

**THE DESIGN, DEVELOPMENT AND EVALUATION OF A
VIRTUAL REALITY (VR)-BASED LEARNING ENVIRONMENT:
ITS EFFICACY IN NOVICE CAR DRIVER INSTRUCTION**

by

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LIST OF ABBREVIATION

ABBREVIATIONS

VR	virtual reality
RTD	Road Transport Department

**REKABENTUK, PEMBANGUNAN DAN PENILAIAN PERSEKITARAN
PEMBELAJARAN BERDASARKAN REALITI MAYA (RM):
KEBERKESANANNYA DALAM PENGAJARAN PEMANDU KERETA NOVIS**

ABSTRAK

Kajian yang bermatlamatkan pembangunan (Reeves, 2000; Richey & Nelson, 1996) ini memberi fokus kepada pembangunan satu penyelesaian yang munasabah bagi suatu masalah pembelajaran dalam konteks sebenar di samping menghasilkan satu kerangka rekabentuk dan pembangunan pengajaran yang sesuai untuk menjadi panduan kepada usaha pembangunan yang seterusnya. Masalah pembelajaran yang telah dikenalpasti berfokuskan kepada pemahaman peraturan lalulintas untuk pelbagai senario jalan yang terdiri daripada jalan biasa, pelbagai jenis persimpangan jalan dan tanda isyarat lalulintas yang berkaitan kerana pemandu kereta novis menghadapi masalah untuk memahami bahan pembelajaran konvensional yang berbentuk teks dan imej statik dua-dimensi. Satu penilaian yang berdasarkan rekabentuk eksperimen kuasi kemudiannya dilakukan untuk mengkaji kesan persekitaran pembelajaran yang dibangunkan, iaitu suatu persekitaran pembelajaran berdasarkan realiti maya (RM), terhadap pembelajaran; untuk mengkaji kesan mengawal penerokaan melalui persekitaran maya yang terdapat dalam persekitaran pembelajaran berkenaan terhadap pembelajaran; dan mengkaji kesan kecenderungan pelajar, iaitu kebolehan visualisasi spatial dan gaya pembelajaran, terhadap pembelajaran. Persekitaran pembelajaran berdasarkan RM ini menggunakan kerangka teori rekabentuk pengajaran yang menggabungkan konsep matlamat integratif (Gagné & Merrill, 1990) dengan model rekabentuk persekitaran pembelajaran konstruktivis (Jonassen, 1999) sebagai strategi makro dan prinsip rekabentuk yang diperolehi dari teori kognitif pembelajaran multimedia (Mayer, 2002) sebagai strategi mikro. Persekitaran pembelajaran ini juga mengambil model Rekabentuk dan Pembangunan Rekursif dan Reflektif (R2D2) (Willis, 1995; Willis & Wright, 2000) sebagai model pembangunan pengajaran. Kajian penilaian yang dijalankan menggunakan rekabentuk pelbagai-

kumpulan pra-ujian-pos-ujian faktorial eksperimen kuasi. Seramai 184 pelajar Tingkatan Empat terlibat dalam kajian ini. Kajian mendapati pelajar yang didedahkan kepada mod RM Berpanduan telah memperolehi pencapaian pembelajaran yang lebih tinggi secara signifikan berbanding dengan pelajar yang didedahkan kepada mod RM Tidak Berpanduan dan pelajar yang didedahkan kepada mod Bukan RM. Kedua-dua kumpulan pelajar dengan kebolehan visualisasi spatial rendah dan tinggi yang didedahkan kepada mod RM Berpanduan juga telah memperolehi pencapaian pembelajaran yang lebih tinggi secara signifikan berbanding dengan kumpulan pelajar dengan kebolehan visualisasi spatial rendah dan tinggi yang didedahkan kepada sama ada mod RM Bukan Berpanduan atau mod Bukan RM. Kajian juga mendapati mod RM Berpanduan telah memberi manfaat yang setara kepada kedua-dua kumpulan pelajar dengan kebolehan visualisasi spatial rendah dan tinggi. Kesan interaksi antara kebolehan visualisasi spatial pelajar dengan ketiga-tiga mod pembelajaran adalah tidak signifikan. Dapatan yang serupa telah diperolehi untuk pembolehubah moderator, gaya pembelajaran, yang membandingkan kumpulan pelajar *assimilator* dengan kumpulan pelajar *accommodator*. Kedua-dua kumpulan pelajar *assimilator* dan *accommodator* yang didedahkan kepada mod RM Berpanduan juga telah memperolehi pencapaian pembelajaran yang lebih tinggi secara signifikan berbanding dengan kumpulan pelajar *assimilator* dan *accommodator* yang didedahkan kepada sama ada mod RM Bukan Berpanduan atau mod Bukan RM. Kajian juga mendapati mod RM Berpanduan telah memberi manfaat yang setara kepada kedua-dua kumpulan pelajar *assimilator* dan *accommodator*. Kesan interaksi antara gaya pembelajaran pelajar dengan ketiga-tiga mod pembelajaran adalah tidak signifikan. Kesimpulan dari kajian ini menyokong nilai positif penggunaan persekitaran pembelajaran berdasarkan RM untuk masalah pembelajaran ini, mencadangkan kepentingan untuk memberi bantuan navigasi yang mencukupi bagi mengawal penerokaan melalui persekitaran maya, dan menunjukkan persekitaran maya berdasarkan RM sebagai media yang berpotensi untuk membantu

pembelajaran individu yang berbeza dari segi kebolehan visualisasi spatial dan gaya pembelajaran.

THE DESIGN, DEVELOPMENT AND EVALUATION OF A VIRTUAL REALITY (VR)-BASED LEARNING ENVIRONMENT: ITS EFFICACY IN NOVICE CAR DRIVER INSTRUCTION

ABSTRACT

This study pursues developmental goals (Reeves, 2000; Richey & Nelson, 1996) by focusing on developing a plausible solution to solve a problem in a real context while at the same time constructing a feasible instructional design and development framework that can guide future developmental efforts. The identified learning problem focuses on the understanding of traffic rules for various road scenarios that consist of ordinary roads, different types of road junction and related traffic signs, in which novice car drivers are found to face difficulty in understanding the conventional learning materials, which are in the form of text and two-dimensional static images. An evaluation that employs a quasi-experimental design is then conducted to investigate the effects of the developed learning environment, which is a VR-based learning environment, on learning; to investigate the effects of controlling the exploration through the virtual environments on learning; and to investigate the effects of learners' aptitudes, both spatial visualisation ability and learning style, on learning. The VR-based learning environment employs an instructional design theoretical framework that combines the concept of integrative goal (Gagné & Merrill, 1990) with the constructivist learning environments design model (Jonassen, 1999) to serve as the macro-strategy and employs the design principles derived from the cognitive theory of multimedia learning (Mayer, 2002) to serve as the micro-strategy. This learning environment also adopts the Recursive, Reflective Design and Development (R2D2) model (Willis, 1995; Willis & Wright, 2000) as the instructional development model. The evaluation study employs a multiple-group pretest-posttest quasi-experimental factorial design. A total of 184 Form Four students participate in this study. The study discovers that learners exposed to the Guided VR mode significantly outperform the learners exposed to the Non-Guided VR mode as well as the learners exposed to the Non VR mode. Both low

spatial visualisation ability learners and high spatial visualisation ability learners exposed to the Guided VR mode significantly outperform their Non-Guided VR and Non VR counterparts. It is also found that the Guided VR mode provides almost equivalent benefits to both low spatial visualisation ability learners and high spatial visualisation ability learners. The interaction effect between the learners' spatial visualisation abilities and the three learning modes is not significant. Similar findings are obtained for the moderator variable on learning style, which is between the assimilator learners and the accommodator learners. Both assimilator learners and accommodator learners exposed to the Guided VR mode significantly outperform their Non-Guided VR and Non VR counterparts. It is also found that the Guided VR mode provides almost equivalent benefits to both assimilator learners and accommodator learners. The interaction effect between the learners' learning styles and the three learning modes is not significant. The conclusion of this study is supportive of the positive value of employing a VR-based learning environment for this particular learning problem, suggests the importance of providing sufficient navigational aids to control exploration through virtual environments, and shows the VR-based learning environment as a promising medium to accommodate individual differences in terms of spatial visualisation ability and learning style.

CHAPTER 1 INTRODUCTION

1.0 Overview

The main focus of this study is to design, develop and evaluate a virtual reality (VR)-based learning environment with the aim to investigate the various issues that are related to the use of this technology in teaching and learning. A learning problem, which is related to the novice car driver instruction in Malaysia, is chosen as the case to examine these issues. This chapter provides some background to the statement of the problem, which then leads to the specification of the problem statement, purpose and specific objectives of the study. It also provides a description of the evaluation framework for this study, which includes the theoretical underpinnings that guided this evaluation, and the respective research questions and hypotheses. Subsequently, both the conceptual and operational definitions, and the significance of the study are provided.

1.1 Background to the Problem Statement

This section provides a brief introduction to the VR technology, the instructional benefits of this technology, and some of its research issues that direct the focus of this study.

The benefits of utilising three-dimensional VR technology in instruction have increasingly gained recognition from many researchers and instructional designers. VR is described as a cutting-edge technology that allows learners to step through the computer screen into a three-dimensional interactive environment. Although VR is recognised as an impressive learning tool, the need for expensive head-mounted displays, gloves, and high-end computer systems has somehow restricted its uses. However, today VR systems can be implemented by affordable personal computers. Human interaction with the generated virtual worlds can be performed using

conventional input devices, such as the mouse and keyboard without introducing any additional peripherals. In short, the availability of this relatively low cost VR system has made this technology feasible to be widely utilised. Indeed, according to Youngblut (1998), this non-immersive technology, when compared with the immersive technology, is much more mature and ubiquitously used in many different application areas.

Augmented reality is a variation of VR. It refers to computer displays that add virtual information to a user's sensory perceptions. Most augmented reality research focuses on 'see through' devices that overlay graphics and text on the user's view of his or her surroundings although virtual information can also be in other sensory forms (Feiner, 2002). It allows the user to see the real world, with virtual objects superimposed upon or composited with the real world (Azuma, 1997). Therefore, unlike VR, augmented reality supplements reality, rather than completely replacing it. Ideally, it would appear to the user that the virtual and real objects coexisted in the same space. According to Milgram and Kishino (1994), augmented reality can be thought of as the "middle ground" between VR (completely synthetic) and telepresence (completely real).

This study focuses on the non-immersive VR technology although there are different types of VR-related technologies. Numerous researchers such as Grove (1996), Roussos (1997), Whitelock et al. (1996), and Winn (1993) point out that VR technology offers unique capabilities that are able to provide significant and positive support for instruction. Some of these capabilities include the ability to allow learners to visualise the three-dimensional representation of a problem, to visualise abstract concepts, to articulate their understanding of phenomena through their development of virtual environments, to visualise the dynamic relationships between several variables in a system, to obtain infinite number of viewpoints of a virtual environment, and to visit and interact with events that are unavailable or unfeasible due to distance, time, cost,

or safety factors. The power of VR as a tool for experiencing pre-built worlds as well as for world building by learners provides rich potential for the technology to be exploited and used for instruction. Moreover, with the current development of VR on the web, other relevant information from the World Wide Web can also be linked to the virtual representation of the problem. Indeed, the integration of the Internet and VR enables us to simultaneously harness the benefits offered by these two exciting technologies.

The introduction of this technology brings about excitement and high expectation of its capabilities among instructors. VR technology demonstrates various capabilities that depict smart technical achievements and the technology will continue to advance as to provide even more capabilities. However, as with any other instructional media, VR should not be seen as a panacea that will work for all kinds of learning problems. Some learning tasks may be uniquely suited to virtual representation, while others may not be effectively performed in such environments (Pantelidis, 1996). Therefore, in order to identify the appropriate problems to be learned using this technology, to bring about cost-effective and meaningful learning, an instructor must first understand the various capabilities of this technology and subsequently choose learning problems that can take cognisance of these capabilities.

Although VR seems to offer promising instructional benefits, there are still many issues that need further investigation. Gustafson (2002) classifies the low cost three-dimensional visualisations and walk-around VR as several of the technologies that will revolutionise how people of all ages learn and work, and Rieber (1996) assures that these technologies have the potential to facilitate the acquisition of higher-order thinking and problem-solving skills. However, they too believe that much exciting research and development remain to be done. These issues include:

- how to design instruction to enable the effective utilisation of the VR capabilities to support the desired learning outcomes. What are the appropriate theories and/or models to guide the design and development of such learning environments?
- investigate how the attributes of this technology are able to support learning in a way that the conventional instructional methods are unavailable to provide, find out whether the use of VR can improve the intended performance and understanding, and investigate ways to reach more effective learning when using this technology.
- investigate the impact of the VR on learners with different aptitudes.

This study is thus, an initiative to investigate some aspects of the above-mentioned issues. It is intended to provide valuable insights to a feasible instructional design theoretical framework, as well as an instructional development framework for VR-based learning environments. In addition, it also aims to give an understanding of the educational effectiveness of such environment, methods to improve its effectiveness, and its effect on learners with different aptitudes.

As an initial step of this study, a practical learning problem appropriate to be implemented using VR is identified. This learning problem serves as a case to examine the abovementioned issues. The identified learning problem for this study is related to the novice car driver instruction of this country.

1.2 Problem Statement

The following statement of the problem focuses on the various design, development and evaluation issues of a VR-based learning environment. The learning problem, which is related to the novice car driver instruction, serves as the case to investigate these issues. This learning problem focuses on the understanding of traffic rules for various road scenarios that consist of ordinary roads, different types of road

junction, and related traffic signs. Generally, this learning problem is chosen in addressing the gradual increase of road accidents in this country as well as a response to a newspaper report (Computer-based traffic rules and regulations test: More than 200,000 failures (in Chinese). 2003, November 28) which reveals that more than 280,000 candidates failed the Road Transport Department (RTD) computer-based theory test from the period of May 2002 until August 2003 due to difficulty in studying the materials. These materials are in the form of text and two-dimensional static images.

Design and development

Three-dimensional VR is indeed one of the latest innovations in the long line of technology, which can be used for teaching and learning. As with any other technological advancement, the introduction of this technology brings about excitement and high expectation among educators of its capabilities. However, it is important to note that this technology is merely a tool, as is a chalkboard, television, overhead projector, or Internet. Tools by themselves do not teach. They have to be carefully and effectively implemented to assist in the learning process. As pointed out by Reigeluth & Frick (1999), more instructional design theories are needed to provide guidance on the use of new information technology tools. Hence, the pertinent question would be on how to design the instruction to enable the effective utilisation of the VR capabilities to support the desired outcomes. What are the appropriate theories and/or models to guide the design and development of such learning environments?

Evaluation

Youngblut (1998) who has done a rather comprehensive review of educational uses of VR technology reveals that most educational applications are not thoroughly evaluated in terms of their educational effectiveness. As pointed out by Jonassen et al. (2000), technologies were previously employed for communicating knowledge.

However, in recent years, technologies are reconceived as contexts, productivity tools, and thinking tools. In view of the fact that effective learning is the ultimate aim of any teaching and learning efforts and the roles of new technologies in teaching and learning are changing, it is thus crucial to perform educational effectiveness evaluation. Such evaluation, focusing on the case of novice car driver instruction, intends to find out whether the use of three-dimensional VR-based learning environment can improve the intended performance and understanding and to investigate how the attributes of this technology are able to support learning in a way that the conventional instructional methods are unable to provide (Kozma, 1994). This is succinctly articulated by Roblyer and Knezek (2003) who suggest that technologies should not be viewed as delivery systems, rather as components of solutions to educational problems.

Trying to control the computer simulation of a complex dynamic system is a typical example of an exploratory learning situation (Van Joolingen & De Jong, 1991). Due to the real-time interactive nature of VR, it is very appropriate for exploratory learning purposes. Exploration is often accompanied by cognitive efforts to develop and apply domain concepts or knowledge (Caroll et al., 1985; Kamouri et al., 1986). However, it is not so easy for learners to obtain good results in exploratory learning as the cognitive efforts may cause cognitive overload that yields an inefficient learning approach, possibly leading to confusion and even discourage them to explore (Kashihara et al., 2000; Touvinen, 1999). Although many of the well-accepted instructional effects can be adopted to reduce a learner's cognitive load in exploratory learning, Kashihara et al. (1995) suggest an approach to reduce the cognitive load during the exploration process, which is by controlling the exploration space. Their work (Kashihara et al., 2000) utilises an interactive simulation-based system as the exploration space. Previous study (Tuovinen, 1999) also reports the importance of providing limited exploration space to produce useful schema development. Limiting the exploration space is a way to reduce extraneous cognitive load. Tuovinen's study

focuses only on text and graphics presentation. However, he also points out the need to conduct similar study for VR. Therefore, it will be meaningful to investigate the methods to reduce this cognitive load in order to obtain a more effective exploratory learning, particularly in VR.

Aptitude-by-treatment interaction (ATI) research investigates the effects of learner aptitudes and traits on learning outcomes from different forms of instruction (Berliner & Cahen, 1973; Cronbach & Snow, 1969). The major assumption of this kind of research is that it is possible and desirable to adapt the nature of instruction to accommodate individual differences in terms of ability, style or preference to improve learning outcomes. Indeed, research concerning individual differences in the context of VR is still at its infancy. Chen et al. (2000) report an overview of some approaches and major findings of various research studies concerning the effects of individual differences on the use of this new technology. However, most of these studies focus particularly on the human-computer interaction aspect. Thus, there is a need for more studies on the interaction of individual characteristics with the characteristics of VR (Salzman et al., 1999).

Out of more than sixty educational projects that use VR technology as reported in Youngblut (1998), evaluation to identify the impact of learner characteristics on learning are conducted in only two of those projects. In the project on the Pacific Science Center Summer Camp, Byrne (1993) investigates the impact of gender, race, and scholarship factors on learners' interaction with and enjoyment of the VR, and the Virtual Reality Roving Vehicle Entrée programme by Winn (1995) looks into the issue of gender and spatial ability. A recent study by Ogle (2002) investigates the effects of VR on recall in participants of differing levels of field dependencies. Looking at the scarcity of the ATI research done, it is thus, reasonable to investigate the effects of the VR of this study on learners with different aptitudes, focusing specifically on spatial

visualisation ability and learning style. Chapter 2 elaborates how these aptitudes are related to VR, and explain why these aptitudes are chosen specifically for the case of novice car driver instruction.

1.3 Purpose of the Study

This study aims to pursue developmental goals (Reeves, 2000) by focusing on the dual objectives of developing a plausible solution to solve a learning problem in real context while at the same time constructing a feasible instructional design and development framework that could guide future developmental efforts. It starts by addressing a learning problem in real context. The identified learning problem focuses on the understanding of traffic rules for various road scenarios that consist of ordinary roads, different types of road junction, and related traffic signs, in which novice car drivers are found to face difficulty in understanding the conventional learning materials, which are in the form of text and two-dimensional static images. Then, a plausible solution to this learning problem is designed and developed by integrating known and hypothetical design principles with technological affordances. A recursive and reflective approach is employed to evaluate and refine the solution. Finally, an evaluation that employs a quasi-experimental design is conducted to investigate the effects of the developed learning environment on learning; to investigate the effects of controlling the exploration through the learning environment on learning; and to investigate the effects of learners' aptitudes, both spatial visualisation ability and learning style, on learning. Indeed, the whole study is in line with the Type 2 developmental research as defined in Richey and Nelson (1996). An instructional design theoretical framework and an instructional development model, both grounded in constructivism, are first proposed. Then the use of these framework and model is described and evaluated in a learning environment for novice car drivers.

The following are the specific objectives of this study:

1. to analyse a learning problem in a real context in collaboration with subject matter experts and by reviewing the related materials. The identified learning problem concerned with the novice car driver instruction of this country, focusing solely on the cognitive aspect.
2. to design a solution for the learning problem, which is a VR-based learning environment, by aligning the technological affordances with the instructional design theoretical framework.
3. to develop the VR-based learning environment
4. to conduct a field test, which is a multiple-group pretest-posttest quasi-experimental study (Spector, 1981), between three learning modes to measure the effects of each learning mode on learning and to investigate the effects of controlling the exploration through the virtual environments on learning.
5. to conduct an aptitude-by-treatment interaction (ATI) study to investigate the effects of learners' aptitudes, both spatial visualisation ability and learning style, and the possible interaction effects between the three learning modes and these aptitudes.

1.4 Research Framework

A multiple-group pretest-posttest quasi-experimental factorial design is employed to measure the effects of each learning mode on learning and to investigate the effects of controlling the exploration through the virtual environments, either with or without additional navigational aids, on learning. The effects of moderator variables, spatial visualisation ability and learning style are also investigated. Figure 1.1 depicts this research design.

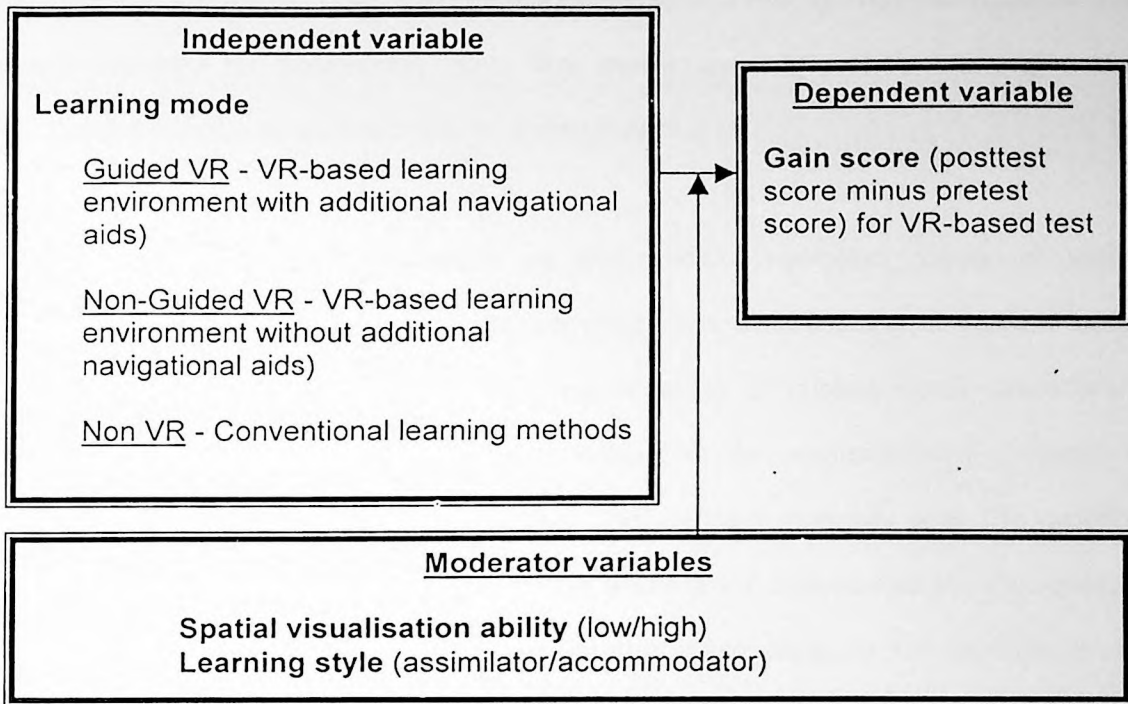


Figure 1.1: Research design

1.4.1 The theoretical framework

The theoretical underpinnings of investigating the effects of the different learning modes on learning and the effects of controlling exploration through the virtual environments on learning are the cognitive theory of multimedia learning (Mayer, 2002) and two of its associated theories; the dual coding theory (Paivio, 1971, 1986) and the cognitive load theory (Sweller, 1999, 2003a, 2003b). Brief mentions of these theories are described here and will be further elaborated in Chapter 2.

Cognitive theory of multimedia learning

Cognitive theory of multimedia learning is a theory of how people construct knowledge from words and pictures. Mayer (2002) points out three fundamental assumptions underlying the theory: dual-channel, limited capacity, and active processing. This theory assumes the human information processing system includes

dual channels for visual/pictorial and auditory/verbal processing, that each channel has limited capacity for processing, and that active learning entails carrying out a coordinated set of cognitive processes during learning.

Processing of pictures (such as illustrations, animation, video, or virtual environments) occurs in the visual/pictorial channel and processing of spoken words occurs in the auditory/verbal channel, but processing of printed words takes place initially in the visual/pictorial channel then moves to the auditory/verbal channel. In accord with the dual-channel assumption, the sensory memory and the working memory of this cognitive model of multimedia learning are divided into two channels. In addition, working memory is limited in the amount of knowledge it can process at one time, so that only a few images can be held in the visual channel or working memory and only a few sounds can be held in the auditory channel of working memory. This is in accord with the limited capacity assumption. Section 2.1.5 provides a further elaboration of this theory.

Dual-channel assumption - Dual coding theory

The dual-channel assumption is that humans possess separate information processing channels for visually represented material and auditorily represented material. This concept of separate information processing channels is closely associated with Paivio's dual-coding theory.

Dual coding theory, proposed by Paivio (1971, 1986) is a model that is based on cognitive information processing theory. According to Paivio (1991), this theory evolves from his studies on the role of imagery in associative learning. The basic assumption of this theory is that information is processed and stored in memory by two separate but interconnected cognitive subsystems (see Figure 1.2). The non-verbal subsystem specialises for the representation and processing of non-verbal objects or

events (i.e. imagery). Processing in the visual system is believed to be more holistic and based on continuous organisational units termed 'imagens'. The verbal subsystem, on the other hand, specialises for representation and processing linguistic information (words, sentences, etc.). Information is stored in discrete, sequential units that are called 'logogens'.

Dual coding theory identifies three types of processing: (a) representational, the direct activation of verbal or non-verbal representations, (b) referential, the activation of the verbal system by the non-verbal system or vice-versa, and (c) associate processing, the activation of representations within the same verbal or non-verbal system. Paivio (1971, 1986) is among the first to demonstrate experimentally that spatial processing (in the form of mental imagery) can enhance the recall of verbal information.

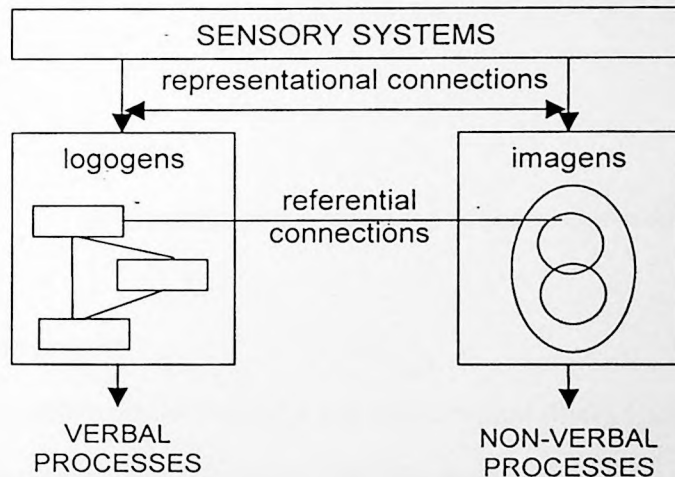


Figure 1.2: Schematic illustration of dual coding theory (Paivio, 1986)

Limited capacity assumption - Cognitive load theory

The second assumption of the cognitive theory of multimedia learning is that humans are limited in the amount of information that can be processed in each channel at one time. The following provides a description of cognitive load theory (Sweller,

1999, 2003a, 2003b), which is an example of theory that is closely related to the conception of limited capacity in consciousness.

Human cognitive architecture consists of a working memory that is very limited in duration and capacity and a large long-term memory used to store many automated schemas that can be brought into working memory for processing when required. Cognitive load theory concerns with the consequences of limited working memory on instructional design. The theory assumes that when dealing with material that has high element interactivity, working memory limitations should be a primary consideration of instructional designers. Instruction should be designed to minimise any unnecessary burdens on working memory and maximise the opportunity for the acquisition and development of automated schema. A good design permits working memory resources to be devoted largely for learning rather than for extraneous activities unrelated to the learning process. Section 2.1.6 provides a further elaboration of this theory.

1.4.2 Research questions

This study attempts to answer the following research questions:

Design and development

1. What are the feasible components of the instructional design theoretical framework that guides the design of a VR-based learning environment?
2. What are the feasible components of the instructional development model that guides the process of designing, developing and evaluating a VR-based learning environment?

Evaluation

3. Is there a difference in gain score for the VR-based test (as measured by posttest score minus pretest score) between the three learning modes (Guided VR, Non-Guided VR, and Non VR)?
4. Is there a difference in gain score for the VR-based test between the low spatial visualisation ability learners of each learning mode (Guided VR, Non-Guided VR, and Non VR)?
5. Is there a difference in gain score for the VR-based test between the high spatial visualisation ability learners of each learning mode (Guided VR, Non-Guided VR, and Non VR)?
6. Is there a difference in gain score for the VR-based test between the high spatial visualisation ability learners of the Guided VR mode and the low spatial visualisation ability learners of the same mode?
7. What is the interaction effect between the learners' spatial visualisation abilities and the learning modes, related to the gain score of the VR-based test?
8. Is there a difference in gain score for the VR-based test between the assimilator learners of each learning mode (Guided VR, Non-Guided VR, and Non VR)?
9. Is there a difference in gain score for the VR-based test between the accommodator learners of each learning mode (Guided VR, Non-Guided VR, and Non VR)?
10. Is there a difference in gain score for the VR-based test between the assimilator learners of the Guided VR mode and the accommodator learners of the same mode?
11. What is the interaction effect between the learners' learning styles and the learning modes, related to the gain score of the VR-based test?

1.4.3 Hypotheses

The following null hypotheses are formulated from the research questions 3 to 11. The probability level of 0.05 is used to test statistical significance.

H₀₁: There is no significant difference in the gain score for the VR-based test between learners exposed to the Guided VR mode, learners exposed to the Non-Guided VR mode, and learners exposed to the Non VR mode.

H₀₂: There is no significant difference in the gain score for the VR-based test between low spatial visualisation ability learners of each learning mode (Guided VR, Non-Guided VR, and Non VR).

H₀₃: There is no significant difference in the gain score for the VR-based test between high spatial visualisation ability learners of each learning mode (Guided VR, Non-Guided VR, and Non VR).

H₀₄: In the Guided VR mode, there is no significant difference in gain score for the VR-based test between the high spatial visualisation ability learners and the low spatial visualisation ability learners.

H₀₅: There is no interaction effect between the learners' spatial visualisation abilities and the learning modes (Guided VR, Non-Guided VR, and Non VR), related to the gain score of the VR-based test.

H₀₆: There is no significant difference in the gain score for the VR-based test between assimilator learners of each learning mode (Guided VR, Non-Guided VR, and Non VR).

H₀₇: There is no significant difference in the gain score for the VR-based test between accommodator learners of each learning mode (Guided VR, Non-Guided VR, and Non VR).

H₀₈: In the Guided VR mode, there is no significant difference in gain score for the VR-based test between the assimilator learners and the accommodator learners.

H₀₉: There is no interaction effect between the learners' learning styles and the learning modes (Guided VR, Non-Guided VR, and Non VR), related to the gain score of the VR-based test.

1.5 Definitions of Terms

The study uses the following terms as per defined below:

1.5.1 Conceptual definitions

VR: An interactive three-dimensional computer generated visual and auditory that can be manipulated. It is implemented on a conventional personal computer without introducing any additional peripherals, and is also referred to as a non-immersive VR.

Novice car driver: Any person who is 17 years old or above and does not possess a driving license.

Spatial ability: A psychometric construct with two major factors: spatial orientation and spatial visualisation (Michael et al., 1957).

Spatial orientation: A measure of the ability to remain unconfused by changes in the orientation of visual stimuli, and therefore it involves only a mental rotation of configuration (Ekstrom et al., 1976).

Spatial visualisation: A measure of the ability to mentally restructure or manipulate the components of the visual stimulus and involves recognising, retaining, and recalling configurations when the figure or parts of the figure are moved (McGee, 1979).

Learning styles: – One's preferred methods for perceiving and processing information (Kolb, 1984).

1.5.2 Operational definitions

Guided VR: A learning mode that employs the developed VR-based learning environment. This learning environment makes available additional navigational aids; in the form of a tracer that provides a real-time indicator of the virtual vehicle position on a map, and directional arrows.

Non-Guided VR: A learning mode that employs the developed VR-based learning environment, except without the additional navigational aids.

Non VR: A conventional learning mode that relies on lectures and reading materials.

Learner: Any novice car driver who is literate, without any major physical deficiencies, and participates in the evaluation study of this study.

VR-based test: A computer-based test, which comprises 15 multiple-choice questions that assesses the learners' understanding of traffic rules and traffic signs. Instead of showing two-dimensional images as in the conventional test, each of these questions

shows a three-dimensional simulation of a virtual road scenario and the learners are instructed to identify an observable error in the simulation, if any.

A high spatial visualisation ability learner: A learner who scores above the mean in the Bennett, Seashore and Wesman Space Relations Test.

A low spatial visualisation ability learner: A learner who scores equal or below the mean in the Bennett, Seashore and Wesman Space Relations Test.

An assimilator learner: A learner where experience is grasped through abstract comprehension (conceptualising) and transformed through thought (intention). This learning style combines abstract conceptualisation and reflective observation (Kolb, 1999). The two combination scores (abstract conceptualisation minus concrete experience and reflective observation minus active experimentation) of this learner fall on the bottom right quadrant of the learning style types grid developed by Kolb (1999). Figure 1.3 shows a simplified version of the grid. A dashed diagonal line is introduced to equally separate the grid into two halves. Any diverger learner, whose learning style combines concrete experience and reflective observation or converger learner, whose learning style combines abstract conceptualisation and active experimentation (Kolb, 1999) with the two combination scores that fall below the diagonal line is also classified as an assimilator learner. In other words, assimilator learners include learners who fulfil the Kolb's definition of assimilator, diverger learners with stronger Kolb's characteristic of reflective observation than concrete experience, and converger learners with stronger Kolb's characteristic of abstract conceptualisation than active experimentation.

An accommodator learner: A learner where experience is grasped through feelings (apprehension) and transformed through action (extension). This learning style combines concrete experience and active experimentation (Kolb, 1999). The two

combination scores of this learner fall on the top left quadrant of the learning style types grid shown in Figure 1.3. Any diverger learner or converger learner with the two combination scores that fall above the diagonal line is also classified as an accommodator learner. In other words, accommodator learners include learners who fulfil the Kolb's definition of accommodator, diverger learners with stronger Kolb's characteristic of concrete experience than reflective observation, and converger learners with stronger Kolb's characteristic of active experimentation than abstract conceptualisation.

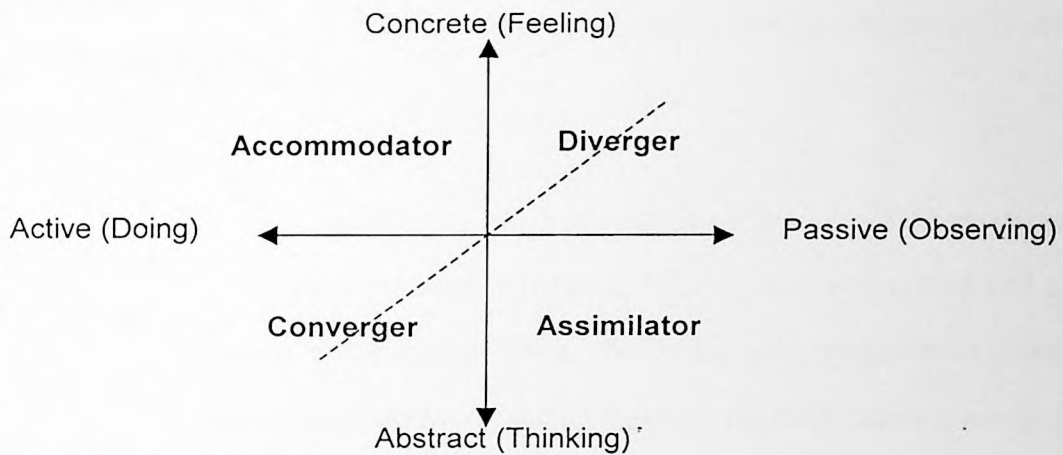


Figure 1.3: Learning style types (Adapted: Kolb, 1999)

1.6 Significance of the Study

The development of the VR-based learning environment makes new learning opportunities available to learners through the unique affordances of the technological solution. This learning environment introduces learning activities, which makes visible concepts and relationships that are not easily grasped or visualised by learners and that, without the aid of the learning environment, instructors have limited means to present.

The VR-based learning environment and the VR-based test showcase innovative approaches to instruct and to test novice car drivers in Malaysia. As the use of VR technology in teaching and learning in this country is still at its infancy, this learning environment and the VR-based test are hoped to create awareness on the potentials and/or weaknesses of current VR technology for the use in teaching and learning.

This learning environment is designed based on the constructivist paradigm. Thus, the successful development of this learning environment provides evidence on how the attributes of the VR technology could afford the constructivist learning principles.

Through the ongoing evaluation, which is conducted throughout the design and development process, a valid and usable VR-based learning environment as well as a body of design principles is produced. Thus, this study also suggests a feasible instructional design theoretical framework and an instructional development model that could guide future developmental efforts.

The outcomes of the educational effectiveness evaluation provide insight on the effectiveness of employing a VR-based learning environment in the current novice car driver instruction. The investigation on the method to reduce the cognitive load in order to obtain a more effective learning is able to suggest another instructional implication or design principle, which is derived from the cognitive load theory, particularly for learning that utilises VR. In addition, the aptitude-by-treatment interaction study depicts its effects on learning for learners of different spatial visualisation abilities and learning styles. The understanding of how these individual differences interact with the different types of learning environment could help in identification of instructional treatments that facilitate individualised learning.

1.7 Summary

This chapter begins by introducing the affordable desktop VR system, its instructional benefits, and some of its research issues that direct the focus of this study. This study pursues developmental goals where it starts by addressing a learning problem in a real context and then design and develop a possible solution by integrating known and hypothetical design principles with technological affordances. A multiple-group pretest-posttest quasi-experimental study is employed to measure the effects of each learning mode on learning and to investigate the effects of controlling the exploration through the virtual environments, either with or without additional navigational aids, on learning. Nine null hypotheses are derived from the research questions. Among the major contributions or significance of this study include: provides a new learning opportunity; showcases innovative approaches to instruct and to test novice car drivers; provides evidence on how the attributes of the VR technology can afford the constructivist learning principles; suggests a feasible instructional design theoretical framework and an instructional development model that can guide future development efforts; provides insight on the effectiveness of employing the VR-based learning environment; suggests another instructional implication or design principle, which is based on the cognitive load theory, to obtain a more effective learning in VR-based learning environments; and provides an understanding on the effects of the different learning modes on learning for learners of different aptitudes.

CHAPTER 2 LITERATURE REVIEW

2.0 Overview

The purpose of literature review is to set the foundation for the specific objectives of this study. This chapter provides a description of the related theories and models that form the instructional design theoretical foundation of the VR-based learning environment. Besides forming the instructional design theoretical foundation, two of the theories that are described in this chapter, the cognitive theory of multimedia learning (Mayer, 2002) and the cognitive load theory (Sweller, 1999, 2003a, 2003b) also serve as the theoretical underpinnings that inspire the investigation on the effects of the different learning modes on learning and the effects of controlling exploration through the virtual environments on learning. This chapter also provides a description of the related instructional development model that guides the design and development of the learning environment, methods to generate non-immersive VR, considerations on how to identify appropriate learning problems to be implemented using this technology and some of its applications in instructional settings. Finally, the role of aptitude-by-treatment interactions with respect to learners' spatial visualisation abilities and learning styles are discussed.

2.1 Instructional Design Theoretical Foundation

Instructional-design theory offers explicit guidance on how to help people learn and develop (Reigeluth, 1999). It identifies methods of instruction and the situations in which those methods should and should not be used. These methods of instruction can be broken into more detail component methods to provide more guidance to instructors. In addition, the methods are probabilistic, which means they increase the chances of attaining goals rather than ensuring attainment of the goals.

Reigeluth (1999) proposes the following changes to the current paradigm of instruction (see Table 2.1). The new paradigm of instruction requires a new paradigm of instructional design theory. The instructional design theories of the new paradigm need to change from one focused on the teacher to one focused on the learner. As elaborated in Reigeluth (1999), learning-focused instructional-design theory must offer guidelines for the design of learning environments that provide appropriate combinations of challenge and guidance, empowerment and support, self-direction, and structure.

Table 2.1: Comparison between current and new paradigm of instruction (Reigeluth, 1999)

Current paradigm	New paradigm
<ul style="list-style-type: none"> • Standardisation • Focus on presenting materials 	<ul style="list-style-type: none"> • Customisation • Focus on ensuring that learners' needs are met
<ul style="list-style-type: none"> • Conveying information to the learner 	<ul style="list-style-type: none"> • Helping learner to build their own knowledge
<ul style="list-style-type: none"> • Passive learning • Teacher initiative, control, and responsibility 	<ul style="list-style-type: none"> • Active learning • Shared initiative, control, responsibility
<ul style="list-style-type: none"> • Decontextualised learning • Holding time constant and allowing achievement to vary 	<ul style="list-style-type: none"> • Authentic, meaningful tasks • Allowing each learner the time needed to reach the desired attainments

This new paradigm also requires the definition of instruction include what many cognitive theorists refer to as 'construction', which is a process in helping the learners to build their own knowledge. Various authors have labelled constructivism as holding a fundamental set of beliefs and assumptions that is in line with this new paradigm (Coleman et al., 1997).

2.1.1 How does VR afford constructivist learning?

Jonassen et al. (2000) and Greening (1998) listed the technologies that are capable of affording constructive learning, and VR is among these technologies. VR provides a controlled real-world environment in which learners can navigate, and manipulate the virtual objects found within and more important, the effects of such

interaction can be observed in real time. VR is therefore, very well suited for providing exploratory learning environments, which enable learners to learn through experimentation. Winn (1993) highlights that the characteristics of VR and the axioms of constructivist learning theory are entirely compatible and claimed that constructivist theory provides a valid and reliable basis for a theory of learning in VR.

Bricken (1990), Chen and Teh (2000b), and Winn (1993) are among others who point out how the various capabilities of this technology can support constructivist learning principles (see Table 2.2 below). Generally, constructivists believe that learners can learn better when they are actively involved in constructing knowledge in a learning-by-doing situation. Indeed, the compatibility of VR capabilities with constructivist learning principles further strengthen the decision on using the philosophy of constructivism to guide the design of the learning environment of this study.

Table 2.2: How do the technical capabilities of VR support the constructivist learning principles (Adapted: Chen & Teh, 2000b)

Constructivist Learning Principles	VR
Interesting, appealing, and engaging problem representation, which describes the contextual factors that surround the problem	<ul style="list-style-type: none"> • Can present problem in a shared three-dimensional environment that simulate aspects of the real world
Multiple perspectives, themes, or interpretations of a problem to encourage diverse ways of thinking	<ul style="list-style-type: none"> • Can provide unlimited number of viewpoints of the three-dimensional environment • Can provide an independent controlled viewpoint for each learner • Can exclude secondary elements in the virtual environments that may divert the learner's attention from the elements of primary importance
Active learning – learners uses sensory input and construct meaning out of it	<ul style="list-style-type: none"> • Can provide a problem manipulation space that allows free exploration and manipulation. Feedback/Interaction can be observed (either through visual, auditory, tactile, and/or kinaesthetic cues) by other participated learners

Table 2.2 continued

Understanding is tracked by experience	<ul style="list-style-type: none">• Can provide virtual experience instead of words or pictures. Virtual experience has natural semantics that provide meaning to the learner without any explanation
Instruction cannot be designed – learners construct their own knowledge	<ul style="list-style-type: none">• VR is designed without a specified sequence – permit any kind of interaction the system is capable of
Rich sources of information	<ul style="list-style-type: none">• VR in itself naturally contains needed information• Can also be complemented with other computer-supported collaborative learning tools to provide other relevant information (e.g. WWW)
Cognitive tools – intellectual devices used to visualise, organise, automate, or supplant information processing	<ul style="list-style-type: none">• Can act as visualisation tool, modelling and design tool, dynamic modelling tool, and automation tool
Conversation and collaboration tools – access to shared information and knowledge building tools to help learners collaboratively construct socially shared knowledge	<ul style="list-style-type: none">• Can provide a shared space for a group of learners, either co-located or at a distance, to collaboratively construct knowledge through synchronous and/or asynchronous communication• Can incorporate virtual bodies (embodiments) to improve the realism of the collaboration process.

2.1.2 Macro-strategy versus micro-strategy

Organisational strategies, a category of instructional variable, are those decisions involved in the design of learning activities. These strategies can be subdivided into two subcategories: macro strategies and micro strategies (Reigeluth & Merrill, 1978). According to them, macro strategies concern with the selection, sequence, and organisation of the subject-matter topics that are to be presented, also described as the overall strategic plans (Gibbons et al., 1997), while micro strategies concern with the individual displays, including their characteristics, interrelationships, and sequence, that are to be presented to the learner. Micro strategies may also be characterised as presentation strategies because they concern with the details of each