.

Chapter 6

6. Summary and Conclusion

The focus of this thesis was to investigate how to design epistemic games to facilitate children's reasoning while entertaining them at the same time. An epistemic game was designed and developed in four different versions. An exploratory experiment was performed to investigate children's reasoning, game-play, and the usability of the epistemic game. The qualitative data from the pilot study were discussed and compared to investigate the performance of the developed epistemic game. Further investigation in a larger scale is indeed required to complete and support the findings of this study.

Eight groups were examined to investigate and evaluate all the four versions of the Super Maze. Version 1 was played by Groups 1 and 2. In this version, subjects were supposed to interact with the software through the latent externalization/tree structure to complete the task. The participants of Version 1 accomplished the highest score in minimum spent time among the other groups. They stated that they enjoyed the game and got used to the tree externalization after a while. However, they preferred to use the arrow keys instead of clicking on the tree nodes and they found it confusing and harder to play the game without the tree externalization.

Version 2 was played by Groups 3 and 4. In this version, subjects were asked to interact with the software through the main puzzle screen via the arrow keys even though the tree externalization was available for them to explore but not interact with. Subjects of Group

3 referred to the tree externalization just in a few cases to verify their moves. The participant of Group 4 had constant attention to the tree despite the fact that he had difficulties to understand it in early levels. Later on, he found the tree externalization helpful while the subjects of Group 3 found the tree confusing but not distracting the game play. All the participants of Version 2, likewise the participants of Version 1, found that Version 3, which had both options of interacting with the main puzzle and interacting with the tree, a better choice to play. Similarly, they found it more difficult to play the game without the tree externalization. Players of Version 2 could finish the task in the second position regarding the total score and minimum required time after the players of the Version 1.

Version 3 was tested by Groups 5 and 6. Subjects of these groups were supposed to interact with the software either through clicking on the tree nodes or using the arrow keys to perform upon the main puzzle screen. Although this version was the most favourite version for the participants according to the interviews, the obtained scores by Groups 5 and 6 were the lowest score in the maximum time amongst other groups. Most likely, the participants of Version 3 looked at the levels' layout as verification for their moves as if the tree might be wrong. They also did not use the side tree except for scrolling.

Version 4 did not externalize the latent structure of the game. Thus, the participants had to directly interact with the main puzzle to complete the game. The subjects of Groups 7 and 8 played this version. Regarding time and score, these two groups are ranked right after Groups 1 and 2. Although all the other groups claimed that this version looked difficult to them, the subjects of Version 4 found this version just similar to other available games in the market and liked the third version after or equal to Version 4.

The camcorder videos, investigators' notes, and subject interviews provided us with enough information to have a preliminary evaluation on this epistemic game. The most interesting version according to our purposes, which is the development of epistemic games to enhance reasoning while they are still fun, is Version 1. However, certain changes as discussed before are required to make this version more entertaining and helpful for reasoning. Moreover, new versions can be developed based on available information to complete this investigation resulting in more accurate and reliable results and designing better games.

6.1 Summary of Findings:

This section summarizes the findings of the pilot study. It must be noted that these findings are inferred based on preliminary study which involved 13 participants. Therefore, comprehensive study including more participants is required to achieve more accurate and reliable results. Nevertheless, the preliminary study results provide us with valuable findings to improve the game to better reflect the affects of externalization in children's reasoning and their enjoyment of the game play. The findings of this study are organized along the two original research questions.

1. Regarding the effects of externalization of the latent structure of the game:
    - Does the externalization of the latent structure of the game affect children's reasoning? How?

The observations of this study imply that interaction with the externalization of the latent structure of the game affects the subjects in their reasoning. This becomes evident by comparing the results of eight participated groups. Groups 1 and 2 who played Version 1 outperformed the other groups. It was observed that direct interaction with the latent structure of the game could actually facilitate children's decision-making. It would support them to think ahead of their actions and to have thoughtful moves instead of having trial and error actions. During this procedure, they learned about the process of decision making. Interacting with the latent structure of the game can actually boost their mental process (cognitive process), leading to the selection of a course of action among several alternatives and help find the best final choice.

The evidence shows that the participants of Version 1 enjoyed playing this version of the game although they suggested that they preferred to use the arrow keys instead of clicking. What is also interesting is that Versions 2 and 3, which provided the arrow keys option, were not able to support the subjects as well as Version 1 was. They did not perform the tasks very well, and they showed an insignificant amount of improvement as they progressed through the tasks.

2. Regarding the usability of this epistemic game from an HCI point of view:
    - Does the design of interaction affect thinking, reasoning, game-play, and enjoyment of the game? How? What are the children's ideas and suggestions regarding the design of the game?

A basic goal of HCI is to improve the interaction between users and computers by making computers more usable and receptive to the user's needs. The Super Maze interface is designed in such a way that it provides a mental model for users by mapping the latent structure of the game. This study has shown that although children are currently used to play games with cutting age graphics, they still enjoy playing this game, which has graphics of a lower quality. One subject did mention that he would recommend playing this game to many children and another subject mentioned that the lines in the background of the main puzzle were very helpful for better decision-making. On the other hand, most of the participants suggested enhancing the graphics of the game and changing the background music.

6.2 Conclusion

This thesis is an attempt to advance our understanding of how to design good epistemic games. However, evaluation of an epistemic computer game is not an easy task since different people perform different roles in the evaluation process. It is especially challenging to investigate the cognitive side of game playing for epistemic games. This results in difficulties of generalizing the findings of this research. Nevertheless, several important conclusions have been obtained from this investigation.

Overall, this research shows that improving reasoning and thinking does not have negative impacts on enjoyment of the game play in the studied cases. The latent structure of an epistemic game must be fully understood in order to be beneficial for subjects.

The design of an epistemic game is also very important. The game should not be confusing for users, and it should be as simple as possible and easy to interact with.

Our investigation yields that different representations and interaction models can put limits on how users think and reason about a subject. In the case of SM, an epistemic game could offer alternative representations of the same structure and attempt to show the relationships between them in a manner that is as understandable as possible. Moreover, it is even superior to allow children to directly interact with the hidden structure of the game to enhance their understanding about the underlying structure of the subject.

Furthermore, our research demonstrates that an indirect interaction with the underlying structure of the game such as the ones in Versions 2 or 4 is not sufficient to adequately assist user's reasoning whereas a direct interaction such as Version 1 has the most supportive effect.

Finally, our research shows that different interaction methods with an underlying structure support user's reasoning differently. Thus, it is essential to investigate and analyze different interaction approaches for designing an epistemic game before finalizing it to make sure that the chosen interaction method is appropriate.

6.3 Future Works

This pilot study provided us with feedbacks on how to design a better epistemic game. We would like to do a further research in this area based on the current study. Our future plan is to develop new versions of SM based on our current information. There are number of changes that should be made to SM for future studies:

1. Develop a new version that allows users to click on a destination node further ahead in the tree than currently is available.
2. Developing a new version that has a pop-out tree externalization instead of a solid one.
3. Improving overall graphics of the game e.g. changing the background colours and texture.

4. Changing the background music.

5. Simplifying and pruning the tree externalization as much as possible to make it less confusing for users.

I hope that this thesis provides some insight into the design of better epistemic computer games.

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Appendix A. Copy of Letter of Consent

Letter of Information

How to design effective game interfaces to support reasoning

Researchers:

Dr. Kamran Sedig, Professor,

Department of Computer Science

Sousan Sheida Taghbostani, M.Sc. student,

Department of Computer Science

The information collected in this study will be used in my thesis.

Robert Haworth, M.Sc. student,

Department of Computer Science

The information collected in this study will be used in my thesis.

The pronoun 'you' and adjective 'your' should be read as referring to the participant rather that the parent/guardian who is requested to sign the attached consent form. Participants will receive a simplified version of this letter and will be requested to sign it.

Purpose

You are being invited to participate in a pilot research study to see if a computer game we have created helps children in their thinking and reasoning. The reason for this letter is to give you the information you need to decide if you want to be part of this research study. Read this letter carefully and take your time to make a decision.

Our research team is trying to understand how to help children of your age to interact with the underlying structure of games. So, to do this, we have created an interactive computer game to help children see and explore this game structure. We have created four (4) different versions of this game. Each version provides a different way of seeing and interacting with the game. This study will allow us to see which of these versions helps children the most.

What we are trying to find out

We would like to find out which version is most useful and helpful. We would like to see if the way we have designed the computer program really helps children to boost their reasoning and consequently their play. Whether or not you already know the concepts or ideas that are in the program does not matter.

Selection criteria

You are being invited to participate because you are a student aged 9 through 13. Fifteen (15) other primary students are also being invited to participate in this study.

How we will go about it

There will be four groups. Each group will have four children. Each group will use a different version of the program. All groups will follow the same sequence of steps.

You will be asked to use the computer program for about one and a half hours, which will be divided into two 45-minute sessions. The sessions will be held on one day. You may choose where these sessions should be held. They can either be held in your home or at the Cognitive Engineering Laboratory at the University of Western Ontario. In the first part of first session, you can freely use the program for about 5-10 minutes. All the information you need to do this can be found in the program. You will be working on a computer with another partner. You and your partner will be video-taped to record how you use the computer program (see about confidentiality section further down). If you do not want to be video-taped, you should not participate in the study.

There will be one member from our research team at all times present with you. She/he will give you a brief introduction to the session and the program. After this introduction she/he will only be present to write some notes about how you use the program. From time to time, this member of the research team might remind you to talk about your thoughts and findings with your partner out loud.

You will be asked to be interviewed to talk to the researcher about your thoughts on the program. The interview will take between 20 and 30 minutes. The interview will also be video-taped. The interview will be conducted in the same room where the study sessions will take place.

After the interview, the researcher will start the other three versions of the game so you can play with them, too. You will be asked to play with each version to get to know it. When you have played with all of them you will be asked to tell us which version you prefer, and why. This part of the session will also be video-taped.

The total time that you are asked to commit to this study is estimated to be about two and half (2.5) hours: 100 minutes to play the game with your partner (this includes a ten minute break after the first 45 minutes of play), about 25 minutes for the interview and about 25 minutes to play with the other three versions.

Potential risks

Playing this computer game is very much like working on a computer: using the mouse and keyboard to interact with the computer. There are no known risks other than what would be typically associated with working with a computer.

Potential benefits

There is an interesting concept or topic you will be exploring using this computer game. You may benefit from participating in this study by exploring search trees using this program as well as develop better reasoning skills.

We, the researchers, are interested in making computer programs that can help users of different ages, especially younger users to enhance their reasoning skills. The results of this study may enable the researchers to understand how to design computer programs and their interfaces that can help people to think and reason better.

What to do if you want to withdraw from this study

Your participation in this study is voluntary. You may withdraw at any point from the study. If you decide to do so, simply tell a member of the research team that you would like to withdraw from the study. The data collected up to your withdrawal may still be considered during the evaluation of the study. This is because the data may still be useful in helping us understand how to help others use the program.

What happens to the information that will be collected

Your research records will be stored in a locked cabinet in a secure office; video tapes and any other documents will only be viewed by members of the research team. All material will be destroyed approximately four (4) years after the conclusion of the study in September 2013. All paper documents will be shredded and the video tapes will be erased.

Specific things you should know about confidentiality

If the results of the study are published, your name will not be used and no information that discloses your identity will be released or published without your specific consent to the disclosure.

Representatives of the Research Ethics Board at the University of Western Ontario may require access to the data collected for the purpose of monitoring the research.

Compensation and costs

You will not be paid to participate in this study. There are no costs for participating in the study.

Who to contact in case you have questions.

If you have any questions about this study, please contact:

Dr. Kamran Sedig

Sousan Sheida Taghbostani

Robert Haworth

If you or your parents/guardians would like to meet with the researchers in person to discuss and clarify any questions/concerns, a meeting can be arranged.

If you have any questions regarding the conduct of this study and/or your rights as a research participant, please contact:

Office of Research Ethics,

The University of Western Ontario.

No waiver of legal rights

You do not waive any legal rights by signing the consent form.

To obtain results of the study

A brief summary letter will be given to all participants or their parents/guardians after the completion of the study.

You will be given a copy of this letter of information and consent form, once the consent form has been signed and returned to the researchers.

Consent Form

How to design effective game interfaces to support reasoning

I have read the Letter of Information, have had the nature of the study explained to me and I agree to participate. All questions have been answered to my satisfaction.

____

(Participant's Name)

____

(Parent/Guardian's Name)

____

(Parent/Guardian's Signature) (Date)

____

(Name of the person obtaining the consent)

____

(Signature of the person obtaining the consent) (Date)

Letter of Consent for participants

How to design effective game interfaces to support reasoning

Researchers:

Dr. Kamran Sedig, Professor,

Sousan Sheida Taghbostani, M.Sc. student,

Robert Haworth, M.Sc. student,

Why you are here.

The researchers want to tell you about a study about how to make better computer games for learning. They want to see if you would like to be in this study. Dr. Kamran Sedig and some other researchers are doing this study.

Why are they doing this study?

They want to compare four versions of their computer game to find out if and how one is better at helping you think.

What will happen to you?

If you want to be in the study you will be asked to play with one version of the computer game with a partner for about 90 minutes. There is going to be a ten minute break after the first 45 minutes. You and your partner will be video-taped while you are playing. If you do not want to be video-taped, you should not be in the study.

One researcher will be in the room while you are playing the computer game. At the beginning the researcher will describe how to play the game. Afterwards the researcher will watch how you play the game and maybe write down some notes.

When you are done playing the game, the researcher will ask you some questions about what you thought of the game. This part will also be videotaped.

At the end, you'll get a chance to play with the other three versions of the game. Play with each version until you feel you know how to play it. When you have tried out every version of the game, you will be asked which one you liked best and why. This part will also be videotaped.

All in all, it will take about two and a half hours to be in the study: one and a half hours to play the computer game, a ten minute break in between playing, twenty five minutes to answer the questions of the researcher, and another twenty five minutes to try out the other three versions.

Will there be any tests?

No there will not be any tests.

Will the study help you?

The computer game is about search trees. You may learn something about search trees playing the game. This study will help the researchers learn about how to make better computer games for the mind.

What if you have any questions?

You can ask questions any time, now or later. You can talk to the researchers, your family or someone else.

Do you have to be in the study?

You do not have to be in the study. No one will be mad at you if you don't want to do this. If you don't want to be in this study, just say so. Even if you say yes now you can change your mind later. It's up to you.

I want to participate in this study.

____

Print name of Child

____

Signature of Child Age Date

____

Signature of Person Obtaining Assent Date