# Exploring the effects of background colours of digital materials on learners' comprehension in higher education

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Submitted in accordance with the requirements for the degree of
Master of Philosophy

The University of Leeds
Faculty of Arts, Humanities and Cultures
School of Design

July 2023

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## Acknowledgements

I am deeply grateful to the following individuals whose unwavering support and encouragement made this thesis possible:

First and foremost, I extend my heartfelt gratitude to my esteemed supervisors, Dr. Philip Henry and Dr. Francisco Oliveira de Queiroz. Their exceptional guidance, academic expertise, and constant encouragement have been invaluable throughout this research journey. I am truly fortunate to have had the privilege of working under their mentorship. Their belief in me has empowered me to overcome challenges and grow academically.

I owe a debt of gratitude to my dearest parents for their unconditional love and unwavering support. Their belief in my abilities and constant encouragement has been the cornerstone of my success. Their faith in me has given me the strength to persevere, and I am forever indebted to them for being my strongest pillar of support.

I extend my heartfelt thanks to my cherished friends for their companionship and emotional support throughout my time in a foreign country. Their presence has made this journey more joyful and less daunting. A special mention goes to my dear friend, Dr. Soojin Lee, whose academic advice and support were instrumental in times of uncertainty. Beyond academia, she has also inspired me in various aspects of life, for which I am truly grateful.

I want to express my sincere appreciation to the University of Leeds, School of Design, where I have had the privilege of making such kind and warm-hearted supervisors and friends. They have made the challenges of studying abroad feel lighter, and their camaraderie has made my academic and personal growth more enriching.

I extend my thanks to all those who have contributed to my academic and personal development. Your support has played an integral role in shaping this thesis and my journey as a researcher.

## Abstract

Recent studies demonstrate that colours could enhance human memory, attract attention, improve concentration and readability, and help information recall. Although colour design is an important factor in education, little scientific research has examined the optical colours for instructional materials. The project encompasses a focus group, pre-experiments, and main experiments all aimed at gaining a deeper understanding of the effects of colours on human comprehension in digital learning environments. 40 participants completed a comprehension ability test with 16 questions displayed on eight different background colours: red, orange, yellow, green, blue, purple, grey, and black. Note that to ensure consistent contrast between foreground (text) and background colour, grey fonts were used for the black background and black fonts for the other seven colours. It also assessed the preference, readability, and legibility of the different colour materials. The study found that native English speakers performed better in the tests with grey and red background colours; there were higher correct rates and shorter response times for the two colour conditions. Especially, there were significant differences in the evaluation scores between grey and black backgrounds, which have black and grey foreground colours, respectively. On the other hand, none of the colours did significantly affect non-native English speakers' comprehension ability. In the subjective assessment of preference, legibility, and readability, however, the two groups had no significant differences. To sum up, this study suggests that people's cognitive performance may be better under light background and dark foreground colour combinations. Also, preferred colours may not lead to a better understanding of text-based information. Educators, instructional designers, and developers of digital educational materials can benefit from these insights to enhance digital learning experiences by optimizing the integration of colour and addressing the impact of language proficiency.

**Keywords:** colour design; digital learning materials; comprehension assessment; higher education.

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# Chapter 1
# Introduction

## 1.1 Contextual Backgrounds

In the domain of education, it has long been recognized that the nature of information in twenty-first-century classrooms has already changed pace (Seely Brown and Adler, 2008). It is now described as digital, networked, overwhelming, immediate, manipulatable, participatory and visual (Lundy and Stephens, 2015). Worldwide, the COVID-19 outbreak has prompted the implementation of measures to control the spread of the virus and safeguard public health. As a result, numerous educational institutions have temporarily closed their campuses and transitioned to online learning platforms. This sudden shift has underscored the crucial role of eLearning tools in facilitating remote education (Rashid and Yadav, 2020). Across diverse disciplines, traditional face-to-face courses have swiftly been converted into distance learning formats. In this unprecedented scenario, the suitability of course content and instructional approaches for online delivery has become not paramount. Both online educators and learners have had to adapt to this rapid change, making the most of available resources. Consequently, the utilization of digital instructional materials has expanded significantly, elevating their importance in the educational landscape.

The primary focus of this study is to effectively utilise colour interventions to enhance learners' comprehension abilities, with the underlying assumption being guided by research-based theories of how students learn. Fortunately, solid theoretical foundations are provided by the advancements in cognitive psychology research. One of the key approaches in cognitive psychology is to understand how to leverage technologies, such as multimedia, to facilitate student learning (Mayer and Moreno, 1998).

One of the theoretical foundations of this study is the cognitive theory of multimedia learning. If we trace its origins, this theory draws upon several previous theories, including Paivio's (1990； Clark and Paivio, 1991) dual coding theory, the generative theory by Wittrock (1989), the cognitive load theory (Sweller *et al.*, 1990； Chandler and Sweller, 1991), Baddeley's (1992) model of working memory, and Mayer's (1996) SOI model of meaningful learning. According to this theory, learners possess a visual information processing system and a verbal information processing system. If information is delivered through multiple channels, it has been proven to positively enhance learners' efficiency in various aspects. In this research,

one of the most important aims is to investigate whether introducing interventions such as colour in the visual system, under equivalent conditions, can have a certain level of impact on learners' comprehension abilities.

In the meantime, based on the memory retention intensification of colour for higher education populations under the context of blended learning and distance learning, Diachenko *et al*.(2022a) affirm the prospect of improving and developing educational materials using colour effects to enhance students' perceptions. According to Roberts (2017), "even though the use of colour in the production of instructional materials is widespread, its relative effectiveness as an aid in improving student achievement remains inconclusive and at best contradictory" (p. 26).

Text-based educational materials are difficult to remember and understand. Studies have shown that colour or colour combinations can help people to recall information and form colour coding to some extent (Zufic and Kalpic, 2009； Diachenko *et al.*, 2022b). The taxonomy initially aimed to categorize cognitive behaviours deemed significant in the learning process. Over time, this classification evolved into three distinct domains (Allen and Friedman, 2010):

(1) The cognitive domain - knowledge based domain, consisting of six levels
(2) The affective domain – the attitudinal-domain-based domain, consists of five levels, and
(3) The psychomotor domain is – a skills-based domain, consisting of six levels.

This represented one of the earliest endeavours in classification. In 2001, the taxonomy underwent revision to align with contemporary insights into educational processes, and it continues to be extensively employed in present times. Following Bloom's taxonomy (Bloom *et al.*, 1956) hierarchical models (see Figure 1.1), the second educational learning objective after remembering is understanding. This phase is also a new area of colour-related research that researchers have not yet touched upon. Because of the difficulties in measuring human comprehension and the complexity and specificity of the potential influence of colour on different individuals, this research aims to link and quantify the cause-effect relationship.

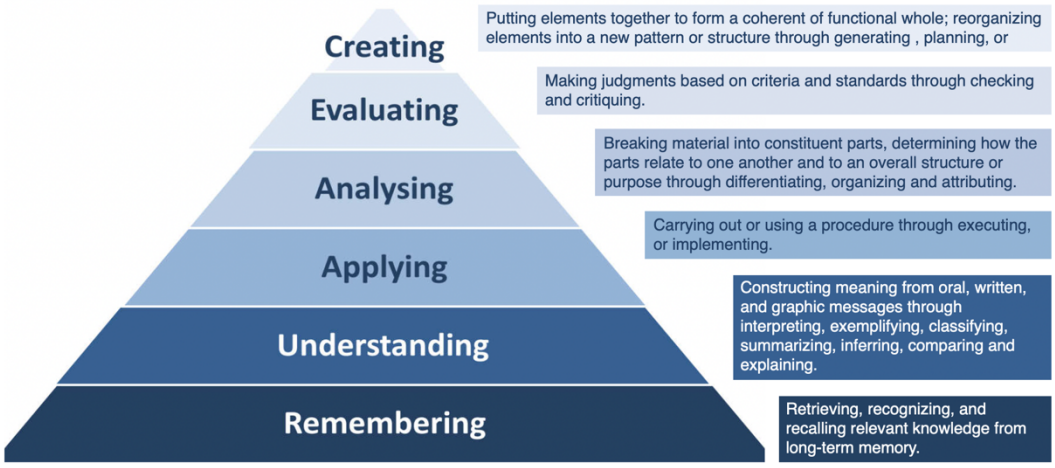



**Figure 1.1** The taxonomy for the cognitive domain pyramid and the definitions for each level in the revised taxonomy. https://www.imperial.ac.uk/staff/educational-development/teaching-toolkit/intended-learning-outcomes/blooms-taxonomy/

Therefore, this study hypothesises that online learners' comprehension ability of text-based information would differ depending on the colour (Hue) of the background. This study will also verify that in the virtual learning context, which colour background would give the best learning outcomes will be the experiment's conclusion. It will also explore whether there is a correlation between the learners' colour preference and their understanding.

## 1.2 Research Questions

(1) What are the current developments and research findings in colour design to facilitate learning?
(2) What are target learners' experiences, preferences and expectations of digital/ online learning?
(3) What colour (hue) would be most appropriate as the primary background colour for digital materials from the perspective of contemporary learners?
(4) Which colour is used as the digital learning materials' background that can give learners the best performance, especially in terms of understanding textual information?

## 1.3 Aim and Objectives

**Aim:** To explore the potential of different background colours in digital educational materials on human comprehension ability in the contemporary virtual learning context for higher education groups.

**Objective 1:** to appraise the concepts, theories, and applications related to this research topic and define the gap.

**Objective 2:** to understand contemporary online learners‘ experience in the virtual learning environment (VLE) with digital learning materials.

**Objective 3:** to gather the preferences of contemporary learners regarding the colour design of digital learning materials.

**Objective 4:** to evaluate which colour can access learners‘ best text-based information comprehension ability.

## 1.4 Thesis Outline

The thesis consists of five chapters:

**Chapter 1** presents the research backgrounds and contextual backgrounds to provide an overview of the existing knowledge and theories relevant to the research topic. The research questions are clearly stated to guide the study. The aim and objectives of the research are outlined, representing the overall purpose and specific goals to be achieved. The chapter concludes with a thesis outline, highlighting the structure and main topics covered in the subsequent chapters.

**Chapter 2** reviews existing literature to establish the foundation for the present study. The learning process is explored, including an examination of various existing learning theories such as the Cognitive Load Theory, Multimedia Learning, and the Cognitive Affective Theory of Learning with Media. Additionally, the cognitive learning processes are discussed, focusing on attention, motivation, memory, and comprehension. The chapter also delves into the key design elements of information design and instructional design, such as fonts, layout, and colour. Furthermore, the relationships between colour and cognitive learning processes are examined in detail, including the effects of colour on attention, memory, readability, legibility,

preference, and the learning environment. The chapter concludes with a summary and synthesis of the key findings from the literature review.

**Chapter 3** provides an overview of the research design including the consideration of qualitative, quantitative, or mixed-methods approaches. The use of focus groups as a research method is discussed, along with the sampling strategy, question materials, and procedure. Pre-experiments are also conducted as part of the research methodology, with a description of the sampling strategy, colour materials, question materials, and procedure. The main experiments are outlined, including the sampling strategy, questionnaires, scaling methods, and procedure. The chapter concludes with a summary of the research methods employed.

**Chapter 4** presents the data analysis and findings of the research. The focus group data is analysed using a coding or thematic analysis approach, and the main themes or patterns that emerge from the data are discussed. The data from the pre-experiments and main experiments are also analysed using appropriate statistical techniques or methods, and the significant findings or trends are presented. The chapter provides a comprehensive summary of the data analysis and findings, highlighting the key insights gained from each stage of the research.

**Chapter 5** discusses the key findings from the main three studies and compares them with the existing literature and theories. Also, it explores the implications of the findings and any limitations or challenges encountered during the research process. Suggestions for further research are provided, identifying areas that require additional exploration. Lastly, it concludes with a summary of the main findings, their contributions to the field, and potential practical applications or recommendations arising from the study.

# Chapter 2
# Literature Reviews

## 2.1 Introduction

The learning process is a complex phenomenon that has been extensively studied in the field of education. Understanding how individuals learn and acquire knowledge is essential for designing effective instructional materials and optimizing the learning experience. This chapter presents a comprehensive literature review on the learning process, focusing on existing learning theories, cognitive learning abilities/processes, and key design elements of information design and instructional design. Additionally, the relationships between colour and cognitive learning abilities/processes are explored.

The chapter begins by discussing existing learning theories that provide theoretical frameworks for understanding the learning process. These theories include the Cognitive Load Theory, which emphasizes the optimization of cognitive load to enhance learning outcomes. Multimedia Learning and the Cognitive Theory of Multimedia Learning are explored, highlighting the role of multimedia elements in facilitating learning through multiple sensory modalities. The Cognitive Affective Theory of Learning with Media and the Dual-coding theory are also examined, emphasizing the influence of affective factors on learning and the benefits of utilizing verbal and visual representations in instructional materials.

Subsequently, the focus shifts to cognitive learning abilities and processes that are crucial in the learning process. Attention and motivation are discussed as key cognitive abilities that impact learners' focus and engagement. Memory and comprehension processes are explored, highlighting how learners encode, store, retrieve information, and construct meaning from instructional materials.

Furthermore, the chapter investigates key design elements of information design and instructional design. Fonts (typography) are examined, considering their impact on readability, legibility, and user experience. Layout design principles are discussed, emphasizing how the arrangement of text, images, and other visual elements can facilitate information processing and comprehension. The role of colour in information and instructional design is also explored, highlighting its psychological and

emotional impact and its potential to enhance user engagement and understanding.

Finally, the relationships between colour and cognitive learning abilities/processes are examined in detail. The effects of colour on attention, memory, readability, legibility, preference, and the learning environment are discussed, providing insights into how colour choices can influence learners' cognitive processes and overall learning outcomes.

This literature review synthesizes the existing knowledge and theories related to the learning process, cognitive abilities/processes, and key design elements in information and instructional design. It sets the foundation for further exploration and analysis in subsequent chapters, ultimately contributing to a comprehensive understanding of the research topic and its practical implications in educational settings.

## 2.2 Learning Process

According to Richard E. Mayer (1982), *"learning is the relatively permanent change in a person's knowledge or behaviour due to experience."* In short, learning is the result of experience. This definition has three components: 1) the duration of the change is long-term rather than short-term; 2) the locus of the change is the content and structure of knowledge in memory or the behaviour of the learner; 3) the cause of the change is the learner's experience in the environment rather than fatigue, motivation, drugs, physical condition or physiologic intervention". Recently, Bingham and Conner (2010) defined learning as the transformative process based on input, process and reflection. The process of this definition is a consequence of ongoing interactions between the learner's prior knowledge and the complex social environment in which the learner occurs. It indicates that the physical and social environment is one of the important variables in the learning process. In the field of design, researchers and instructional designers focus on developing educational materials to help students' learning process.

### 2.2.1 Existing Theories on Learning

This section explains three existing learning theories (1 the Cognitive Load Theory, 2 Multimedia Learning theories, and 3 Dual-coding theory) that help

understand the role of visual elements in the design of instructional materials.

#### 2.2.1.1 Cognitive Load Theory

Cognitive Load Theory (CLT) asserts that when learning conditions are consistent with human cognitive architecture, people will achieve the best learning state, and seeks to integrate our cognitive process knowledge with instructional design principles (Sweller, 2011). The instructional design should aim to reduce unnecessary demand on this system. In simple words, cognitive load theory can be described as *the "knowledge of human cognitive architecture"* and its influence on learning (Owens and Sweller, 2008, pp.29-45). Human cognitive architecture is a system for processing information. In CLT, long-term memory is conceptualised as a large information repository that constitutes professional knowledge, which largely determines people's ability to recognize situations, solve problems and obtain fluency in a skill. It emphasizes strategies to manage *“working memory load to facilitate the changes in long-term memory associated with schema construction and automation”* (Paas *et al.*, 2004, p.2). The purpose of instruction is to make appropriate alterations to this information and to assist learners in acquiring fluency (Paas and Sweller, 2014). CLT can assist instructors in recognizing the limitations and potential of human cognition and instructional design practices that should be considered when facilitating knowledge acquisition. Cognitive performance is how to understand the cognitive architecture components, including three aspects: 1) working memory and its processing capabilities, 2) long-term memory storage abilities, and 3) three types of cognitive load, intrinsic, extraneous, and germane that impact learning (Owens and Sweller, 2008, p.29-31).

According to Paas and Sweller (2014), the intrinsic Cognitive Load (CL) is caused by the nature and difficulty of the task. Because it is an intrinsic object of the content, it cannot be modified through instructional design. Extraneous CL is generated through the presentation of information and instructional tasks. It is generally recommended to avoid the use of an instructional design that contains unnecessary elements and exclude irrelevant content for learners to process to increase the extraneous CL. Germane CL is an effective CL required in the learning process, the working memory resources that deal with intrinsic CL rather than extraneous CL.

Previously, a study found that working memory works when there are no greater than 7 elements at the time and it starts losing information after 20 seconds of being exposed (Sweller *et al.*, 1998). It means that working memory has a limited “capacity and duration” to store large amounts of unorganized pieces of new information. If information and instructional design are used to improve the information in the instructional materials, it should be displayed in a well-organised manner. At the theoretical level, it would help improve germane CL and learning effectiveness.

To clarify, working memory could impact cognitive load and this is mainly based on the organisation of learning materials or information. Minimizing extraneous cognitive load and optimising the allocation of the learner's cognitive resources towards task engagement would be important in instructional design. However, limited research has focused on analysing individuals' information processing capacity and cognitive load potential.

#### 2.2.1.2 Multimedia Learning Theories

Multimedia refers to a presentation containing texts, pictures, photos, videos, animations. The texts can be verbal or printed and the images can be static or dynamic. It is comprised of information in both verbal and pictorial form. Multimedia learning is the process of building mental representations and constructing knowledge from verbal and/or visual information. The benefits of enhancing text materials with visuals are well documented. However, using visuals for learning might not come easily to all students.

Some studies found that students learn better when the information or instruction materials include both texts and images which helps them facilitate the development of mental models, knowledge integration and application, and transfer (Mayer *et al.*, 2005； Butcher, 2006； Mayer, 2014a). More specifically, Butcher (2014) explained that, for learners with limited prior knowledge, visual representations should be kept to essential components and well-organized structures.

Especially, in terms of image construction, when motion is important in the instructional concepts, animation should be included; however, if the learners can mentally animate the materials themselves, static images may be more effective because they facilitate more active processing (Hegarty *et al.*, 2003). Whether the images are static or dynamic, visual cues should be added whenever possible to direct the learners’ attention and support meaningful processing of the visual elements (Boucheix and Guignard,

2005). Whenever possible, it is best to provide learners with both concrete and more abstract representations of the concept or object (Moreno *et al.*, 2011). When presenting instructional materials in digital environments, another important consideration is interaction. According to Butcher (Butcher, 2014), interactive elements have the potential to guide the students' attention and facilitate the processing of concepts. Effective interactions can also help the integration of visual and verbal content (Bodemer *et al.*, 2004). Requiring learners to generate their visual models has been shown to improve learning outcomes by fostering active learning (Gadgil *et al.*, 2012), and digital environments offer the possibility to easily compare the learner's model with a high-quality one. Because many online learning resources are becoming more and more accessible.

Other studies have shown that many students miss the advantages of visuals because they skip over the graphics or engage with them in a superficial manner (Cromley *et al.*, 2010). They also do not know how or when to generate their own diagrams (Uesaka *et al.*, 2007). However, training students on how to use visuals has been effective (Moore, 1993), and providing adequate guidance can also help overcome this issue, especially in a digital environment where signalling and interaction can ensure optimal sequencing and highlighting of content. When designing instruction, it is important to remember the role of each of these elements and be clear about what they bring to the table.

According to multimedia learning theory, there are three methods of instructional design to enhance learning: less-is-more, more-is-more, and focused-more-is-more (Mayer, 2014b). The less-is-more approach is focused on reducing or eliminating extraneous materials to avoid interference during the learning process. The more-is-more approach is focused on adding some elements to increase the motivation and engagement of learning, such as graphics features. Lastly, the focused-more-is-more learning method provides learners with sufficient time to learn instructional materials, supplemented by additional functions such as graphics and challenging learning situations. The multimedia option provides learners with multiple opportunities to try to master the content of the course and does not require educators to repeat the same educational materials multiple times (Miller, 2014). Educators or instructional materials designers can refer to these principles when designing learning materials.

Formerly, Mayer (2005) proposed the Cognitive theory of multimedia learning (CTML) model. The CTML is a human information processing

system, which has three memory stores: sensory memory, working memory, and long-term memory. Figure 2.1 illustrates the CTML model to explain how learning takes place.

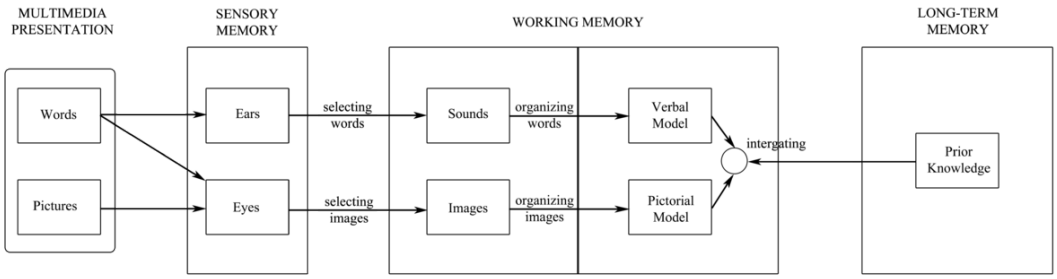



**Figure 2.1** The Cognitive theory of multimedia learning (Mayer, 2005).

Stimuli (images and text) from multimedia presentations enter sensory memories, where they are temporarily saved as visual and auditory images. After, the relevant selected visual and sound images will enter the working memory and be organized into verbal and pictorial models. The third storage is long-term memory, which is virtually unlimited and can hold materials for a long time. However, these materials also need to be brought into working memory to think actively about it and integrate new knowledge with old. The role of design in this process is to effectively influence the presentation of visual information.

The CTML model proposes that learning is an active and autonomous process of filtering, selecting, organizing and integrating information based on prior knowledge. These cognitive processes depend on the learner's working memory, but the working memory capacity is very limited. Therefore, it is essential to optimise them through appropriate stimulation (Mayer and Fiorella, 2014). The multimedia learning theory just provides this opportunity.

In a later study, Mayer (2014b) suggested three elements of cognitive processing capabilities: (1) extraneous processing, (2) essential processing and (3) generative processing. First, extraneous processing refers to the processing of unnecessary elements that are irrelevant to the learning objective. It is produced by poor instructional design and does not lead to the construction of knowledge. Examples are irrelevant pictures or attempts to find a piece of information back and forth. Second, essential processing refers to the cognitive processing (selection and organization of relevant

information) of the instructional content and is caused by the nature and difficulty of the content. The result of essential processing is to construct verbal and graphical representations in working memory. Third, generative processing is a process that supports a deeper understanding of the material by reorganizing the information and combining it with a priori knowledge and depends on the learner's motivation to make sense of the instructional material.

It is important to use cognitive resources on essential and generative processing and minimize unnecessary processing since the working memory capacity of the learners is limited. A good instructional design of learning materials and tasks can be made when following some design principles. For example, (Pettersson, 2010) suggested four cognitive design principles and these are (1) Facilitating attention; (2) Facilitating perception; (3) Facilitating processing and (4) Facilitating memory.

In the field of digital and multimedia learning environments, there has been a great attempt to develop the original CLT (Sweller, 1988) and CTML (Mayer, 2005) models. Recent studies have emphasised the role of various types of cognitive processes and suggested advanced theories; for example,

- affective processes (see the cognitive-affective theory of learning with media (CATLM) (Moreno, (2006);
- motivational processes (see the augmented Cognitive Load Theory (aCLT) (Huk and Ludwigs, 2009);
- metacognitive processes (the Integrated Cognitive Affective Model of Learning with Multimedia (ICALM) (Plass and Kaplan, 2016); and social processes (see the Cognitive-Affective-Social Theory of Learning Environment (CASTLE) (Schneider *et al.*, 2022).

Especially, the CATLM and ICALM models highlight the importance of environmental factors on learners' emotional responses. The CATLM, developed by (Moreno, 2006), is a theoretical framework that underlines the role of both cognitive processes (related to information processing and memory) and affective processes (related to emotions, attitudes, and motivation) in the context of learning with media, such as multimedia presentations or digital learning materials. This theory posits that learning is influenced not only by cognitive factors but also by learners' emotional states, perceptions, and engagement with the learning materials. This

theoretical model suggests that effective instructional design should take into account both cognitive and affective aspects to optimize learning outcomes (Moreno, 2006). From another perspective, another concept can make The Cognitive Affective Theory of Learning with Media easier to apply— perceptual fluency, which is the people's subjective sense of the difficulty in information processing (Oppenheimer, 2008). The impact of this concept on cognitive processes has also been extensively studied. Some researchers have examined perceptual fluency in various disciplines and across 65 different modalities, including and not just visual and auditory. The study found that when stimuli were harder to perceive (for example, fonts are difficult to read, the contrast between text and background, unfamiliar pronunciation, audibly difficult to hear content, *etc.*), it may influence the judgment of the participants on the presented information. They will think that the content is more difficult, time-consuming, less intelligent, more risky or unlikely to be true, and the credibility will be greatly reduced (Reber and Schwarz, 1999；Schwarz, 2004；Song and Schwarz, 2009；Sanchez and Jaeger, 2015). Therefore, the designer of the instructional material must ensure the clarity and attractiveness of their work, to promote the motivation of students to participate and engage with the content.

The ICALM model, developed by Plass and Kaplan's (2016), emphasises the importance of considering learners' emotions, motivations, and attitudes when designing and delivering multimedia-based educational content. It posits that learning with multimedia involves the interplay between cognitive processes (such as attention, perception, memory, and problem-solving) and affective processes (such as motivation, emotion, and engagement). Figure 2.2 illustrates the ICALM model's learning process on how digital media stimuli can be formed as long-term memory.

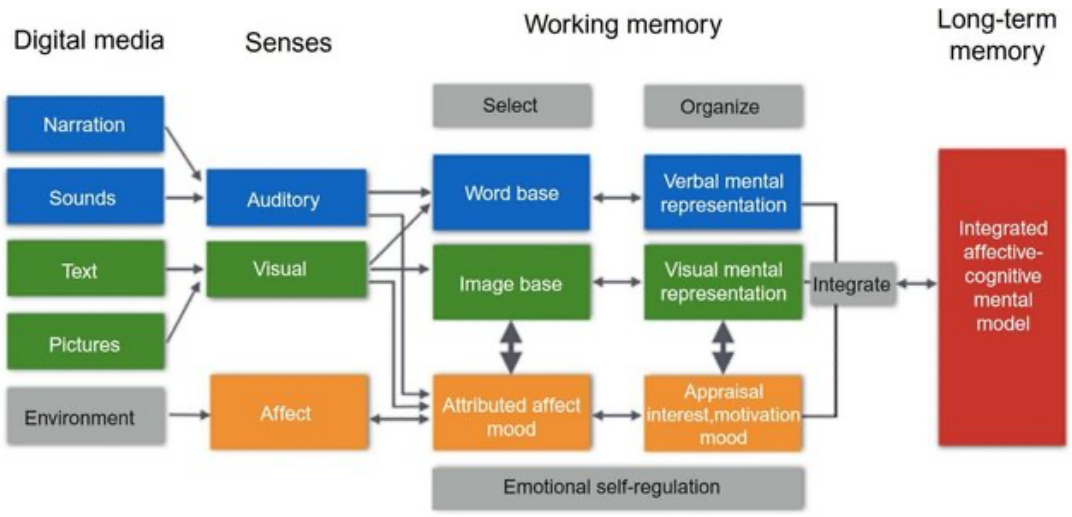



**Figure 2.2** Integrated Cognitive Affective Model of Learning with Multimedia (ICALM), Plass and Kaplan (2016, p.150).

This model suggests that learners' affective states, motivations, and attitudes can impact their cognitive processing of multimedia content. For example, a highly motivated learner and emotionally engaged with the material may allocate more attention and cognitive resources to processing the information, leading to improved comprehension and retention. On the other hand, negative emotions or low motivation might hinder effective cognitive processing. Educators and instructional designers can create more engaging and effective multimedia learning experiences by addressing both cognitive and affective aspects.

The visual sense has a substantial influence over the ultimate outcomes of both working and long-term memory across various dimensions. However, not much evidence exists on the effects of various types of information design elements, for example, colour and typo, on peoples' visual acuity, cognitive processes and learning outcomes.

#### 2.2.1.3 Dual-coding Theory

The Dual Coding Theory (DCT) is a cognitive theory developed by Paivio (1990). It offers an explanation of human behaviour and perception by highlighting the dynamic associations that occur within a complex network of verbal and nonverbal representations, often referred to as imagery. It explains various psychological phenomena by considering the combined functioning of two cognitive systems: one specialized in linguistic information and the other in processing nonverbal imagery. Especially, (Paivio, 2013)

explicitly explained that the verbal code involves processing information in a linguistic or symbolic form, such as words, sentences, and numbers and the imaginal code consists of processing information in a non-verbal, visual, or sensory form, such as mental images, diagrams, and charts. Figure 2.3 presents the verbal and nonverbal symbolic systems of the DCT. It shows the representative units and their referential (between-system) and associative (within-system) interconnections.

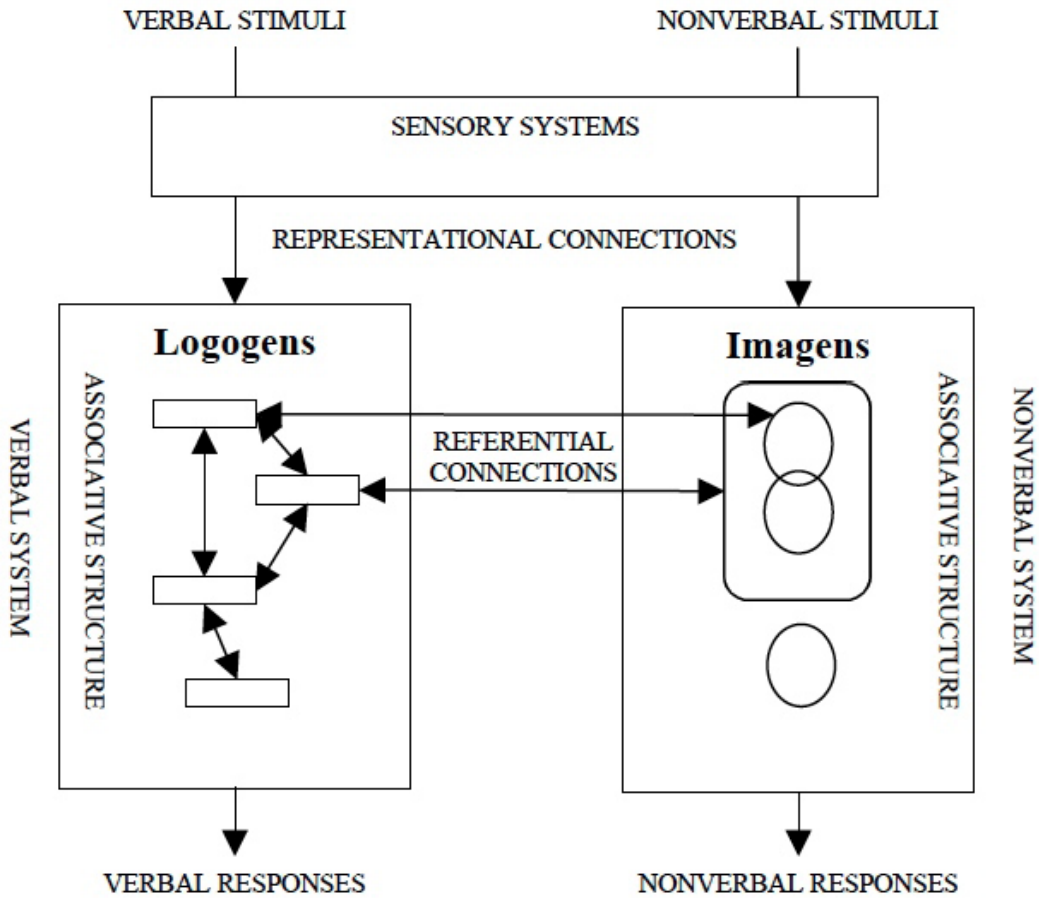



**Figure 2.3** Verbal and nonverbal symbolic systems of Dual Coding Theory.

The theory suggests that when information is presented using both verbal and non-verbal formats, the chances of better comprehension, retention, and recall are increased. The combination of verbal and imaginal encoding is believed to create a more elaborate and interconnected representation of the information in memory, making it easier for individuals to retrieve and apply the knowledge later on.

The theoretical mechanisms of DCT, along with the empirical phenomena associated with them, have implications across multiple domains of human cognition, including emotion, motor skills, and other psychological aspects. Given the wide scope of DCT, it holds the potential to serve as a solid foundation for a comprehensive psychological model of education and contribute to ongoing efforts aimed at explaining cognitive mechanisms underlying educational phenomena (Dillon and Sternberg, 1988). Dual-coding theory has significant implications for education and instructional design. By incorporating both verbal and non-verbal elements in teaching materials, educators can help students better understand and remember the subject matter. For instance, using visual aids, such as diagrams or illustrations, alongside written explanations can enhance students' comprehension and retention of complex concepts. Research findings consistently highlight the importance of concreteness, imagery, and verbal associations in several educational contexts. These contexts include the representation and understanding of knowledge, the acquisition and retention of information in academic settings, effective teaching methods, individual differences in learning, motivation to achieve, test anxiety, and the development of motor skills. The comprehensive nature of DCT allows for a cohesive understanding of diverse topics within the field of education, while its mechanistic framework accommodates theories focused on strategies and other higher-level psychological processes (Clark and Paivio, 1991).

In summary, the dual-coding theory proposes that humans process and store information using two separate but interconnected systems – verbal and non-verbal. By leveraging both types of encoding in learning and communication, individuals can improve their understanding and memory of information. The tangible models provided by the Dual Coding Theory (DCT) contribute to our comprehension of the behaviours and experiences exhibited by students, teachers, and educational psychologists. These models enhance our understanding of various educational phenomena and bolster pedagogical practices in the field.

### 2.2.2 Cognitive Learning Abilities

#### 2.2.2.1 Attention

Attention is the process of deciding what information to keep in working memory and make it available for the current task. It also involves coordinating working memory components and allocating resources based

on needs and goals (Miller, 2014). Attention is the major process by which information enters our consciousness (MacKay, 2012). Attention is also vital to memory. Without attention, learners won't remember much (Miller, 2014). This means that attention is limited, and to a large extent depends on the learner's voluntary control. The attention is directed depends on the way the content is presented and the nature of the content itself (Richey *et al.*, 2010). Therefore, the visual elements of the learning materials in this study are highly dependent on attention. When designing teaching materials, the presentation method selected by online instructors and designers will directly affect the attention of online learners, and in turn, affect the content and quantity stored in their memory. This will ultimately lead to the effectiveness of the content of the learning materials to convey learning outcomes. Some researchers believe that attention and working memory are the same. Although not everyone agrees, it is undeniable that they are highly interconnected and overlapping processes (Engle, 2002； Cowan, 2011).

#### 2.2.2.2 Motivation

Motivation is generally divided into two concepts: intrinsic motivation and external motivation. Intrinsic motivation refers to someone's desire to do something from their interest or needs in the topic or activity. External motivation is the desire to do something due to external rewards or punishments. In general, intrinsic motivation is considered to be superior, and sometimes extrinsic motivation can even affect intrinsic motivation negatively (Deci, 1971). However, many extrinsic motivators can be very powerful. Formerly, Deci and Ryan (2014) proposed Self Determination Theory (SDT) which states that people are motivated the most by the need for three basic psychological needs: competence (being good at something), relatedness (having connections with other people), and autonomy (making their own choices). The SDT presents a continuum of motivation, from extrinsic (only due to a reward or punishment) to intrinsic (purely from enjoyment of the task). Between the extremes, there are different degrees of intrinsic/extrinsic motivation, such as doing something because it will make someone else happy or to fit in a group.

Certainly, instructional design cannot purely change the intrinsic motivation of a learner. However, it can help make the learning activities meaningful and interesting to the learners. Strategically, it can enhance motivation by designing materials that catch and sustain the learners' attention, providing an appropriate degree of control, creating opportunities for success,

ensuring timely and informative feedback, and including social and collaborative learning activities (Wang and Kang, 2006).

#### 2.2.2.3 Memory and Comprehensions

Memory is an indispensable part of any learning mode. Miller (2014, p.88) described memory as "the mechanism by which our teaching changes students' minds and brains" Miller (Miller, 2014, p.88). The three major processes involved in memory are encoding, storage, and retrieval. Working memory is currently one of the most commonly used memory models to explain how people encode and store information. This term is also often mentioned in the cognitive theory of multimedia learning. Long-term memory is closely related to retrieval (recall). This part is also generally regarded as the most challenging in the learning process. The success of retrieval depends on several important factors, one is the form of the content, and the other is whether the information that serves as a starting point can effectively evoke memory (Simionescu, 2020). Generally, information with rich sensory associations should be easier to remember. There are five kinds of human senses: hearing, sight, smell, touch, and taste. In the context of distance education, hearing and vision are directly accessible to learners in the learning process. That means that, apart from audio materials, educational materials with strong visual stimuli have the effect of enhancing the memory of online learners. LeGrand and ElHage's (2013) research can also prove this view, that is, the sense of sight provides more than 80% of the information that the brain receives through the senses. In this research, with this theory as a limit, the main focus is on the visual impact of the information-receiving process in distance education. Ignore the remaining minor factors, such as hearing, emotions, environmental impacts prior experience, *etc.* Because there are many uncontrollable factors, such as the learning environment, it includes the remote virtual learning environment and the physical environment where the learner is located. What can be unified is the online virtual learning environment, and the actual environment is difficult to control as a variable. Different space has different colours, decorations, and even different social environments, such as family members living together, roommates, and even pets. These factors have different effects on people's emotions to a certain extent. Since there is no way to control these variables one by one, this research is limited to a more idealized environment and explores one of its most important influencing factors as an independent variable- visual influence.

The concept of working memory was first proposed by Alan Baddeley (1974). This model describes immediate model describes instant memory as a system composed of sub-components, each of which processes different types of information, such as sound and visual-spatial information. memory as a system composed of sub-components, each of which processes different types of information, such as sound and visual-spatial information. This information is managed uniformly by a mechanism called the central executive. The central executive combines the information from the various sub-components of the working memory and integrates it with the knowledge stored in long-term memory (Baddeley, 1986). This process coincides with the process of learning.

Since these components are independent and limited, the same kind of information will interfere with each other. On the contrary, different types of information will not cause any interference. For example, it was mentioned in Baddeley's (1986) study that visual information interferes with other visual information, but not with another type of information, such as verbal information. This can also explain why more efficient learning materials usually contain more than one type of different information, such as a combination of images and text, and even audio or other types of multimedia in some cases, rather than just a single type of information.

## 2.3 Key Design Elements of Information Design and Instructional Design

Design is a topic that has been widely discussed for more than a decade, and it also plays an important role in many different fields. In the Digital Learning Innovation Trends report, design is defined as "the structuring of the learning environment and interactions"(Joosten *et al.*, 2020, p.23), to some extent, it is complementary to the definition of instructional design, that is, Reiser and Dempsey (2007, p.11) defined instructional design as a "systematic process that is employed to develop education and training programs in a consistent and reliable fashion". Construction and development are the key to design. It can build a bridge of communication between the learning environment, learning content, and learning activities participants. High-quality design can make this process more efficient and give learners a better learning experience.

In other words, the role of design is usually reflected in attending to the course and/or the instruction's design so that students can learn in an organised way. Whether it is digital or physical, the purpose of instructional design is toward an efficient, effective, appealing, engaging and inspiring acquisition of knowledge (Merrill *et al.*, 1996). Several important issues and challenges for teaching successful online courses are related to the interaction among online learners, instructors and content (Kebritchi *et al.*, 2017), to ensure consistency between learning objectives, assessments and activities (Joosten *et al.*, 2020). Among the issues and challenges mentioned above, design cannot solve all the problems. Therefore, in the literature review later, it is necessary to discuss in which aspects the design can play a key role in the process of learning.

The definition of information design can be described in the following ways: "In order to satisfy the information needs of the intended receivers information design comprises analysis, planning, presentation and understanding of a message – its content, language and form. Regardless of the selected medium, a well-designed information set, with its message, will satisfy aesthetic, economic, ergonomic, as well as subject matter requirements" (Pettersson, 2002, p. 19). The main goal of information design is the clarity of communication. To achieve this goal, it is necessary to accurately design, produce and distribute all messages to ensure that the intended audience can correctly interpret and understand the information. These processes are guided by principles, performed with the help of tools, and affected by the social environment (Pettersson, 2010). The term instruction design (InD) is used to integrate related instruction areas and disciplines (Pettersson, 2002). It is based on the confluence of the following disciplines and knowledge: audio-visual instruction, educational technology, instructional design, instructional message design, instructional technology, the technology of instruction and visual literacy. Principles related to information design are basically around four main aspects: text, pictures, colour, and layout. This research focuses on static screen-based educational materials.

### 2.3.1 Fonts (Typography)

Typography has greatly influenced the visual aspect of the text. Williams' (2015b) research recommended that different methods of combining typefaces will result in different effects. Use fonts with similar characteristics to get a calm, formal look; use contrasting design fonts with very different

features to get a more interesting, eye-catching look. However, how to choose the combination of fonts should be judged according to the content and type of design work. For designing instructional materials, it is better to choose fonts with the same characteristics. Private documents may be suitable for the use of more ornate and stylish fonts to highlight the unique aesthetic and character, but professional documentation, like instructional materials, still requires optimum readability. Because dissatisfaction with the execution of the message may also lead to dissatisfaction with the content of the message (Pettersson, 2010). The main three principles are as follows:

*(1) Use typefaces designed for screen display (Sans serif font).*

Dyson's (2011) research also supports the view that suitable typefaces make the readers feel pleased, which will help enhance readability. According to Henestrosa *et al.* (Henestrosa, 2017), different fonts have their characteristics, typefaces can be roughly divided into three categories: serif fonts, sans-serif fonts and display fonts.

The readability of graphic messages is determined by the content and its presentation. The readability of information also relates to the reader's ability to understand the style of text and pictures (Pettersson, 2010). One of the responsibilities of the information designer is to help readers better understand the information. The first step a designer must take is to avoid the use of irrelevant information and any part of the content, which may distract the user's attention from the main goal (Pettersson, 2010). The style depends on many aspects such as the choice of words, consistency, expression, picture elements, symbols and graphic design. This is especially significant to online education.

*(2) Maintain a good contrast between text and background (Use black text on a white or yellow background).*

When two items have opposing features, a contrast occurs. When the designers set the contrast correctly, they determine which part of the design should be regarded as the background and which part must be in the foreground (Tselentis, 2012). The designers have ensured that the content is visible and does not overlap with the background's colour (Lipton, 2011). Low contrast between the element and its background or colour codes might cause problems in understanding the information, especially for those who have visual impairments (Coates, 2014). Contrast is not only related to colour but also the difference between the size of the headings and body

text. The gradation of image size can also inform the viewer of the content hierarchy (Tselentis, 2012； Golombisky and Hagen, 2013).

*(3) Avoid the use of all capital letters.*

Hierarchy is the order and the sequence of information based on its importance. The information must be divided into different levels according to what should be seen in the first, second and third parts. Organising information in this way will help navigation (Schlatter and Levinson, 2013； Coates, 2014). Visual hierarchy can be displayed in many ways by utilising a diversity of sizes, weights of the typeface, colour, placement, space and even graphical elements such as lines and shapes (Coates, 2014； Lupton, 2014). An efficient visual hierarchy can reduce the workload of viewers by organizing content and prioritizing it, allowing them to recognize it immediately (Krug, 2000).

### 2.3.2 Layout

With the development of electronic technology, more and more teaching materials always appear in the eyes of learners in the form of websites, mobile applications or e-learning modules. The design methods of these platforms also mostly follow the principle of reducing unnecessary cognitive burden as much as possible, that is, the less-is-more approach, and maximising generative processing (Mayer and Fiorella, 2014). However, in the design of educational materials, sometimes also add some less relevant visual information. This is also consistent with the signalling principle of multimedia learning and Lowe's (1999； 2003) findings which show that even if the elements appearing in the learning material do not support the task, the learner's attention will be attracted by visually salient elements.

Here are five-step guidelines provided by Krug (2000) to ensure users can effortlessly see and understand what we want them to do. These guidelines are some features that need to be considered in the design of instructional materials.

*(1) Use conventions.*

Using the standardised patterns to see them more easily and quickly and know exactly what to do — For example, related or connected parts are grouped on the page or designed in the same style.

*(2) Create effective visual hierarchies.*

The cues represent the relationship between things on the page — users can judge the importance of the element by its size.

*(3) Separate the content into clearly defined areas.*

If the content is divided into various areas, and each area has its specific purpose. This makes the page easier to parse, and users can quickly find the important information they need.

*(4) Eliminate distractions.*

Too complicated information on the page may frustrate users and affect their ability to perform tasks effectively. Therefore, we need to avoid too many things that are ‘clamouring for your attention’ (Krug, 2000), which is consistent with the coherence principle of multimedia learning (Mayer and Fiorella, 2014) and states that elements that do not support learning objectives should be kept to a minimum and pay attention to avoid clutter. Additionally, proper use of alignment and layout can also make the learning content look neat and organized.

*(5) Format text to support scanning.*

The users usually need to scan the page to find the content they need. This is also very similar in the online learning environment. So when designing instructional materials, we must do some things to achieve this goal: Including many well-written headings, the format difference between headings at different levels should be clear, the appropriate distinction and clarity between the headings and the following text; paragraphs should not be too long and the distance between paragraphs; use bulleted lists; highlight key terms; *etc*.

### 2.2.3 Colour

Williams' (Williams, 2015b) research describes four basic principles that well-designed materials should follow: contrast – contrast should be made through design to make the elements (type, colour, size) have obvious differences to each other, alignment – each item on the page should establish a visual connection with another item to make the content cleaner, organized, and cohesive, repetition –some design elements should be appropriately repeated throughout the material to ensure the consistency and unity of the page and proximity – Related items should be placed side by side to make them as one visual unit. Discussions with the above four

basic principles also include how to use colours and types to enhance readability, improve organization and increase attractiveness (Williams, 2015b). Williams (2015b) also explained how to use the colour wheel to create a pleasant combination and apply certain guidelines about how to use bright colours (some kinds of red or yellow) to moderately highlight things. Malamed (2015) pointed out that colour has the function of improving visual discrimination, working as a signal, enhancing storytelling and evoking emotions, which means it can have a beneficial impact on learning.

The font colour of the learning materials is black, and the contrast with the background colour is guaranteed to reach a higher level to ensure the readability of the learning materials to the greatest extent (Williams, 2015a). And against different colour backgrounds, the black text will be more readable compared to other colours (Richardson *et al.*, 2014).

In the context of images, colours represent a more intricate variable since they serve as supplementary elements to convey information. For images to efficiently communicate information, they must exhibit a strong correlation with textual content (Houts *et al.*, 2006). Consequently, the content of an image often dictates its colour scheme.

This small chapter discusses the potential impact of colour on the learning process from the perspective of well-designed educational materials. However, most guidelines and principles are derived from visual surveys or design experience rather than experimental findings. In the next chapter, there will be a more comprehensive expansion on the various functions of colour in the learning process and the extent of its influence. These discussions will be based on reliable conclusions drawn from experimental data. The chapter will reveal the development and conclusions of colour in several critical areas.

## 2.4 Relationships Between Colour and Cognitive Learning

Human cognition involves many highly interrelated mental processes, such as perception, attention, memory, thinking and understanding (Dzulkifli and Mustafar, 2013). Many studies in this area aim to improve the performance of these cognitive abilities at different levels through different approaches. Among the many influences, colour is a more critical and central element, which usually induces several physical and psychological responses in humans. So colour in the learning and educational environment (Wilkins,

2003；Ludlow and Wilkins, 2009), marketing (Morton, 1995b；Moore *et al.*, 2005；Popa *et al.*, 2013), comminution, and even in the sportswear area (Hill and Barton, 2005；Rowe *et al.*, 2005；Iwase *et al.*, 2012) all these areas are very effective. When linking colour and cognitive learning abilities, most research findings emphasise the functional rather than the aesthetic nature of colour. Efficient cognitive functioning relies on utilizing the cognitive system to its fullest (Dzulkifli and Mustafar, 2013).

A short description can be given from the point of view of colour perception to understand better how colour acts psychologically and physiologically. Firstly, all colours originate from sunlight and are perceived through the theory of subtractive colour. Different wavelengths of light shine on various objects, absorbing or subtracting all coloured light depending on the properties of the object's surface, except for the light reflected from the object. This colour is received by reflection from the cells of the retinal wall of the eye (Morton, 1995a). The cones of the eye define the visible colours. Humans have three types of cones: red, blue and green. These three wavelengths can decipher millions of your colours. About 2-3% of females and some animals have at least four cones, dramatically increasing colour differentiation For example, two relatively similar colours may be complex for a person with normal vision (with three cones) to see the difference between the two colours. However, people with four cones have a more sensitive colour perception than ordinary people and can detect subtle differences between similar colours more easily. The receptor cells take up the hue and send the information to the brain, where the colour is deciphered. Brain impulses are also sent to the main endocrine regulatory glands, causing emotional and psychological responses (Nielson, 2007).

As the effect of colour on people is emotional and psychological, sometimes, the role of colour is subconscious and perhaps not as apparent as it could be. Still, its role cannot be ignored in many aspects. The well-executed colour can enhance the absorption of information and facilitate the thinking process, even impacting student behaviour has been proved in many previous studies. This section will focus on the relationship between colour and cognitive learning abilities in the following subsections. The four primary areas of interest for literary review are colour and attention, colour and readability, colour and memory, and colour in the learning environment. The former study was used to determine the importance of colour in the cognitive-related area and to lay the theoretical foundation for the subsequent experimental design.

### 2.4.1 Colour and Attention

Attention is the cognitive process of selecting information available in the environment, and the effect of colour on changes in mood and attention is a psychological response (Engelbrecht, 2003). Some colour reactions are temporary, others can last a long time, and many are immediate (Morton, 1998), just like attention. Verghese (2001) has discussed the process of visual search and attention from the perspective of signal detection theory. This theory states that the human brain constantly struggles to organise visual information. Too much colour, movement or pattern functions as a mere distraction, making visual search more difficult. Some researchers, such as Kennedy (2005), believe and prove that colour stimulation in the learning environment can improve attention and motor processes and thus improve academic performance. Because monotonous environments can cause irritability, excessive emotional reactions, difficulty concentrating and negative emotions such as irritability, which can lead to people being less effective in this environment (Engelbrecht, 2003).

Earlier studies have experimented with the effects of colour on attention. Farley and Grant (1976) found that colourful multimedia presentations led to increased levels of attention and memory. Some experiments and studies similar to this (Smilek *et al.*, 2002； Spence *et al.*, 2006； Pan, 2010), are all indirectly and directly confirm the influence of colour on human cognitive processes (Pan, 2010). Attention is often the first element, followed by memorisation and comprehension. Because colour can influence the level of attention, it can also cause emotional arousal, which helps to control the process and thus improves memory (Farley and Grant, 1976； Pan, 2010). In summary, information that people pay more attention to will be remembered more readily than information that they ignore or do not pay attention to, and the performance of attention in improving memory levels has even been quantified in studies by some researchers in terms of increased recall rates (Smilek *et al.*, 2002； Pan, 2010) and accelerated response times (MacKay and Ahmetzanov, 2005) to objectively represent the extent to which memory is optimised by attention from different dimensions. Greene *et al*. (1983), their study explains in more detail the extent to which colours have a greater impact on memory, concluding that warm colours such as yellow, red and orange have a greater impact on attention than cooler colours such as brown and grey.

In other studies on working memory and visual attention, researchers have conducted comparative experiments on the shape and colour of objects

under equivalent conditions (Pan, 2009). In the first set of experiments, the two objects were the same colour but different shapes. In the second set of experiments, the conditions were the opposite of the first set, i.e. the objects had the same shape but different colours. The results showed that in both experimental conditions, participants had faster reaction times to recognise colour differences compared to differences in object shape. This finding can be indirectly explained by the fact that colour has a better and more robust ability to attract attention than other variables. Pan (2010) used visual geometries with various colours in their subsequent extended study. A total of 22 participants were asked to memorise the object's shape and colour. Participants were then asked to identify the colour and shape of the previously presented items. The final results were in high agreement with the results of his previous experiments, with participants performing significantly better at identifying objects' colour than at identifying objects' shape. Once again, colour has been proven to have a stronger attention-getting effect than shape. The relationship between colour and attention holds the promise of further development, with the use of colour maximising the generation of higher attention and thus effectively improving memory performance.

### 2.4.2 Colour and Memory

Memory generally refers to the mental process of encoding, retaining and retrieving information about the environment (Radvansky, 2015). Colour is considered one of the most important visual experiences for humans. It acts as a powerful information channel in the human cognitive system and has been shown to play an essential role in improving memory. Colour helps us to remember certain information by increasing our level of concentration. As mentioned in the previous sub-section, colour has the potential to attract attention (MacKay and Ahmetzanov, 2005； Pan, 2010). The more attention is focused on certain stimuli, the more likely they will be transferred to a more permanent memory store, i.e. long-term memory (Sternberg, 1996).

Studies related to memory also refer to arousal, particularly emotional arousal, because of its essential role in retaining information in the memory system. Colour can also strengthen the relationship between arousal and memory; Naz and Helen's (2004) study found a link between these three. They collected data from 98 university student volunteers from public institutions to investigate the association between colour and mood. The results demonstrate that most participants associate certain colours with specific sensations and have certain commonalities. This finding means that

colour has an evocative effect on emotions. However, it is worth noting that the degree of arousal may vary depending on the type of emotion or feeling (Naz and Helen, 2004). A similar result is corroborated by other researchers' work (Jackson *et al.*, 2009); their findings also confirm that certain types of emotions may have a more significant impact on arousal than others. For example, anger has been found to have a more significant arousing effect than happy or neutral emotions. Alternatively, red is imbued with stronger emotion or feeling than other colours. The relationship between arousal, colour and memory can be summarised as follows: colour can produce an emotional arousal effect, but the degree or extent of arousal depends on the particular type of colour and the different emotional factors.

While most research findings about colour and memory performance demonstrate the positive effects of colour on memory, a few studies have found conflicting results. Lloyd-Jones and Nakabayashi (2009) conducted a study on the effects of colour on object recognition and memory. They found that the object-colour spatial integration and spatial separation made a difference in the participants' memory performance. A total of 213 undergraduate students, all non-colour blind, were recruited for the study. Seventy-five coloured ordinary objects were used as stimuli, each with three colour conditions: correctly coloured (object and its original colour), incorrectly coloured (object without its actual colour) and a greyscale condition. Tests were conducted in two experimental conditions, one with object-colour space integration, where coloured objects were placed on a grey background. The other was object-colour space separation, in which grey objects were placed on a coloured background. Participants were asked to judge whether the object colour was correct, and the corresponding reaction speed was recorded. The conclusions showed that coloured objects with a non-coloured background had better memory retention and produced faster reaction times compared to coloured objects with a coloured background.

The findings of another study demonstrate that colour has no positive effect on memory retention. Hall and Hanna (2004) conducted a study with 136 university students to explore the impact of different text and background colour combinations on memory retention. Participants viewed educational and commercial websites with four colour combinations: black on white, white on black, light blue on dark blue, and teal on black. After assessing readability, retention, aesthetics, and behavioural intention, the researchers found that the black-on-white background condition had the highest

readability performance due to its high contrast. However, the contrast of colour combinations did not significantly affect memory or retention rates, indicating that colour contrast primarily influenced readability rather than memory retention.

In addition to textual information, the researchers have also used alphanumeric characters as information carriers to test whether colour has a positive effect on memory. In a study conducted by McConnohie (1999), participants were shown alphanumeric characters through a slideshow with three different background colours: white, blue, and green. The expectation was that if colours positively affected memory, performance would be the same across these conditions. Surprisingly, the results showed that slides with a white background had higher retention rates in immediate and delayed recall tasks than those with blue and green backgrounds. This finding contradicts previous studies suggesting that only specific colours improve memory. However, it is essential to note that the particular colours were chosen, and the manipulation of figure and background colours in this study may explain the obtained results.

Memory research suggests that colour plays a significant role in enhancing memory abilities. Colours have the potential to increase the successful encoding, storage, and retrieval of environmental stimuli. However, the choice of colours and manipulative factors can impact the extent to which they influence human memory performance (Dzulkifli and Mustafar, 2013).

### 2.4.3 Colour and Readability, Legibility and Preference

Readability is also a factor highly associated with colour and plays a significant role in the experimental design part of this study. A significant amount of research on the readability of text on computer screens was conducted before the existence of the World Wide Web. However, there are several limitations in applying these research findings to the current digital environment. Due to early technological constraints, such studies were conducted on displays with poor performance in terms of brightness and contrast. Yet, brightness and contrast are crucial factors in determining the effectiveness of font/background colour combinations (Bouma, 1980). Furthermore, early comparative experiments on readability primarily focused on the differences between paper-based materials and screen-based text. Apart from the manufacturing technology limitations of computer screens at that time, there were also acceptance issues regarding reading text on

computer screens. Most experimental results indicated that people generally perceived paper-based text to be more readable than text displayed on computer screens (Mills and Weldon, 1987).

Regarding readability, one aspect must be considered: the appropriateness of the colours or colour combinations used in the background and foreground. Because the right colour combination is essential, it directly impacts contrast, and higher contrast can effectively influence memory retention. Hall and Hanna (2004) stated higher contrast ratio might refer to the hue of colour (the wavelength) and luminance (brightness of the colour). However, it is predicted that higher contrast levels will result in better visibility of objects or information, and the visibility of textual information can also be referred to as legibility. A higher contrast level attracts more attention and thus positively affects memory. Similarly, using a white background and black foreground has better contrast and positively affects both short-term and long-term memory retention (McConnohie, 1999). However, in research on text-background colour combinations, many studies have failed to determine which colour combinations are the most readable with the highest legibility effect. Peace's (1984) study, for instance, utilised 24 different colour combinations and found no significant differences in performance in a text search task. Shieh and Lin (2000) conducted a study comparing the effects of 12 different colour combinations on participants' performance in basic visual recognition tasks. In addition to colour combinations, they also considered screen type (LCD or CRT) and environmental lighting. The results showed that colour combinations had a greater impact on performance than other factors, highlighting the importance of colour combinations. Their study also included subjective preference measurements for colour combinations, and the surprising findings regarding colour combination preferences were consistent with the readability results.

For the choice of foreground and background colours, several web design guidelines often include advice on appropriate colour combinations, and high contrast between text and background is repeatedly mentioned, with particular emphasis on the traditional black text on a white background. As Jakob Nielsen (2000) recommended, colours with a strong contrast between the text and background for optimal legibility. The best legibility is achieved with black text on a white background (referred to as positive text). White text on a black background (negative text) is also effective, although it may slightly slow down reading due to the inverted colour scheme. Legibility significantly decreases when the text is lighter than pure black or if the

background is darker than pure white. In summary, regardless of the specific colour combination, higher contrast generally leads to higher readability.

However, recent studies have also indicated inconsistent findings regarding the readability of font/background colour combinations. Two main reasons can be observed for these inconsistencies. Firstly, confusion arises from the mixing of hue contrast and luminance contrast (Hall and Hanna, 2004). Secondly, there is confusion regarding the concepts of readability and legibility.

Hue refers to the dimension of colour that is typically associated with the wavelength of light, while luminance refers to the intensity or "brightness" of a colour, which is determined by the wave height. Colours differ not only in hue but also in luminance. This distinction can be easily understood from the conclusions of Lin's (2003) experiments. A series of three experiments were conducted, where chromatic (non-black and white) colours were presented on a grey background, systematically varying the brightness of the colours. In most cases, reading performance could be explained by luminance contrast rather than hue. The only exception was at very low levels of luminance contrast, where purple and cyan performed better than yellow, despite similar luminance contrast between the colours and the background.

There is a slight difference in the definitions of readability and legibility. Still, they are both essentially used to describe how easy it is to read individual characters or paragraphs for the reader to access information. Readability is focused on how easy it is to read and understand large passages of text. Legibility is the recognition of individual characters, not whole words or paragraphs (Ellison and Coates, 2014).

Furthermore, the function of colour is not just to maximise readability but to ensure readability and legibility with potential effects on the physiological and psychological aspects of the user. This study focuses on the impact of colour on the comprehension of learners.

It has been shown that colour preference influences decision-making to a large extent and that colour preferences are differentiated in a specific order (Yu *et al.*, 2021). In Hall and Hanna's study (2004), preferred colours (i.e. blue and colours with high chroma) led to higher ratings of aesthetic quality and purchase intention, and consumers' ratings of and aesthetic quality were significantly associated with purchase intention. In the same year, Naz and Helen’s (2004) study results demonstrate that the emotional response to colour is heavily influenced by personal preference and past experiences

with that specific colour. Colour preferences vary across different societies because colour symbolism differs in various cultures (Saito, 1996), even though there is some commonality in certain colour (white) preferences among the neighbouring Asian regions, there are indeed statistically significant differences in colour preferences for certain hues and tones. The reasons provided for these preferences suggested that, in addition to age and gender, associative images rooted in environmental and cultural factors could play a significant role in influencing colour preference.

Since colour can play a role and influence decision-making, purchase intention and colour-emotion associations to a certain extent, another issue is raised. Colour has been proven many times in exploring the potential influence on learners' attention and memory during the learning process. But it is also uncertain whether there are any effects on the deeper and more complex aspects of comprehension, regardless of whether these effects are positive or negative. One of the aims of this study is to investigate whether learners' comprehension may be influenced to different extents in the context of their preferred colours. Whether they can achieve higher learning efficiency and a better understanding of textual information under their preferred colour conditions is one of the research questions that this study aims to explore.

### 2.4.4 Colour and Learning Environment

Much of the research has attempted to identify key design elements that optimise student performance and behaviour (Rigolon and Alloway, 2011). Some of the more important and repeatedly mentioned design elements are lighting, colour and geometry (Fajardo *et al.*, 2023). Colour is important in designing functional learning spaces as it is a powerful design element that can create profound psychological and physiological responses (Gaines and Curry, 2011). When colour travels through the eyes, the brain releases a hormone that affects mood, mental clarity and energy levels (Engelbrecht, 2003). Interestingly, the effect of colour is not limited to the visual aspect, as the wavelengths of colour are also absorbed by the skin (Torrice and Logrippo, 1989). Other studies have also shown that changes in environmental colour can lead to lower blood pressure and less aggressive behaviour in blind and sighted children (Wolfarth and Sam, 1982). However, it is uncertain whether this finding also applies to changes in the colour of the virtual learning environment. The so-called digital learning environment is the size of the screen within the visual range of the learner. Its size is

certainly not as large as the impact of changes in the physical environment. Therefore, this study aims to find out whether, in the context of a virtual learning environment, colour has any effect on digital learners. If so, to what extent and whether there is any positive or negative effect on a particular cognitive ability, such as comprehension.

The theoretical basis of the environment as an essential influence in the learning process, as explained in the context of the study in Chapter 1, coincides. Learning is an important part of human behaviour. When people interact with information from the outside world, they also unconsciously receive information, including the emotional and psychological information conveyed by colour. When we pay attention to certain information, we select and focus on a certain amount of information to be processed in our cognitive system. The degree of attention to certain stimuli increases the likelihood that this information will be stored in memory (Heuer and Reisberg, 1992； MacKay and Ahmetzanov, 2005). The stimulus in this study is specifically the colour. According to Mahnke's theory (1996), students' preferences for colour are age-related, and there are some basic guidelines to follow. Colours can be classified according to temperature, with half of the colour wheel being classified as warm and the other half as cool. The visual temperature may also be influenced by intensity (Nielson, 2007). Generally, preschool and primary school students prefer warm colours (red/orange/yellow). However, secondary and high school students prefer the cooler shades of the colour wheel (blue/green/violet) (Engelbrecht, 2003). However, there is no clear evidence of the colour preferences of the higher education population. But many studies show a significant relationship between colour preference, mood and student achievement (Karp and Karp, 1988； Boyatzis and Varghese, 1994； Terwogt and Hoeksma, 1995). The reasons that lead to people’s preference for a particular colour are complex, and preferences are constantly changing. Possible influences include personal aesthetics of colour but also the presence of certain social factors, with trends and colours varying from era to era. Some studies have also concluded that there is a general pattern of colour preference based on personality; as an example, Torrice and Logrippo (1989) findings show that active children prefer cool colours, while passive children feel more comfortable surrounded by warm colours. It is also important to consider the amount of colour when designing a physical learning environment. Regardless of colour temperature or learner preference, many colours can overstimulate an individual (Gaines and Curry, 2011), just like information overload. To prevent over-stimulation, some

researchers (Stokes, 2001； Myler *et al.*, 2003) suggest an understated colour palette of warm neutrals. They encourage low contrast in wall and floor colours. More specific recommendations also include Engelbrecht's (2003) finding that painting the walls that students focus on when they look up from their work in a medium shade will ease eye strain, while the rest of the walls should be a warm beige or tan colour. It can be seen that the colour choice of the wall facing the student in the learning environment is more critical, as is the colour of the background of the screen that the student is directly facing in the digital learning environment. Still, the medium hue is more general and has no exact colour preference, i.e. a more detailed hue value. And is it still possible to follow this finding for the screen background colour in the virtual learning environment. The background colour of the digital environment is displayed on an electronic screen and has the property of being luminous. Even if the same colour is applied to the wall of the physical environment and displayed on a computer screen, the human perception of the colour should be somewhat different due to the difference in medium. Whether that is consistent remains to be seen.

Gender differentiation is also a significant influence that needs to be considered in studies related to colour preference. Researchers at the University of Texas at Austin, USA, Kwallek *et al.* (1996), their study then chose nine different colours (red, white, green, orange, yellow, blue, beige, grey, and purple), painting all four walls and doors of the test space with the chosen colour. The 675 students were assessed separately regarding task performance, mood and colour preference. The final results revealed significant differences in colour preferences between genders. The downbeat mood changes induced by different colours, such as depression, confusion and anger, were also quite different between the gender groups. However, there was no strong link between colour preference and task performance, and although participants claimed to prefer beige or white for work and study spaces, they did not perform as well as in blue and red environments. (Kwallek *et al.*, 1996).

Table 2.1 provides an overall view of the list of 26 peer-reviewed papers on the topic of colour and cognitive performance used as references in this chapter, highlighting the selection criteria for participants have been grouped into the following five categories, which are: A_ Gender B_ Age C_ Educational level D_ Colour vision E_ Region/ Country. Among the 26 academic articles examined, only 7 articles explicitly mentioned the geographical regions or countries from which the participants were recruited.

Due to the complexity of age distribution among participants, there were considerations when establishing selection criteria. For adult participants, even if they were affiliated with the same university or college, determining their nationality and ensuring consistent native language and cultural backgrounds was challenging, given the internationalization trend in higher education. However, in some studies, participants from the same region were recruited from middle schools or primary schools, and it was assumed that these participants shared consistent native language and cultural backgrounds, considering the fundamental attributes of education at this stage.

It is worth noting that in studies related to colour and education, participant characteristics such as gender, age, education level, and visual abilities were often considered more important than the participants' native language and cultural backgrounds, depending on the specific research focus. Nonetheless, the ability of participants to receive and comprehend textual information is crucial for the progress of any study relating to memory of textual information, comprehension of study materials or test items, or understanding of informed consent forms and experimental procedures.

**Table 2.1** The list of 26 peer-reviewed papers on the topic of colour and cognitive performance, highlighting the selection criteria for participants (A_ Gender B_ Age C_ Educational level D_ Colour vision E_ Region/ Country).

| Authors | Title | Participants | Categories |
|---|---|---|---|
| (Farley and Grant, 1976) | Arousal and Cognition: Memory for Color Versus Black and White Multimedia Presentation | > 52 undergraduate nursing students<br>> 50 females, 2 males<br>> Age 19-25 years old | A, B, C |
| (Wolfarth and Sam, 1982) | The effects of color psychodynamic environment modification upon psycho-physiological and behavioral reactions of severely handicapped children | >14 severely behaviorally disordered blind and nonvisually handicapped<br>> 8-11 yeaes old | B, D |
| (Greene et al., 1983) | Coloring the environment: Hue, arousal, and boredom | >140 undergraduate psychology students<br>> 70 males, 70 females | A, C |
| (Pace, 1984) | Color Combinations and Contrast Reversals on Visual Display Units | > 18 females and 18 males | A |
| (Karp and Karp, 1988) | Color Associations of Male and Female Fourth-Grade School Children | > 85 fourth-grade students<br>> Two classes of female and two classes of male students<br>> Age of 9 or 10 years | A, B, C |
| (Boyatzis and Varghese, 1994) | Children's Emotional Associations with Colors | > 60 children (preschool, kindergarten, first-grade class)<br>> 30 girls, 30 boys<br>> Two age groups, 4- to 5-year-olds and 6- to 7-year-olds<br>> Predominantly White and middle class | A, B, C, E |
| (Terwogt and Hoeksma, 1995) | Colors and Emotions: Preferences and Combinations | > 72 participants in three age groups, youngsters were 7.3 years (range = 6.7-7.8) and 11.2 years (range = 10.5-12.0), the adult group was about 30 years (range = 20-56).<br>> Both sexes were equally represented in the three groups. | A, B |
| (Kwallek et al., 1996) | Effects of nine monochromatic office interior colors on clerical tasks and worker mood | > 675 Introductory Psychology students<br>> 341 males and 334 females<br>> The mean age of the subjects was 18.89 years, ranged from 16-37.<br>> No color- blind individuals<br>> 74% Caucasian, 10.8% Spanish-American, 8.6% Asian, 5.0% African American, and 1.2% were un- specified. | A, B, C, D, E |

| | | | |
|---|---|---|---|
| (Saito, 1996) | Comparative Studies on Color Preference in Japan and Other Asian Regions, with Special Emphasis on the Preference for White | > Each sample population contained 400 subjects (Japanese, Korean and Taiwanese)<br>> 803 males and 797 females<br>> 193 subjects ( 12.1%) were in the age range of 15-19 years, 364 (22.8% ) in the age range of 20-29 years, 384 (24.0% ) in the age range of 30-39 years, 367 (23.0%) in the age range of 40-49 years, and 292 ( 18.3%) in the age range of 50-59 years. | A, B, E |
| (McConnohie, 1999) | A Study of the Effect of Colour in Memory Retention When Used in Presentation Software | > 28 public school students<br>> 8 boys and 20 girls<br>> Ages varied from approximately 11 to 14 years<br>> Subjects were no color-blindness.<br>> Students were from a rural, mountainous area of Appalachia. | A, B, C, D, E |
| (Shieh and Lin, 2000) | Effects of screen type, ambient illumination, and color combination on VDT visual performance and subjective preference | > 48 college students<br>> Subjects were all male<br>> All had 0.8 corrected visual acuity or better and normal color vision. | A, C, D |
| (Smilek et al., 2002) | Synesthetic Color Experiences Influence Memory | > C and 7 non-synesthetes who were undergraduate students<br>> Both C and the nonsynesthetes had normal or corrected-to-normal vision. | C, D |
| (Lin, 2003) | Effects of contrast ratio and text color on visual performance with TFT-LCD | > 20 college students<br>> 10 males and 10 females<br>> All had 0.8 corrected visual acuity or better and normal color vision. | A, D |
| (Hall and Hanna, 2004) | The impact of web page text-background colour combinations on readability, retention, aesthetics and behavioural intention | > 136 university students | C |
| (Naz and Helen, 2004) | Color-emotion associations: Past experience and personal preference | > 98 volunteered college students<br>> 44 men and 54 women | A, C |
| (MacKay and Ahmetzanov, 2005) | Emotion, Memory, and Attention in the Taboo Stroop Paradigm: An Experimental Analogue of Flashbulb Memories | > 72 undergraduates | C |
| (Moore et al., 2005) | Banner advertiser-web site context congruity and color effects on attention and attitudes | > 195 undergraduate students in Study 1, 90 undergraduate students in Study 2<br>> Age range from 18 to 30, with a median age of 21<br>> Slightly more males (56%) than females (44%) | A, B, C |
| (Spence et al., 2006) | How Color Enhances Visual Memory for Natural Scenes | > 120 participants had normal color vision | D |
| (Lloyd-Jones and Nakabayashi, 2009) | Independent effects of colour on object identification and memory | > 213 undergraduate students<br>> All had normal or corrected-to-normal visual acuity, and none were colour-blind. | C, D |

| | | | |
|---|---|---|---|
| (Elliot et al., 2011) | A subtle threat cue, heart rate variability, and cognitive performance | > 33 students (30 men, 3 women)<br>> ages 18–35 years (M = 23.0)<br>> not red–green or blue–yellow color deficient | A, B, D |
| (Elliot and Aarts, 2011) | Perception of the color red enhances the force and velocity of motor output | Experiment 1:<br>> 30 4th through 10th grade students<br>> mean age = 13.00 years, range 10–16<br>> 20 female, 10 males<br>Experiment 2:<br>> 46 undergaduates<br>> mean age = 21.52 years, range 18 –31<br>> 32 females, 14 males | A, B, C |
| (Brooker and Franklin, 2016) | The effect of colour on children's cognitive performance | > 359 children from the East Sussex and Kent regions<br>> 156 8-year-olds (88 female), 149 9-year-olds (74 female)<br>> mean age = 8.47 year | A, B, C, E |
| (Duan et al., 2018a) | The influence of color on impulsiveness and arousal: Part 1 – Hue | > 27 university students<br>> 14 females and 13 males<br>> Age between 20 to 38<br>> All participants had normal color vision<br>> All subjects were Chinese | A, B, C, D, E |
| (Duan et al., 2018b) | The influence of color on impulsiveness and arousal: Part 2 – Chroma | > 28 university students<br>> 14 females and 14 males<br>> Age between 20 to 38<br>> All participants had normal color vision<br>> All subjects were Chinese | A, B, C, D, E |
| (Yu et al., 2021) | Analysis of experiments to determine individual colour preference | Online survey<br>> 173 participants were university students or staff<br>> 62 males, 111 females<br>Laboratory Experiment I<br>> 37 participants were university students or staff<br>> 18 males, 19 females<br>Laboratory Experiment II<br>> 85 participants were university students or staff<br>> 42 males, 43 females | A, C |
| (Fajardo et al., 2023) | Lighting, colour and geometry: Which has the greatest influence on students' cognitive processes? | > 200 subjects were all students<br>> 100 male and 100 female<br>> Average age 23.34 years<br>> Not having visual acuity and field problems | A, B, C, D |

## 2.5 Conclusions

This chapter has provided a comprehensive literature review on the learning process, exploring existing learning theories, cognitive learning abilities/processes, and key design elements in information and instructional design. The relationships between colour and cognitive learning abilities/processes have also been examined.

First, the review of existing learning theories, including the Cognitive Load Theory, Multimedia Learning and the Cognitive Theory of Multimedia Learning, and the Cognitive Affective Theory of Learning with Media and Dual-coding theory, has highlighted the importance of optimising instructional design to enhance cognitive load management, leverage multimedia elements, and consider affective factors in learning. These theories have laid the foundation for understanding the underlying mechanisms of the learning process and provided valuable insights for instructional design practitioners. Second, the exploration of cognitive learning abilities/processes, such as attention and motivation, and memory and comprehension, has emphasized the significance of these cognitive processes in the acquisition and retention of knowledge. Understanding how learners direct their attention, sustain motivation, encode, store, retrieve information, and construct meaning from instructional materials is essential for designing effective learning experiences. Third, the examination of key design elements, including fonts (typography), layout, and colour, has shed light on their impact on information and instructional design. The choice of fonts affects readability, legibility, and user experience, while layout design principles guide the arrangement of visual elements to facilitate information processing and comprehension. The use of colour has been shown to have psychological and emotional effects, influencing attention, memory, readability, legibility, preference, and the overall learning environment. Lastly, the relationships between colour and cognitive learning abilities/processes have been explored, demonstrating how colour choices can influence learners' attention, memory, readability, and the learning environment. Understanding these relationships can help designers make informed decisions when selecting colour schemes and combinations in instructional materials.

In summary, this chapter has provided a comprehensive review of the learning process, incorporating existing learning theories, cognitive learning abilities/processes, and key design elements. The examination of the

relationships between colour and cognitive learning has offered insights into the potential impact of colour choices on learners' cognitive processes and learning outcomes. It serves as a valuable foundation for the subsequent chapters, informing further analysis and contributing to the understanding and practical application of effective instructional design principles in educational settings.

# Chapter 3
# Research Methods

## 3.1 Introduction

In the ever-evolving landscape of virtual education, the design of digital learning materials holds immense potential to shape the learning experience for contemporary higher education students. One crucial aspect of this design lies in the choice of background colour, which has been recognised as a significant factor influencing learners' comprehension abilities. To delve deeper into this realm, our research seeks to explore the impact of different background colours on learners' comprehension abilities within the contemporary virtual learning context.

To accomplish this, our research design adopts a comprehensive approach, encompassing both qualitative and quantitative methodologies, along with three distinct components: online focus groups, online questionnaires, and psychometric tests. Each component is specifically aligned with corresponding research questions and objectives to achieve a comprehensive understanding of the topic.

Research Question 2 and Objective 2 will be addressed through the utilization of online focus groups. By engaging with target learners in virtual learning environments, we aim to gain valuable insights into their experiences, preferences, and expectations regarding digital learning materials. These online focus groups will offer us in-depth perspectives that can guide the design and development of learner-centric virtual learning resources.

To address Research Question 3 and Objective 3, we will employ online questionnaires. By gathering the preferences of contemporary learners concerning the colour design of digital materials, we aim to identify the most suitable background colour, particularly from the perspective of our target audience. The data collected through these questionnaires will provide quantitative insights into the learners' colour preferences and inform our subsequent experimental design.

Finally, to resolve Research Question 4 and Objective 4, we will conduct psychometric tests as part of the main experiment. These tests will enable us to evaluate the learners' text-based information comprehension abilities while exposed to different background colours. The psychometric test results

will be analysed quantitatively to ascertain the colour that offers the best performance in terms of enhancing learners' comprehension abilities.

Through this multi-faceted research design, we endeavour to contribute valuable knowledge to the field of digital learning design. By examining the impact of background colours on learners' comprehension abilities, our study seeks to provide practical insights to educators and instructional designers, facilitating the creation of effective digital educational materials that optimize the learning experience for higher education students in the contemporary virtual learning era.

## 3.2 Research Design

### 3.2.1 Qualitative and Quantitative Approaches

In research, different strategies are employed to gather and analyse data. Two commonly used approaches are qualitative and quantitative research. These approaches provide distinct ways of studying phenomena and offer unique insights into research questions. Qualitative research is concerned with understanding the complexities and nuances of human experiences, behaviours, and social phenomena (Ormston *et al.*, 2014). It involves exploring subjective meanings, beliefs, attitudes, and motivations through methods such as interviews, observations, focus groups, and analysis of textual or visual data (Wolff *et al.*, 2019). Qualitative research emphasizes context, interpretation, and the exploration of individual perspectives (Cope, 2014). It allows researchers to gain a deep understanding of phenomena, generate new theories, and capture rich, detailed data. However, qualitative research may be subjective and less generalizable due to its focus on specific cases or contexts (Hollstein, 2011). Quantitative research, on the other hand, focuses on the measurement, analysis, and interpretation of numerical data. It aims to identify patterns, relationships, and trends in variables by employing statistical and mathematical techniques (Williams, 2007). Quantitative research involves the collection of structured data through methods such as surveys, experiments, or observations with predefined categories (Hox and Boeije, 2005). It allows for statistical analysis and generalization of findings to larger populations. Quantitative research is valued for its objectivity, replicability, and ability to provide precise and measurable results. However, it may overlook the complexity and rich context of human experiences that qualitative research can capture

(Queirós *et al.*, 2017). Researchers often choose between qualitative and quantitative approaches based on their research questions, the nature of the phenomenon under investigation, and the available resources. In some cases, a mixed-methods approach, which combines both qualitative and quantitative methods, may be employed to gain a more comprehensive understanding of the research topic (Lund, 2012). The choice of research strategy depends on the goals of the study, the type of data needed, and the strengths and limitations of each approach (Halcomb and Hickman, 2015).

### 3.2.1 Focus Group

First, the focus group research method originated in sociology (Merton and Kendall, 1946). In recent years, it has been mainly applied in two fields, one in the field of market research and is increasingly used as a research tool in the social sciences (Templeton, 1987), the focus group has been widely used in research especially

The domain to which this research belongs is in the category of social sciences, and a focus group is an appropriate choice. According to Hughes and DuMont (1993, p.776), they describe focus groups as group interviews ‘Focus groups are in-depth group interviews employing relatively homogenous groups to provide information around topics specified by the researchers’. Therefore, if researchers want to get more in-depth views and opinions on a specific topic from a specific group of people, focus groups are suitable. According to Kitzinger's (1995, p.299) research, interactions within groups also generate a specific type of data. Ideally, some participants’ comments will inspire and influence the thinking and sharing of other participants, triggering deeper thinking about the topic. Some participants even change their minds and perspectives in the process (Eliot, 2007). This special group interaction also leads to the essential difference between focus groups and one-on-one interviews. Moreover, in the context of this research, the online learning experience is a kind of subjective feeling and impression, and a qualitative approach with the majority of open-ended questions may be more appropriate than a quantitative approach. Because it is difficult for researchers to accurately and comprehensively describe the different experiences and feelings of all people in a given population. Apart from the semi-structured interview, the focus group method is by far the best option for this research.

In this section the researcher expects to use focused groups to discover contemporary higher education students' experiences of distance learning, the following are serval goals would be achieved:

(1) To make a reliable discussion between groups of people, obtain deeper opinions and perspectives about the online education experience.

(2) To know about the actual behaviours of higher education groups in the virtual learning context.

(3) To understand recent changes/developments that have occurred over time in the distance education domain and people's acceptance of these changes.

The focus group method was chosen to collect primary data before collecting quantitative data not only the reasons described at the beginning of this section but also a similar case study published in Studies in Higher Education (Breen *et al.*, 2001) that aims to inform university policy on the provision of IT resources. A key attribute of the focus-group methodology is mentioned within this study, an important purpose of pedagogic research: to generate recommendations for designing future changes and improvements in student learning (Breen *et al.*, 2001). There are many similarities between this study and the present study. There are many similarities between this study and the present study. Firstly, the target groups were both higher education populations. Secondly, the themes of the studies are both related to teaching and learning research, but in different contexts. The last point is that both studies focus on the cognitive learning experience of the students. It is also expected that new ideas will emerge from the focus-group discussion and contribute to the subsequent research.

#### 3.3.1.1 Sampling

In the pursuit of a comprehensive study on online education, the researcher established specific participant inclusion/exclusion criteria to ensure the integrity and diversity of the data. Four criteria were applied and there are:

(1) Homogeneous Strangers: Participants were required to be strangers to one another to create a level playing field and reduce potential inhibitions during the study (Eliot, 2007).

(2) Experience in Online Education: Participants needed to possess prior experience with online education to provide valuable insights.

(3) Higher Education Background: The study focused on individuals from the higher education group to gain relevant and substantial perspectives.

(4) Random Selection of Demographics: To enhance reliability and diversity, participants' age, gender, nationality, first language, and academic background were randomly chosen analysis (Breen, 2006). These factors were deemed significant as they could potentially influence the analysis in large-scale studies.

Due to safety concerns during an epidemic, the focus groups were conducted online using Microsoft Teams. Participants were encouraged to participate from a familiar and comfortable physical location, fostering a conducive environment for open discussions. The researchers ensured that participants had the option to remain anonymous by not requiring them to turn on their cameras throughout the process, respecting their preferences and privacy.

Table 3.1 and Table 3.2 provide participants' demographic information including age, gender, nationality, primary language, educational level and background, year of the study and the mode of study. A total of 15 online participants were recruited, all with higher education backgrounds and online learning experience, trying to balance the gender of the participants, i.e. 7 females and 8 males, to ensure as much diversity as possible in terms of cultural and educational backgrounds, and age spread across different range of ages.

**Table 3.1** Participants' demographic information in Focus Group 1.

| Participant Demographics Form_Focus Group 1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Participant ID** | **Age** | **Gender** | **Nation** | **First Language** | **Education Level** | **Name of the Programme** | **Year of study** | **Mode of study** |
| 1 | 20-30 | F | Dubai | Arabic Language | Postgraduate | Social and Public Policy | Other | Full-time |
| 2 | 20-30 | F | Chinese | Mandarin | Postgraduate | Interior Architecture and Design | Master | Full-time |
| 3 | 20-30 | M | Spain | Spanish | PhD | Design and Colour | Year 2 | Full-time |
| 4 | 20-30 | F | South Korea | Korean | PhD | Design and Colour | Year 2 | Full-time |
| 5 | 20-30 | M | Chinese | Mandarin | Postgraduate | Genetics | Year 2 | Full-time |
| 6 | 20-30 | F | Chinese | Mandarin | Postgraduate | English Language Teaching | Other | Full-time |
| 7 | 20-30 | M | UK | English | Postgraduate | Business | Master | Full-time |

**Table 3.2** Participants' demographic information in Focus Group 2.

| Participant Demographics Form_Focus Group 2 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Participant ID** | **Age** | **Gender** | **Nation** | **First Language** | **Education Level** | **Name of the Programme** | **Year of study** | **Mode of study** |
| 1 | 20-30 | F | Turkish | Turkish | PhD | Design | Year 2 | Full-time |
| 2 | 40-50 | F | Chinese | Mandarin | PhD | Environment and Development | Year 1 | Full-time |
| 3 | 20-30 | F | UK | English | Undergraduate | International Business | Final year | Full-time |
| 4 | 30-40 | M | South Korea | Korean | PhD | Information Design | Year 2 | Full-time |
| 5 | 20-30 | M | Chinese | Mandarin | PhD | Design | Year 2 | Full-time |
| 6 | 20-30 | M | Chinese | Mandarin | Postgraduate | Media and Communication | Master | Full-time |
| 7 | 30-40 | M | Chinese | Mandarin | PhD | Computer Science | Other | Full-time |
| 8 | 20-30 | M | UK | English | Postgraduate | Graphic Design/Design Communication | Other | Full-time |

All participants were very active throughout the process, interacting with the moderator and other group members and adding their ideas as others finished their statements. The whole discussion went very well and was informative. So the researchers also determined that the two online focus groups had collected enough data to reach the theoretical saturation (Service, 2009), which means that after the second online focus group, no new themes have been revealed.

#### 3.3.1.2 Questions

There was a total of 11 questions raised in the online focus group. The first two are engagement questions, designed to break the ice and to give an initial insight to the moderator about the general view of all participants in distance learning. In the exploration question, the aim is to continue exploring some of the details of online learning. The main focus is on the situation, frequency, course types and the devices used by contemporary online learners for distance education context. The more significant discussion focused on questions 6-8, participants' perceptions of the advantages and disadvantages of the current distance education mode and whether there were any suggestions for changes to the current challenges. The following presents questions used in the online Focus Group on distance and online education experience. These include Experience, Opinion, Preference, Frequency, Equipment, and Exception.

**Engagement questions:**

Q1. Have you ever been to online courses/ webinars during the pandemic? (Experience)

Q2. Do you think learning online is an effective way to support your learning? (Opinion)

**Exploration Questions:**

Q3. How knowledgeable are you with distance/online learning? (Experience)

Q4. In what situations do you think is best to learn online? Why? (Preference)

Q5. How often do you use online education? Has this frequency changed during the pandemic? (Frequency)

Q6. What kind of courses do you often use online education to learn? (Experience)

Q7. What device do you usually use for online courses? (Equipment)

Q8. What are the difficulties and benefits do you think of using online education? (Opinion)

Q9. Do you have any opinions on the platforms or websites you use frequently? Their pros or cons? (Opinion)

Q10. When you look for the course information you need on the platform or webpage, do you encounter some obstacles? (Experience)

**Exit question:**

Q11. Is there anything else you would like to say about why you do or do not do online education? (Exception)

#### 3.3.1.3 Procedure

The online Focus Group process follows the following five steps:

(1) Start the session by introducing the moderator (researcher), the participants, and the purpose of the focus group.

(2) Remind participants of the ground rules, including maintaining confidentiality, respecting each other's opinions, and avoiding interruptions.

(3) Encourage active participation and ensure everyone has an opportunity to share their insights.

(4) Use probing questions and follow-up prompts to delve deeper into participants' responses and encourage meaningful discussions.

(5) Record the focus group session (with participants' consent) to review the discussion later accurately.

### 3.2.2 Pre-Experiments

Before the start of the formal experiment, to test whether the content and questions chosen for the digital learning materials meet the expectations of this study.

**Colour Blindness**

The online Ishihara Colour Blindness Test (ICBT) has been used for checking participants' colour vision. The online test consists of 12 plates, each with a circular image of coloured dots with one or two numbers in the images. Participants were asked to identify the numbers they saw in the pictures one by one or choose nothing if there were no numbers, for a total of 18 numbers. When the test is complete, click the finish button to submit, and the results will be displayed directly. Only participants with normal colour vision will be eligible for subsequent experiments.

#### 3.3.2.1 Sampling

The researcher recruited eight participants (aged 25-38, six female and two male) with similar academic backgrounds (all from the School of Design, University of Leeds). Two had English as their primary language, one had Turkish as their primary language, and the others all had Chinese as their primary language.

#### 3.3.2.2 Colour Materials and Question Materials

**The fixed colour contrast between text and background**

The first step in designing experimental materials is to maximise the legibility and readability of the online learning material. In this study, six colours (red, orange, yellow, green, blue and purple) were selected from an Adobe HSB colour system (Camgöz *et al.*, 2002), and a grey reference colour was used as a control group. Additionally, the grey background colour enhances the maximum contrast (Pett and Wilson, 1996). Colour samples can also be presented in many different ways, such as colour chips, colour cards/papers/fabric or digital colour patches displayed on a computer monitor (Taylor *et al.*, 2013). This study aims to investigate the potential impact of different background colours of digital learning materials on people's comprehension ability. As a result, the various colours will be displayed to the participants via electronic devices. Since half of the participants completed the experiment on their computers, it was impossible to control the colour brightness and Chroma settings at the same time because this was not a laboratory setting. Each participant was using a different-branded digital screen, and people's habits with electronic devices varied. The chosen colour will be the background colour for the learning

material. As discovered during the preliminary research, black is frequently used as a background colour for digital teaching materials (Hanafy and Sanad, 2015). Furthermore, dark-coloured systems are available in many electronic devices today, indicating the habits and preferences of modern digital users. As a result, black is added to the colour set in this study, and the resulting text colour is chosen as reference grey to ensure that the relative contrast between the text and background colours is consistent with the other colour combinations.

The fonts used in the learning materials follow Pettersson's (2010) screen information design principles, which is "Use typefaces designed for screen display (Sans serif font)." As a result, the typefaces chosen were classics, Verdana because it is supported by most computers, and Microsoft's Times New Roman because it is a common benchmark for legibility evaluation (Hall and Hanna, 2004). The font size was set at the optimal size range (Rambally, 1986), with a body size of 24 points (typically 32px) for text and a body size of 30 points (typically 40px) for the headings in Verdana typeface. In the footnote section below the learning material, in the serif font Time New Rome, with a body size of 18pt (typically 24px). The luminance contrast between the background and key visual cues is fixed in 3:1 (Lin, 2003； Roberts, 2017) OR 7:1 threshold set by the W3C specifications (2018). The experiment was designed to investigate whether a change in the primary background colour of digital learning materials, i.e. hue, might positively or negatively affect the comprehension skills of the higher education population. So the text colour is used as a fixed variable. The font colour of the learning materials is black, and the contrast with the background colour is guaranteed to reach a higher level to ensure the readability of the learning materials to the greatest extent (Williams, 2015a). And against different colour backgrounds, the black text will be more readable compared to other colours (Richardson *et al.*, 2014). To summarise, the font colours used in this study were uniformly black (#000000), with an RGB value of C=0,0,0. To ensure that all foreground and background colours have the same contrast ratio, only texts on a black background will have reference grey (#999999 or #595959) selected as the text colour (3:1 or 7:1). The following formula calculates two sets of colours with text and background colour contrasts of 3:1 and 7:1, respectively.

**Contrast ratio calculation:**

Using linear colour components C= [ R, G, B], one may get the relative luminance by $L = 0.2126R + 0.7152G + 0.0722B$

Knowing the relative luminance, calculate the contrast ratio of a coloured text and background by the formula: *(L1 + 0.05) / (L2 + 0.05)*, where

- L1 is the relative luminance of the lighter of the foreground or background colours, and
- L2 is the relative luminance of the darker of the foreground or background colours.

- relative luminance of text and background colour (L1>L2). The ANSI/HFS 100-1988 standard requires that the contribution from ambient light be considered when calculating L1 and L2. The value is based on the [IEC-4WD] Typical Viewing Flare (2018).

The terms "contrast ratio" and "relative luminance" are used in this Success Criterion and its definitions rather than "luminance" to reflect the fact that Web content does not emit light. The contrast ratio calculates the relative luminance that would be produced if the image were displayed. (It has no dimensions because it is a ratio.)

Finally, ensure that the contrast ratio is equal to or greater than 7:1.

Table 3.3 shows the sRGB colour coordinates of the reference grey and seven primary background colours. The contrast ratio between the foreground and background colours is controlled at about 3:1 to two decimal places. Figure 3.1 shows the examples of the corresponding colours.

The sRGB values presented in Table 3.4 show the numerical details of the foreground and background colours with a contrast ratio of about 7:1 (again to two decimal places), describing the colours in terms of six dimensions of data: H_ Hue, S_ Saturation, B_ Brightness, R_ Red, G_ Green, B_ Black. Black. Figure 3.2 illustrates the corresponding colour examples in Table 3.4.

It is worthwhile to note that the first step in performing the calculations is to determine the value of Hue, the hue measured in degrees of the colour circle ranging from 0 to 360 (red = 0°, orange= 30°, yellow= 60°, green = 120°, blue = 240°, purple= 270°). Under the premise of ensuring that the hue value remains unchanged due to the different brightness of different colours, the brightness is adjusted first. Then the saturation value is adjusted if the brightness adjustment fails to achieve the desired contrast. However, the researcher is trying to ensure that the saturation value is as significant as possible to ensure that the colours can have a more noticeable colour tendency.

**Table 3.3** The sRGB colour coordinates of the reference grey and six primary background colours. The contrast ratio between the text and the background colour is around 3:1, and the calculation precision is two digits after the decimal point.

**H**_ Hue, **S**_ Saturation, **B**_ Brightness, **R**_ Red, **G**_ Green, **B**_ Black.

| | H | S | B | R | G | B | Contrast ratio |
|---|---|---|---|---|---|---|---|
| **Reference Grey (595959)** | 0 | 0% | 35% | 89 | 89 | 89 | 3 |
| **Red (b80000)** | 0 | 100% | 72% | 184 | 0 | 0 | 3.04 |
| **Orange (8c4600)** | 30 | 100% | 55% | 140 | 70 | 0 | 2.99 |
| **Yellow (5c5c00)** | 60 | 100% | 36% | 92 | 92 | 0 | 2.99 |
| **Green (006900)** | 120 | 100% | 41% | 0 | 105 | 0 | 3.02 |
| **Blue (3030ff)** | 240 | 81% | 100% | 48 | 48 | 255 | 2.99 |
| **Purple (7700ed)** | 270 | 100% | 93% | 119 | 0 | 237 | 3.01 |
| **Black (000000)** | 0 | 0% | 0% | 0 | 0 | 0 | |

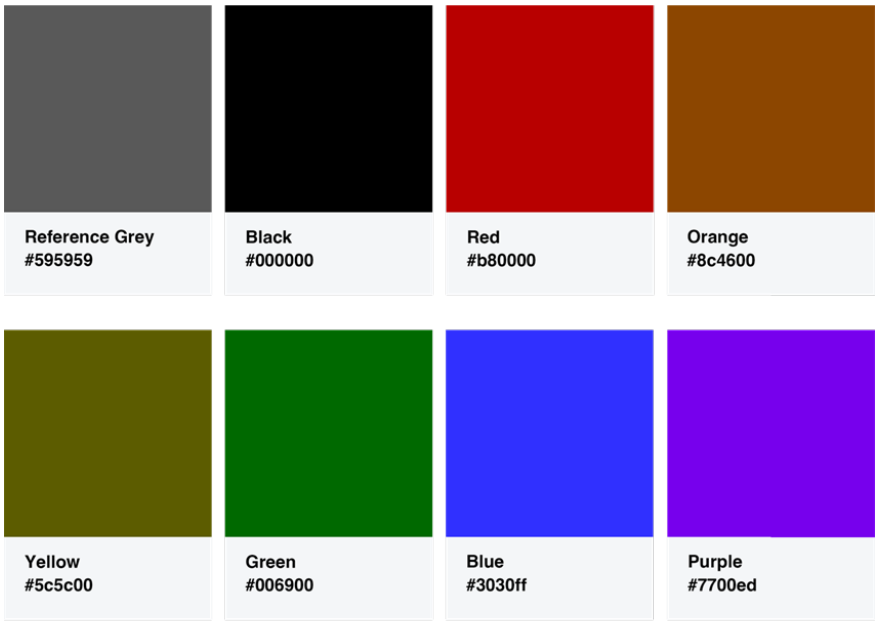



**Figure 3.1 Samples of selected colour contrast ratio 3:1.**

**Table 3.4** The sRGB colour coordinates of the reference grey and six primary background colours. The contrast ratio between the text and the background colour is around 7:1, and the calculation precision is two digits after the decimal point.

**H**_ Hue, **S**_ Saturation, **B**_ Brightness, **R**_ Red, **G**_ Green, **B**_ Black.

| | H | S | B | R | G | B | Contrast ratio |
|---|---|---|---|---|---|---|---|
| **Reference Grey (999999)** | 0 | 0% | 60% | 153 | 153 | 153 | 7.37 |
| **Red (ff6666)** | 0 | 60% | 100% | 255 | 102 | 102 | 7.34 |
| **Orange (f07800)** | 30 | 100% | 94% | 240 | 120 | 0 | 7.39 |
| **Yellow (9e9e00)** | 60 | 100% | 62% | 158 | 158 | 0 | 7.34 |
| **Green (00b200)** | 120 | 100% | 70% | 0 | 178 | 0 | 7.37 |
| **Blue** (8c8cff) | 240 | 45% | 100% | 140 | 140 | 255 | 7.31 |
| **Purple (bd7aff)** | 270 | 52% | 100% | 189 | 122 | 255 | 7.39 |
| **Black (000000)** | 0 | 0% | 0% | 0 | 0 | 0 | |

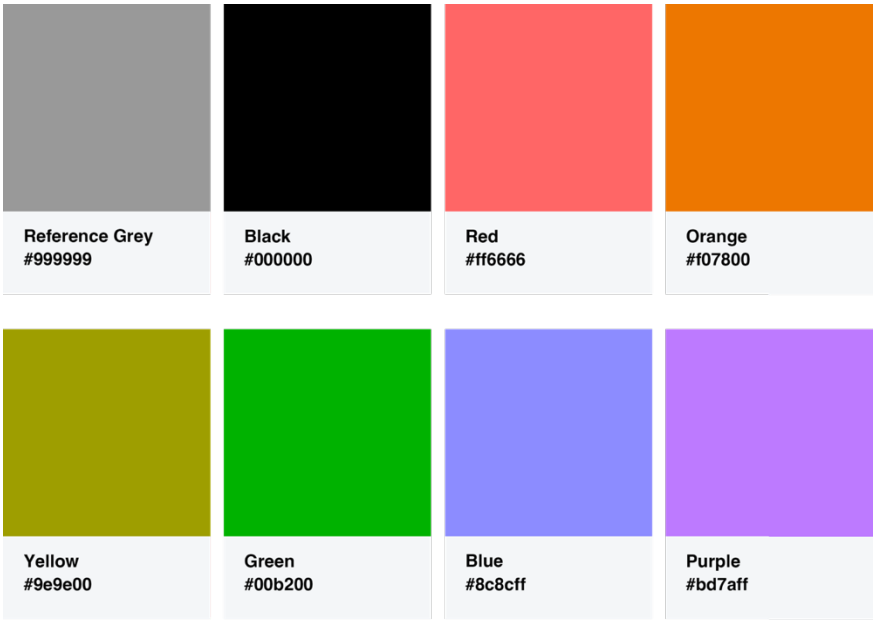



**Figure 3.2 Samples of selected Colour contrast ratio 7:1.**

The selection of colours: Provided that the value of the colour hue is determined and that the contrast between the text colour and the background colour is at a similar level (with a slight deviation only in the second decimal place and a maximum deviation of $\leq 0.08$). However, it is worth noting that the inequality of the luminaries of the primary colour cannot be avoided easily. It is not unique to this physical display. It results from a combination of traditional graphics techniques and colour vision properties (Mogford, n. d.). Therefore, when adjusting the values, brightness is the priority. The saturation value is only changed if the brightness of the colour is altered, and there is no way to achieve the desired level of contrast. Saturation is kept as high as possible to ensure that the colours have a more pronounced colour tendency.

Also, due to the different auto luminescence of the various primary colours, the relative contrast between the text and background colours is guaranteed to be the same even in digital materials. The same conclusion can be drawn from the feedback from the pilot study. Therefore, in the subsequent online questionnaire, the choice of colour preference was designed to include two dimensions of readability and legibility, in addition to the participants' preference for the combination of text and different background colours, to assist in assessing the usability of different colour backgrounds.

Contrast occurs when two items have opposing characteristics. When the designers set the contrast correctly, they determine which part of the design should be regarded as the background and which part must be in the foreground (Tselentis, 2012). The designers have ensured that the content is visible and does not overlap with the background’s colour (Lipton, 2011). Low contrast between the element and its background or colour codes might cause problems in understanding the information, especially for those who have visual impairments (Coates, 2014). Contrast is not only related to colour but also the difference between the size of the headings and body text. The gradation of image size can also inform the viewer of the content hierarchy (Tselentis, 2012； Golombisky and Hagen, 2013).

The rationale is based on a) the WCAG 2.1 Understanding Docs (2022) standard's adoption of the 3:1 contrast ratio for minimum acceptable contrast for normal observers and b) the empirical finding that in the population, visual acuity of 20/40 is associated with a contrast sensitivity loss of about 1.5. A user with 20/40 vision would need a contrast ratio of 3 * 1.5 = 4.5 to 1. Following similar empirical findings and logic, a user with 20/80 visual acuity would require a contrast of approximately 7:1.

The contrast ratio of 4.5:1 was chosen for level AA because it compensated for the loss in contrast sensitivity that users with vision loss equivalent to approximately 20/40 vision typically experience. (20/40 equals approximately 4.5:1.) At around the age of 80, 20/40 is commonly reported as the average visual acuity of the elderly.

The contrast ratio of 7:1 was chosen for level AAA because it compensated for the loss in contrast sensitivity that users with vision loss equivalent to approximately 20/80 vision typically experience. People with severe vision loss typically use assistive technologies to access their content (and the assistive technologies usually have contrast enhancing and magnification capabilities built into them). The 7:1 level compensates for the loss of contrast sensitivity experienced by low-vision users who do not use assistive technology, as well as providing contrast enhancement for colour deficiency (2018). Therefore, to ensure that the final results of this study can be applied to the majority of the population. Readability was chosen at the highest AAA level within the available options, which is 7:1.

With the help of the online web design text colour and background colour contrast checker, when the text colour and background colour's contrast ratio is settled in 7:1 has higher readability and is more easily accessible compared to 3:1.

In the pilot study, the researcher used the IELTS reading test to measure the participants' comprehension, and the results were extreme in some cases. The following four points are considerations made by the researcher in the selection of test materials and the collection of primary data:

(1) The content of the test materials is extracted from the actual sections of the Academic Reading Test of the International English Language Testing System (IELTS) Examination. The contents of the reading test are adapted from sources such as academic journals, periodicals, books and newspapers. The essays cover a wide range of subjects, with familiar topics corresponding to some candidates' knowledge level in undergraduate and postgraduate courses or for professional registration.

(2) Two different passages were used for testing in the pilot study. The length of each paragraph is limited to around 200 words (±20 words). To ensure that participants understand the selected paragraphs, some unusual proper nouns or difficult words are annotated at the bottom of the learning material. So that even if the content of the material provided was not in the participants' familiar field of knowledge. The range of the

selected passages is not hindered to the greatest extent possible by the participants' understanding.

(3) Each paragraph is available in two different colour versions (Reference Grey_#999999 and Red _#ff6666). The combination of content and the background colour is presented to participants in a randomised sequence. After reading each passage, participants are asked to answer five questions about the reading material. All questions are objective, and the types of questions are divided into single-choice, multiple choice and true/false/ not given questions.

(4) As reading speed and comprehension vary from participant to participant, there is no limit to how long a participant can read a test passage, but the time is recorded. It is convenient to measure in the subsequent analysis under which colours the participants performed better, i.e. for the same content, the speed of comprehension, i.e. faster and the percentage of correct answers to the questions.

Figure 3.3 and Figure 3.4 show some examples of the test materials used in the pre-experiment.

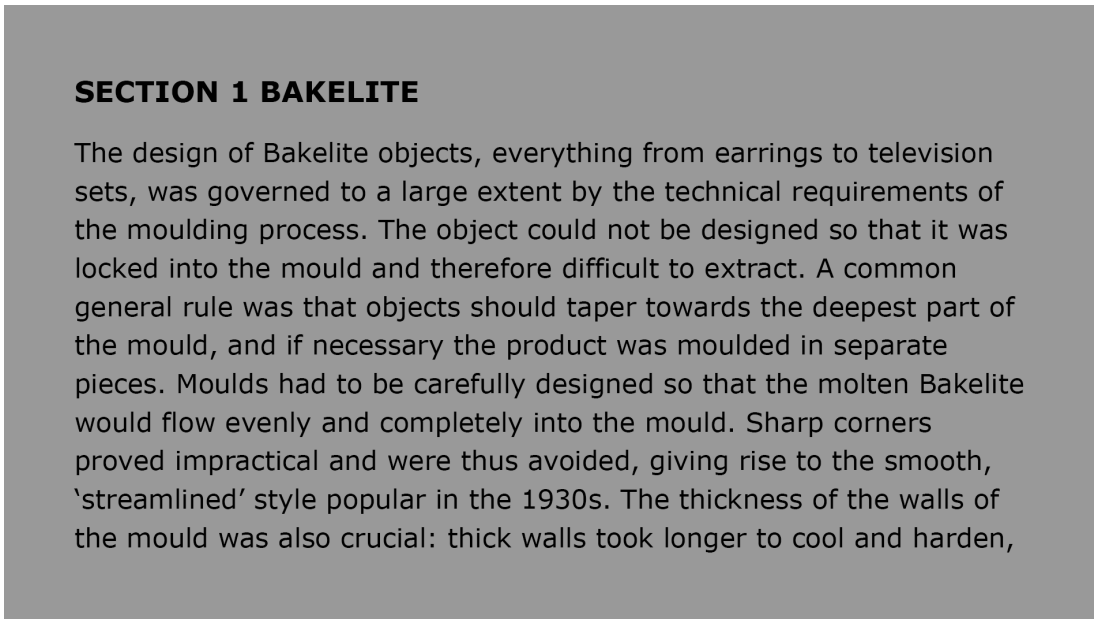
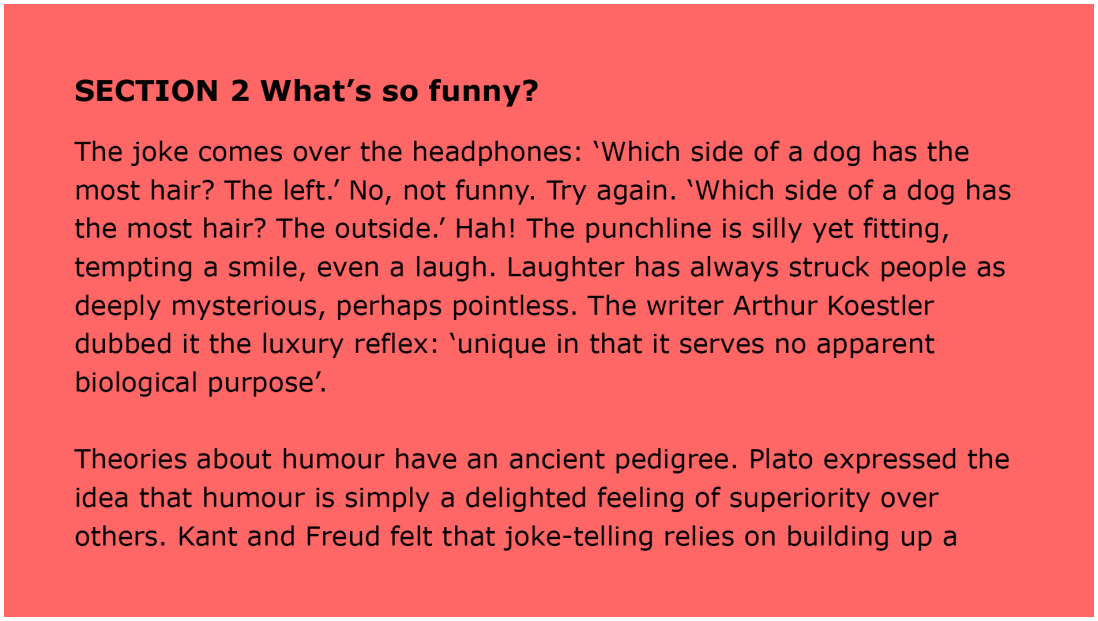



**Figure 3.3 Pre-experiment test materials in grey colour.**



**SECTION 2 What's so funny?**

The joke comes over the headphones: 'Which side of a dog has the most hair? The left.' No, not funny. Try again. 'Which side of a dog has the most hair? The outside.' Hah! The punchline is silly yet fitting, tempting a smile, even a laugh. Laughter has always struck people as deeply mysterious, perhaps pointless. The writer Arthur Koestler dubbed it the luxury reflex: 'unique in that it serves no apparent biological purpose'.

Theories about humour have an ancient pedigree. Plato expressed the idea that humour is simply a delighted feeling of superiority over others. Kant and Freud felt that joke-telling relies on building up a

**Figure 3.4 Pre-experiment test materials in red colour.**

#### 3.3.2.3 Procedure

The participants were asked to pass the Ishihara Colour Vision Test before entering the test to ensure they had normal colour vision. The whole experiment was conducted online through Microsoft Teams. As this was a pilot study, only two colours with a contrast ratio of 7:1 in the text and background colour (one reference grey as the control group and the other is red) were selected to see if there were significant differences between the two groups and feedback on the difficulty of the test questions and content.

The researcher will record the reading time for each paragraph and the time taken to answer the five content-related questions for each participant. After completing data collection, the researcher will calculate the accuracy rate of answers for each question in every paragraph.

### 3.2.3 Main Experiments

#### 3.3.2.1 Sampling

**Participant inclusion/exclusion criteria:**

(1) Higher education group. The distance education model may not be appropriate for all types of learners because data shows that successful online graduates tend to be older (in the range of 25 – 30 years). This is because online courses necessitate a relatively high level of intrinsic motivation and self-discipline (Kaplan and Haenlein, 2016). If this

methodology produces consistent results in the higher education population, future researchers may consider applying the findings to different age groups.

(2) With normal colour vision. The participants are required to have normal colour vision according to the Ishihara Colour Vision Test (Ishihara, 1996). As half of the experiment was conducted online, there was a consideration that if the colour vision test was conducted online, due to the difference in personal computer display settings, ambient light, and other factors could affect the final test result. However, based on Marey and Gjærde *et al*. (Marey *et al.*, 2015； Gjærde *et al.*, 2021) research, presenting the computer-based colour deficiency test software on an LCD screen can be used to test colour vision deficiency with nearly similar sensitivity and specificity to the Ishihara test with the advantage of reducing the cost by decreasing required resources over time and decreasing the time to analyze the results. Based on the above study's findings, it was determined that an online colour vision test was feasible. The online Ishihara colour vision test tool was used to ensure that all participants had normal colour vision before the experiment began.

(3) Have prior experience with online learning. Because the follow-up online questionnaire contains questions about people's online learning experiences, participants must have had online learning experiences to provide realistic answers to the relevant questions on the questionnaire.

Table 3.5 describes the details of the 40 participants involved in the main experiment, including their gender, cultural background and whether the experimental conditions were conducted online or offline. Particular care was taken when recruiting participants to ensure a balance of gender, cultural background and experimental conditions.

**Table 3.5** The distribution of the 40 participants (offline and online).

| | Offline Condition | | | Online Condition | | | |
|---|---|---|---|---|---|---|---|
| Gender | Chinese | Mixed Culture | Native Speaker | Chinese | Mixed Culture | Native Speaker | Total |
| Female | 5 | 2 | 3 | 5 | 2 | 3 | 20 |
| Male | 5 | 3 | 2 | 5 | 3 | 2 | 20 |
| Total | 10 | 5 | 5 | 10 | 5 | 5 | 40 |

For the sample size, Nielsen (2006) summarised 83 case studies related to the evaluation of the user-centred design. Most projects should stay with the tried-and-true, five users per usability test, and 30 users can find almost all the problems.

The experiment's final results may be influenced by age, gender (Venkatesh *et al.*, 2002), educational background (Hanafy and Sanad, 2015), and cultural background. This study was conducted to balance the number of participants between several groups and facilitate subsequent analysis. A total of 44 participants were recruited, and after the first round of data counting and screening, valid data from 40 participants were adopted for the final data analysis and a second round of analysis.

#### 3.3.2.2 Questionnaires and Scaling Methods

**Online learning experience & Online learning materials colour preference Questionnaire**

This questionnaire was designed to evaluate participants' online learning experiences and their preferences for the background colour of online learning materials. The entire questionnaire has 29 questions and takes about 7 minutes to complete. Section A, Questions 2-7, collects basic participant information such as age, gender, nationality (cultural background), primary language, and programme of study. According to the previous survey, genders, contexts, cultures, and even age levels all have varying degrees of influence on the learning experience.

Section B, questions 8-21, focused on the participants' prior online learning experiences, with multiple choice, single choice, and Likert scale questions. Participants were asked specific questions about their preferred mode of learning (online/offline/blended), the frequency and scenarios in which they use online education, their satisfaction with online education, the types of online education materials they frequently use and their usage habits, and the difficulties they face when learning online. The resulting data is intended to provide a summary of the current higher education population's dominant perceptions and preferences for online learning in the aftermath of the pandemic.

The final section of the questionnaire asks about your preferred background colours for online learning materials, from 22 to 29 questions. Each question presented participants with a picture and asked them to rate it on three different dimensions using the Likert scale: preference, readability, and

legibility. 8 The only variable in a picture is the background colour; the size, aspect ratio, text colour, content, and layout are all the same. As illustrated in the image below.

Figures 3.5 and 3.6 show a series of optimisation of the overall layout of the experimental materials, the choice of typographic and font sizes and the addition of footnotes after summarising some of the feedback received from the participants during the pre-experiment and following some basic information design principles.

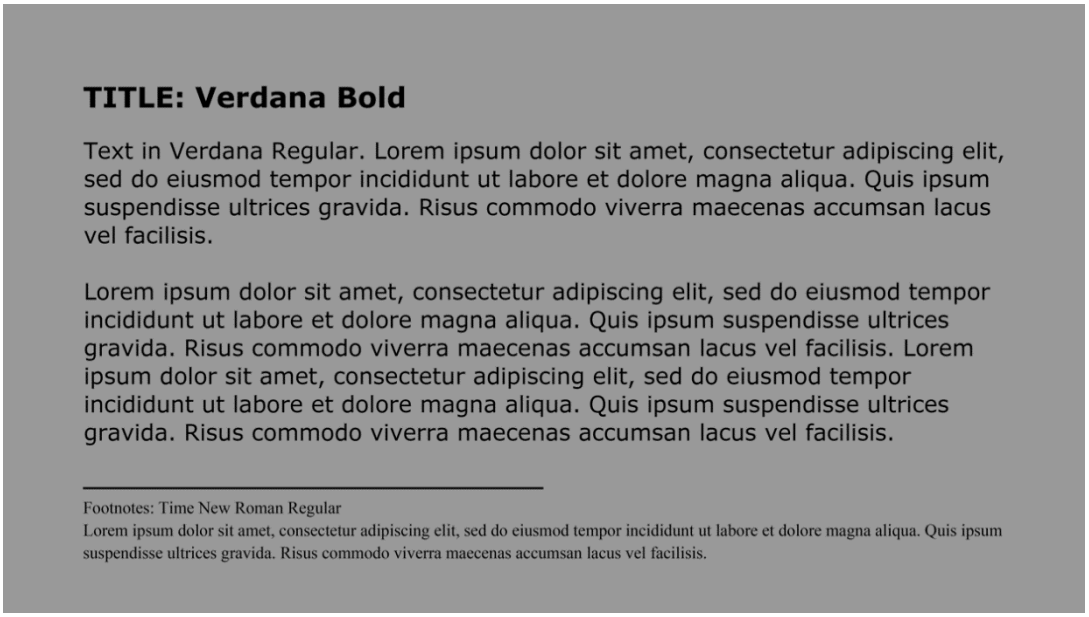



**Figure 3.5** Example of images used in the questionnaire —1.

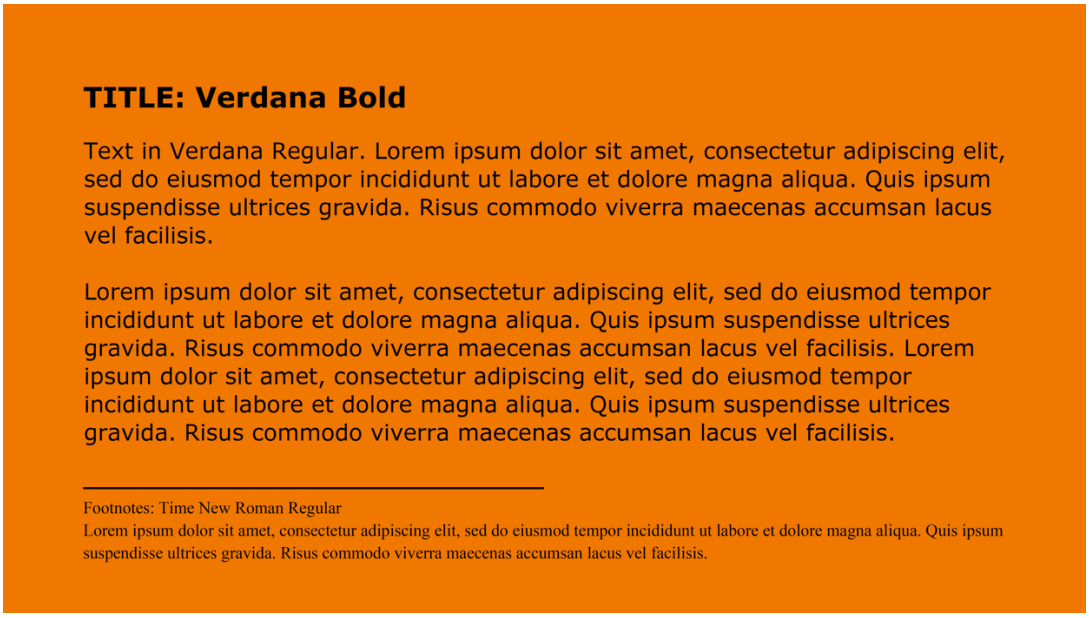



**Figure 3.6** Example of images used in the questionnaire —2.

### The Psychometric Test

The test questions used in the main experiment are Comprehension tests - word changes questions, a series of questions specifically designed to test the verbal skills and ability to comprehend, understand and appreciate written text (Carter, 2005). This type of question fits well with the purpose of the experiment. It avoids some of the limitations of single- or multiple-choice questions, especially the disadvantage of participants being able to guess correctly without really understanding the textual information provided by the researcher. In each question, if scrutinized closely, there are some errors, either in grammatical or word meanings. The subjects only need to change the position of the number of words indicated. After swapping these words, it is possible to make the sentence completely comprehensible.

Before starting the formal experiment, the researcher will show the participants an example (see Figure 3.7) and explain how to answer this type of question. The example is shown using white as the background colour. While the participant answers the questions, the researcher records the time spent on each question and counts the percentage of correctness at the end of the experiment.

**Example:**

**Change the position of FOUR WORDS only in the sentence below in order for it to make complete sense.**

The discovery of today's plastics materials begins with the semi-synthetic history of a series of thermoplastic in the mid-nineteenth century.

**Answer:**

The **history** of today's plastics begins with the **discovery** of a series of **semi-synthetic** thermoplastic **materials** in the mid-nineteenth century.

---

Notes:
1. Synthetic: produced by combining different artificial substances, rather than being naturally produced.
2. Thermoplastic: a plastic that is soft and bendable when heated but hard when cold.

**Figure 3.7** An example of a word changes test used in the main experiment.

The set of questions has its performance rating system, scoring 1 point for every two words correctly placed plus a bonus 3 points for each entirely correct sentence. As the number of words changed varies for each question,

the total score for the corresponding sentence also varies. To standardise the rubric, the score obtained was divided by the total score for each question. A percentage was used to show what portion of the whole sentence was answered correctly, representing what percentage of the sentence was understood by the test taker. This test measured the participant's ability to understand the textual information provided.

#### 3.3.2.3 Procedure

Each participant was required to answer 16 questions throughout the experiment. Under each background colour, participants will answer two different questions. To ensure that the difficulty of the various questions does not affect the final experimental results, the combination of material content and colour needs to appear randomly. It is also essential to ensure that each question appears the same number of times on the same colour background by calculating the following:

*40 participants × 2 questions = 80 questions in each colour background*

*80 questions ÷ 16 questions = 5 times*

Each question appeared five times against the same background colour. To eliminate potential bias raised by different levels of question difficulty, the study tried to make the order of questions randomised using an online random sequence generator.

In the preparatory phase for testing materials, Table 3.6 illustrates an example of a randomised sequential order for a participant.

**Step One:** First, individually number the 16 test questions, for example, Q1, Q2, Q3, ..., Q15, Q16. Also, assign numbers to the 8 colours, such as C1, C2, C3, ..., C7, C8.

**Step Two:** The researcher will use an online Random Sequence Generator to create three sets of random sequences for each participant. The first set will determine the order of the test questions, with Sequence Boundaries set from the smallest value of 1 to the largest value of 16, as shown in Table X, Sequence A. The second and third sets will decide the order of colours, with Sequence Boundaries set in the range of 1-8, as shown in the tables for Sequence B and C.

**Step Three:** The three sets of generated random sequences will be combined next.

However, it's important to note that this method may not apply to all participants' material preparation. This is because it's necessary to ensure that each question appears an equal number of times under each colour condition. Therefore, for some participants, the combination of questions and colours will require manual adjustment by the researcher.

**Table 3.6** The example of a randomised sequential order for a participant's test material.

| Sequence A (1-16) for Questions | Sequence B (1-8) and C (1-8) for Colours | Combination |
|---|---|---|
| Q8 | C4 | Q8_C4 |
| Q2 | C2 | Q2_C2 |
| Q11 | C8 | Q11_C8 |
| Q14 | C3 | Q14_C3 |
| Q1 | C5 | Q1_C5 |
| Q6 | C1 | Q6_C1 |
| Q4 | C7 | Q4_C7 |
| Q16 | C6 | Q16_C6 |
| Q7 | C4 | Q7_C4 |
| Q3 | C8 | Q3_C8 |
| Q5 | C7 | Q5_C7 |
| Q13 | C2 | Q13_C2 |
| Q12 | C6 | Q12_C6 |
| Q9 | C1 | Q9_C1 |
| Q10 | C5 | Q10_C5 |
| Q15 | C3 | Q15_C3 |

**The main experiment followed four steps:**

(1) The experiment commenced by dividing the 40 participants into two distinct environments, each with its unique setup. For half of the participants, a real-time connection was established through Microsoft Teams software, allowing them to engage with the researcher remotely. They undertook the experiments in an online setting, where the physical surroundings were beyond their control. In contrast, the remaining participants took part in the experiment in an offline lab environment

equipped with a D65 standardised light source and a standard sRGB display setting. Upon entering the lab, these participants had 1-2 minutes to acclimate themselves to the surrounding ambient light.

(2) Before commencing the experiment, all participants needed to complete the online Ishihara Colour Blindness Test (ICBT), ensuring their possession of normal Colour vision.

(3) Following the colour blindness test, participants were directed to complete an online questionnaire, which typically required around 8-9 minutes.

(4) A total of 16 experimental questions were presented to the participants in a randomised order. Once they felt prepared, they commenced answering the questions while the researcher meticulously recorded the time taken to complete each inquiry.

## 3.3 Conclusions

In this chapter, we provide a detailed description of the experiment's progress and the data collection process. Despite discovering some imperfections in the research design during the experiment and data preservation phase, these details will be discussed in subsequent chapters. Our primary objective is to present the experimental process thoroughly, ensuring readers have a clear understanding of the research methodology and data collection procedures.

The experiment involves three distinct components: online focus groups, online questionnaires, and psychometric tests. Online focus groups allow us to engage with the target learners in virtual learning environments, gaining valuable insights into their experiences, preferences, and expectations regarding digital learning materials. By participating in online focus groups, we obtain rich information about the learners' perspectives, which will guide the subsequent design and development of learner-centric virtual learning resources.

Online questionnaires are another essential component of the research design, aiming to investigate contemporary learners' preferences regarding the colour design of digital materials. Collecting data through these questionnaires allows us to directly understand the perspectives of the target audience and identify the most suitable background colour. Aligning the

experimental design with learners' preferences facilitates the creation of more engaging and effective digital learning materials.

Finally, as a key part of the main experiment, we conducted psychometric tests to address Research Question 4 and Objective 4. These tests enable us to evaluate learners' text-based information comprehension abilities when exposed to different background colours. Quantitative analysis of the psychometric test results helps determine the colour that optimizes learners' comprehension abilities.

Overall, this chapter aims to provide a comprehensive description of the experiment's progress and the data collection process. While we may have encountered some imperfections in the research design during the experiment, these issues will be discussed and addressed in subsequent chapters. By ensuring transparency and detailed reporting of the experimental process, we aim to provide readers with a clear understanding of the research methodology and our data collection procedures.

# Chapter 4
# Findings

## 4.1 Introduction

This chapter presents the data analysis and findings on online learning and educational material design from online focus groups and psychometric experiments. Section 4.2 explains the outcomes of an online focus group that examined the impact of the COVID-19 pandemic on online learning experiences. Section 4.3 provides an in-depth examination of the pre-experiments conducted to investigate the relationship between material design and comprehension in online educational settings. Section 4.4 presents the main experiments that were conducted using online questionnaires and a series of psychometric tests to explore the intricate interplay between primary language and colour effects in digital learning. Lastly, section 4.5 closes the chapter by synthesising critical insights from all three studies.

## 4.2 Focus Group

### 4.2.1 Data Analysis

The focus group data were analysed using two methods: (1) Coding Categories Method ((Moretti *et al.*, 2011) and (2) TF-IDF matrix method (Aizawa, 2003).

**Method 1: Coding Categories Method**

*Step 1: Numbering the Participants*

Assigning numerical identifiers to each participant within the respective groups is recommended to facilitate organisation and analysis. This numbering system allows for easy reference and tracking of individual responses throughout the research process.

*Step 2: Transcribing and Summarizing Focus Group Responses*

Next, it is essential to carefully re-listen to the recording of the focus group session. While listening, transcribe each participant's responses in the order they were given. This transcript serves as a valuable resource for analysis and interpretation.

Once the transcription is complete, analyse the content and extract the main ideas expressed by each participant. Look for common themes, insights, and perspectives shared during the discussion. Summarise these main ideas to capture the essence of each participant's contribution to the focus group. This step helps identify patterns and key points from the group discussion.

*Step 3: Coding High-Frequency Vocabularies*

After the transcription and summarisation of the focus group responses, it is advisable to code high-frequency vocabulary based on the participants' statements. This coding process involves identifying and categorizing recurring or significant words and phrases used by the participants.

Create a coding system or use established coding categories to assign codes to the identified high-frequency vocabularies. The purpose of coding is to organize and categorize the data for further analysis. By coding the vocabularies, it becomes easier to identify common patterns, themes, or trends across participants and to explore connections between specific concepts or ideas.

The diagram below illustrates the coded high-frequency vocabularies, providing a visual representation of the relationships and frequencies of these vocabularies within the participants' statements. This diagram aids in understanding the distribution and prevalence of certain ideas or themes within the focus group discussion.

By following these steps of numbering participants, transcribing and summarizing responses, and coding high-frequency vocabularies, researchers can systematically analyze and interpret the data gathered from the focus group. This process enhances the depth of understanding and provides valuable insights into the participants' perspectives and experiences. Table 4.1 and Table 4.2 show examples of the questions raised in the online focus group being summarised and analysed using the Coding Categories Method.

**Table 4.1** Example of analysis in Group 1.

| Group 1 | | | | |
|---|---|---|---|---|
| **Question 1: Have you ever been into online courses/ webinars during the pandemic?** | | | | |
| **Category code** | **Participant ID** | **Responses** | **CODING CATEGORIES** | |
| B | 6 | I have participated in some online courses before, and I currently teach online as a teacher. | A | Always |
| A | 1 | The course schedule is full, so I often take online courses. | B | Sometimes |
| B | 5 | I have participated, and most of them are training courses. | C | None |
| A | 3 | I often attend, whether it is online courses or webinars. | | |
| A | 4 | I participate frequently because many courses require online learning. | | |
| B | 2 | I have participated in some self-study courses about software skills. | | |
| B | 7 | Participate occasionally, basically online meetings. | | |

**Table 4.2** Example of analysis in Group 2.

| Group 2 | | | | |
|---|---|---|---|---|
| **Question 2: Do you think learning online is an effective way to support your learning?** | | | | |
| **Category code** | **Participant ID** | **Responses** | **CODING CATEGORIES** | |
| D E | 6 | I don't think it is an effective way for me. It's hard to concentrate on my courses. | A | Time |
| D E | 1 | I think it's not so effective for me. Especially for software webinar, it's difficult to manage to listen and practicing simultaneously. | B | Repeat learning |
| B | 8 | Yes, to support learning outside of class. Suitable for the pandemic, easily to find instruction. | C | Mass resources |
| A C | 2 | I think for me, is an effective way. I don't live on campus, this kind of courses ave me a lot of time travelling. Because my research is still in the literature reviewing stage, a lot of information is easily found on the Internet. So far, this method doesn't have any downline impact on me. | D | Interaction |
| D | 4 | I think an online tutorial to me is like a very supportive and effective way. Even sometimes feel very stressful, I am taking some online to one tutorial and don't have time to do something else during the courses. I also need to do a lot of preparation and practice before class, which is a very efficient learning method. | E | Distractibility |
| A C | 7 | Yes, because people can learn anything anywhere. There is sufficient and variable knowledge online. People can save massive travelling time and use their piecemeal time better on the study. | | |
| A C | 3 | Yes, I agree with the previous person. | | |

### Method 2: TF-IDF matrix method

The TF-IDF statistical method (Aizawa, 2003) was used to translate the qualitative data into an analytical visual result. TF-IDF stands for term frequency-inverse document frequency, and the TF-IDF weight is often used in information gathering and text mining. This weight is a statistical measure method specialised for evaluating the importance level of a word to a document in a collection or corpus. In a target document, the term frequency (TF) means the frequency of a specific word in the document; inverse document frequency (IDF) represents the general importance level, TF-IDF weight is multiplied by TF and IDF, Equation:

$$w_i = tf_{i,j} \times df_i = \frac{n_{i,j}}{\text{size}(j)} \times \log \frac{|D|}{|\{\text{j} : \text{ti} \in \text{dj}\}|}$$

Therefore, the high frequency of the words in a particular file can produce a high-weight TF-IDF. In this study, three sets of data were analysed, the 20 most frequent words in Focus Group 1, Focus Group 2 and Focus Group 1 and 2.

## 4.2.2 Findings

### Coding Categories Method

Table 4.3 and Table 4.4 visually present the analysis results of two online focus groups using the coding categories method, with different colours in

the bar charts indicating different categories. The column charts show the proposition of the two groups' most frequently mentioned categories under each question. These can be summarised in Table 4.5.

**Figure 4.1 Visualisation results for Focus group 1.**

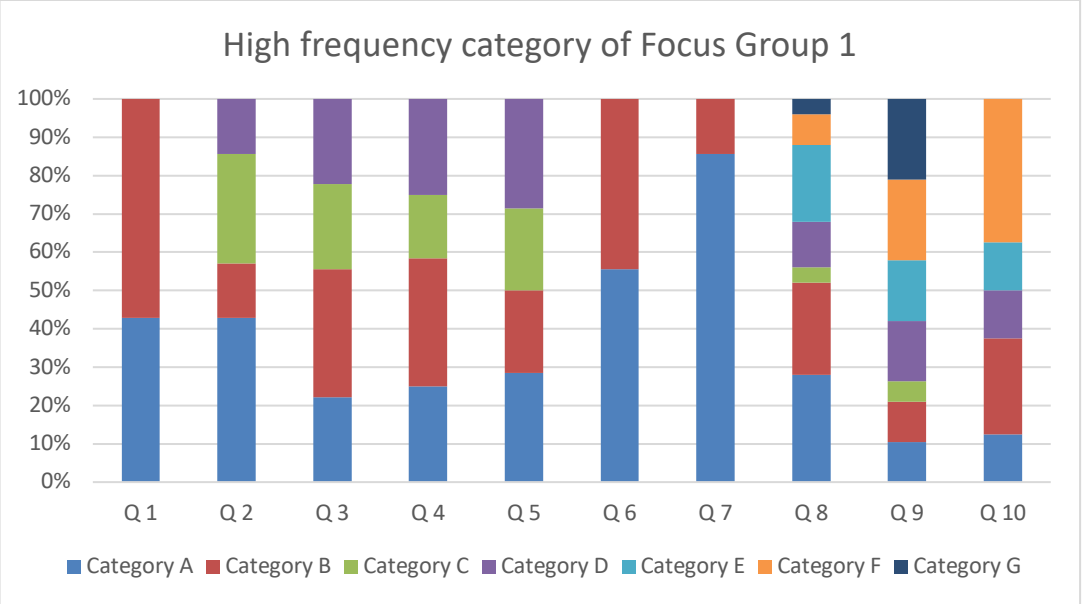



**Figure 4.2 Visualisation results for Focus group 2.**

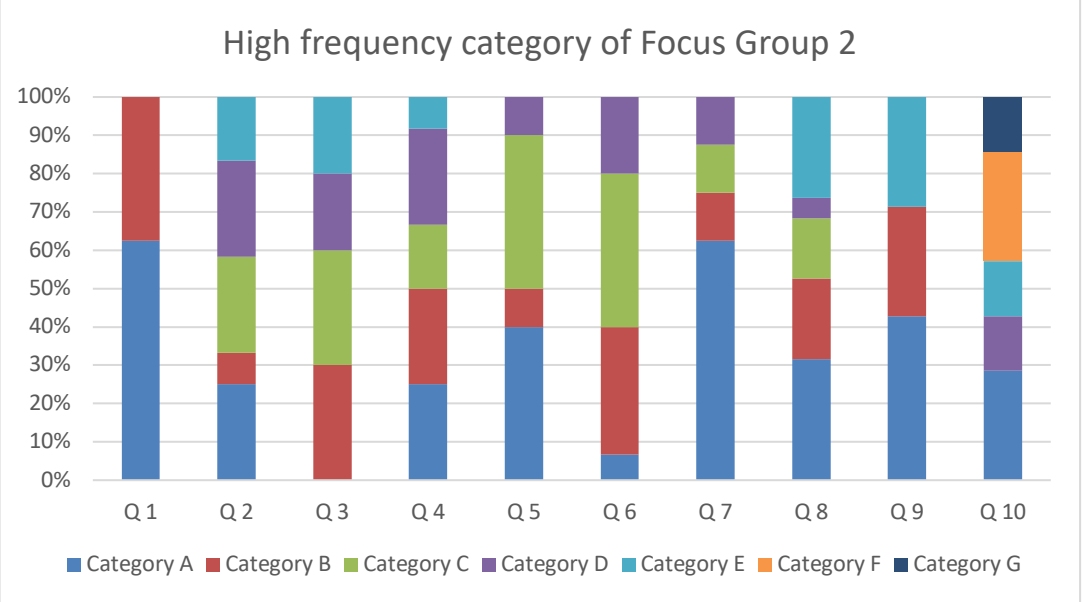


**Table 4.3** High-frequency categories of two focus groups.

| | **Focus Group 1** | **Focus Group 2** | **High Frequency Categories** |
|---|---|---|---|
| **Question 1** | Category B- Sometimes | Category A- Always | Category A- Always<br>Category B- Sometimes |
| **Question 2** | Category A- Time | Category A- Time<br>Category C- Mass resources<br>Category D- Interaction | Category A- Time |
| **Question 3** | Category B- Interface design | Category B- Interface design<br>Category C- Web design | Category B- Interface design |
| **Question 4** | Category B- Space | Category A- Time<br>Category B- Space<br>Category D- Flexibility | Category B- Space |
| **Question 5** | Category A- Frequent<br>Category D- Weak influence | Category A- Frequent<br>Category C- Important influence | Category A- Frequent |
| **Question 6** | Category A- Language | Category C- Seminar/Lecture | Category A- Language<br>Category C- Seminar/Lecture |
| **Question 7** | Category A- Laptop | Category A- Laptop | Category A- Laptop |
| **Question 8** | Category A-Time | Category A- Time | Category A- Time |
| **Question 9** | Category F- Colour<br>Category G- Guidance | Category A- Easy to use | Category A- Easy to use<br>Category F- Colour<br>Category G- Guidance |
| **Question 10** | Category F- Web Design | Category A- Advertising<br>Category F- Web design | Category F- Web Design |

From the Coding Categories analysis, seven key findings were made. These are:

(1) Most students used the online learning method frequently during the pandemic.
(2) Learning online is an effective way to support learners' learning, particularly in terms of time savings and a large amount of accessible information.
(3) The best way or method of performing online learning is dependent upon the limitations of the course's physical space or rather the learning outcome that ought to be achieved.
(4) The language courses that learners study independently and the seminars/lectures and informal learning courses act as the most common courses that are often used in online learning methods.
(5) Laptops and tablets act as the most common devices used in online learning.
(6) The main advantage is the time used in online learning. Efficiency and efficacy of the learning act as the main advantages.
(7) The main three disadvantages shown in the focus groups are the usability, the design of colour and the audience /navigator of the educational websites.

**TF-IDF matrix method**

First step: Relisten to the recorded file of the online focus group and transcribe every signal word answered by each participant to ensure that everything was noticed. Second step: Import the prepared text material into NVivo for analysis and produce the results in the table below. Table 4.6 and Table 4.7 separately show the frequency of words in the online focus groups 1 and 2. The filtering condition for this analysis is that the word length is greater than or equal to 4 letters, and similar terms (e.g., singular and plural nouns, different tenses and person of verbs) are grouped. When the words with significance are highlighted in the table, it is easy to find a high degree of similarity in the high-frequency words in the two focus groups. Therefore, the data from the two online focus groups were integrated and analysed again in Table 4.8.

**Table 4.4** Focus Group 1_ Top 20 highest frequency words.

| Word | Length | Count | Weighted Percentage | Similar Words |
|---|---|---|---|---|
| think | 5 | 161 | 0.72% | think, thinking, thinks |
| online | 6 | 134 | 0.60% | online |
| well | 4 | 126 | 0.57% | well |
| learning | 8 | 124 | 0.56% | learn, learned, learning |
| just | 4 | 116 | 0.52% | just |
| like | 4 | 94 | 0.42% | like, liked, likely, likes |
| course | 6 | 80 | 0.36% | course, courses |
| class | 5 | 75 | 0.34% | class, classes |
| time | 4 | 74 | 0.33% | time, times |
| teacher | 7 | 72 | 0.32% | teacher, teachers |
| right | 5 | 69 | 0.31% | right |
| questions | 9 | 67 | 0.30% | question, questions |
| also | 4 | 60 | 0.27% | also |
| want | 4 | 59 | 0.26% | want, wanted, wants |
| kind | 4 | 56 | 0.25% | kind |
| example | 7 | 54 | 0.24% | example |
| next | 4 | 54 | 0.24% | next |
| good | 4 | 52 | 0.23% | good, goods |
| software | 8 | 52 | 0.23% | software, soft wares |
| students | 8 | 50 | 0.22% | student, students, students' |

**Table 4.5** Focus Group 2_ Top 20 highest frequency words.

| Word | Length | Count | Weighted Percentage | Similar Words |
|---|---|---|---|---|
| like | 4 | 159 | 0.89% | like, likely |
| just | 4 | 102 | 0.57% | just |
| think | 5 | 88 | 0.49% | think |
| online | 6 | 84 | 0.47% | online |
| yeah | 4 | 74 | 0.41% | yeah |
| know | 4 | 68 | 0.38% | know |
| learning | 8 | 57 | 0.32% | learn, learned, learning |
| question | 8 | 53 | 0.30% | question, questions |
| courses | 7 | 49 | 0.27% | course, courses |
| want | 4 | 46 | 0.26% | want, wanted, wants |
| maybe | 5 | 38 | 0.21% | maybe |
| something | 9 | 38 | 0.21% | something |
| sometimes | 9 | 34 | 0.19% | sometimes |
| mean | 4 | 31 | 0.17% | mean, means |
| lecture | 7 | 29 | 0.16% | lecture, lectures |
| answer | 6 | 29 | 0.16% | answer, answered, answers |
| time | 4 | 27 | 0.15% | time, times |
| education | 9 | 25 | 0.14% | educates, education, educational |
| face | 4 | 25 | 0.14% | face, faced |
| causes | 6 | 25 | 0.14% | cause, causes |

**Table 4.6** Focus Group 1 and 2_Top 20 highest frequency words.

| Word | Length | Count | Weighted Percentage | Similar Words |
|---|---|---|---|---|
| like | 4 | 253 | 0.63% | like, liked, likely, likes |
| think | 5 | 249 | 0.62% | think, thinking, thinks |
| just | 4 | 218 | 0.54% | just |
| online | 6 | 218 | 0.54% | online |
| learning | 8 | 181 | 0.45% | learn, learned, learning |
| well | 4 | 137 | 0.34% | well |
| courses | 7 | 129 | 0.32% | course, courses |
| questions | 9 | 120 | 0.30% | question, questions |
| want | 4 | 105 | 0.26% | want, wanted, wants |
| know | 4 | 104 | 0.26% | know, knowing |
| time | 4 | 101 | 0.25% | time, times |
| right | 5 | 87 | 0.22% | right, rights |
| class | 5 | 87 | 0.22% | class, classes |
| also | 4 | 84 | 0.21% | also |
| kind | 4 | 81 | 0.20% | kind |
| teacher | 7 | 79 | 0.20% | teacher, teachers |
| yeah | 4 | 79 | 0.20% | yeah |
| maybe | 5 | 78 | 0.19% | maybe |
| next | 4 | 69 | 0.17% | next |
| feel | 4 | 65 | 0.16% | feel, feeling, feelings, feels |

The key limitations and findings from the online focus group are：

One limitation of focus groups is that their sample size may be relatively small compared to other research methods, so they are rarely used as the sole data collection method in many studies (McClelland, 1994). Additionally, there were certain deviations from the researcher's anticipated responses to the third question (Exploration Question 1) within these two groups.

However, in a focus group setting, it is acceptable for participants' responses to inevitably influence each other, particularly following the initial participant's input, thereby significantly impacting the subsequent reactions of other participants. The researcher employed focus groups in this study as an exploratory qualitative phase. This approach represents a logical and established data collection process aimed at generating more reliable and valid questionnaires based on the insights garnered from the focus groups (Constantine and Bourne, 2005).

Due to the factors associated with the pandemic, contemporary learners have exhibited a substantial increase in the frequency and acceptance of online/distance education compared to the period before 2019. The primary findings of this study centre around the shifts in the learning habits of contemporary learners and the pros and cons of the digital learning materials they encounter during their educational journey. Moreover, through an analysis of high-frequency vocabulary present in the content of the focus groups, keywords related to "Colour" did not emerge within the top 20 list. This observation suggests that the aspect of "Colour" is frequently disregarded as one of the elements within the digital educational environment.

## 4.3 Pre-Experiments

### 4.3.1 Data Analysis

Descriptive statistical techniques (per cent) were used to analyse the reading time and the correct rate.

### 4.3.2 Findings

The pilot experiment assessed the impact of utilizing a red background in digital learning materials on learners' comprehension ability. The data relating to reading time and the percentage of correct responses from a sample of 8 participants is presented in Table 4.9.

**Table 4.7** Each participant's reading time and correction rate of the test in the pilot study.

| Participants | Reading Time _1 | Reading Time_2 | Correction rate_1 | Correction rate_2 |
|---|---|---|---|---|
| **Participant 1** | 6min 50s | 5min 10s | 60.00% | 40.00% |
| **Participant 2** | 3min 08s | 2min 33s | 40.00% | 40.00% |
| **Participant 3** | 4min 45s | 2min 51s | 40.00% | 20.00% |
| **Participant 4** | 4min 10s | 3min 45s | 20.00% | 20.00% |
| **Participant 5** | 3min 13s | 3min 05s | 60.00% | 40.00% |
| **Participant 6** | 8min 03s | 5min 32s | 80.00% | 0.00% |
| **Participant 7** | 4min 32s | 3min 20s | 20.00% | 40.00% |
| **Participant 8** | 5min 07s | 3min 57s | 0.00% | 100.00% |
| **Average** | 4min 58s | 3min 47s | 40.00% | 40.00% |
| **Maximum** | 8min 02s | 5min 32s | 80.00% | 100.00% |
| **Minimum** | 3min 08s | 2min 33s | 0.00% | 0.00% |

The study found main five key points from the pre-experiments and these are:

(1) Extreme Cases and Timely Feedback:

Some participants (e.g., Participant 6 and Participant 8) exhibited significant differences in correction rates between the two selections, indicating that one selection was much more correct than the other. Timely feedback revealed that the correct selection was more challenging for participants, even though they did not fully understand the content of that segment.

(2) Flaws in Material Design:

The experiment revealed flaws in the design of the materials, specifically the limited variety of question types (single-choice, multiple-choice, and true/false). Participants could answer questions correctly without fully grasping the content, leading to potentially misleading results about their comprehension.

(3) Variation in Passage Themes and Lengths:

Test Material 1 and Test Material 2 had different themes and word counts, affecting participants' reading speeds and comprehension difficulty. The theme of the passage and the complexity of sentences can influence participants' reading speed and comprehension level.

(4) Educational Background and Expertise:

Participants' varied educational backgrounds and potential areas of expertise could lead to differences in their understanding of different sections. Some participants might have coincidental familiarity with specific content areas, affecting their comprehension and scores.

(5) Overall Limitations:

The comprehension assessment method employed in this experiment has limitations and may not be sufficient to accurately determine participants' comprehension levels. The experiment highlights challenges in assessing comprehension due to the factors mentioned, including passage difficulty, question types, and participant background.

In conclusion, the experiment brings to light the complexities and limitations of using this particular comprehension assessment method. The observed differences in correction rates and participant feedback emphasize the need for a more comprehensive and nuanced approach to assessing comprehension. The design of assessment materials, the selection of passages, and the consideration of participant diversity are all critical factors that can influence the validity and reliability of such assessments.

## 4.4 Main Experiments

### 4.4.1 Data Analysis Methods

This study uses two statistical techniques. First, the average values were calculated. And, the correlation test was conducted to determine the meaningful relationships between two variables.

### 4.4.2 Findings

#### 4.4.2.1 Correction Rate and Response Time Mean Comparison in the group of Native and Non-Native English speakers.

As can be seen in Figure 4.1 (a), the average correction rates of the comprehension test for the native English group were about twice as high as for the non-native English group across all eight colour conditions. Also, it can be seen that the native English group showed a larger data variation in the correction rates between colours than those of the non-native English group. For example, the native English speakers performed best on average in the grey condition (M: 0.77; SD: 0.34), which is followed by red (M: 0.72; SD: 0.36), blue (M: 0.68; SD: 0.35), and black (M: 0.68; SD: 0.37). They showed lower correction rates in the other four colours, which ranged between 0.50 and 0.60. The non-native speakers, on the other hand, performed better on average in green (M: 0.35; SD: 0.32), yellow (M: 0.34; SD: 0.31) and blue (M: 0.33; SD: 0.32) conditions, however, the differences were not significant.

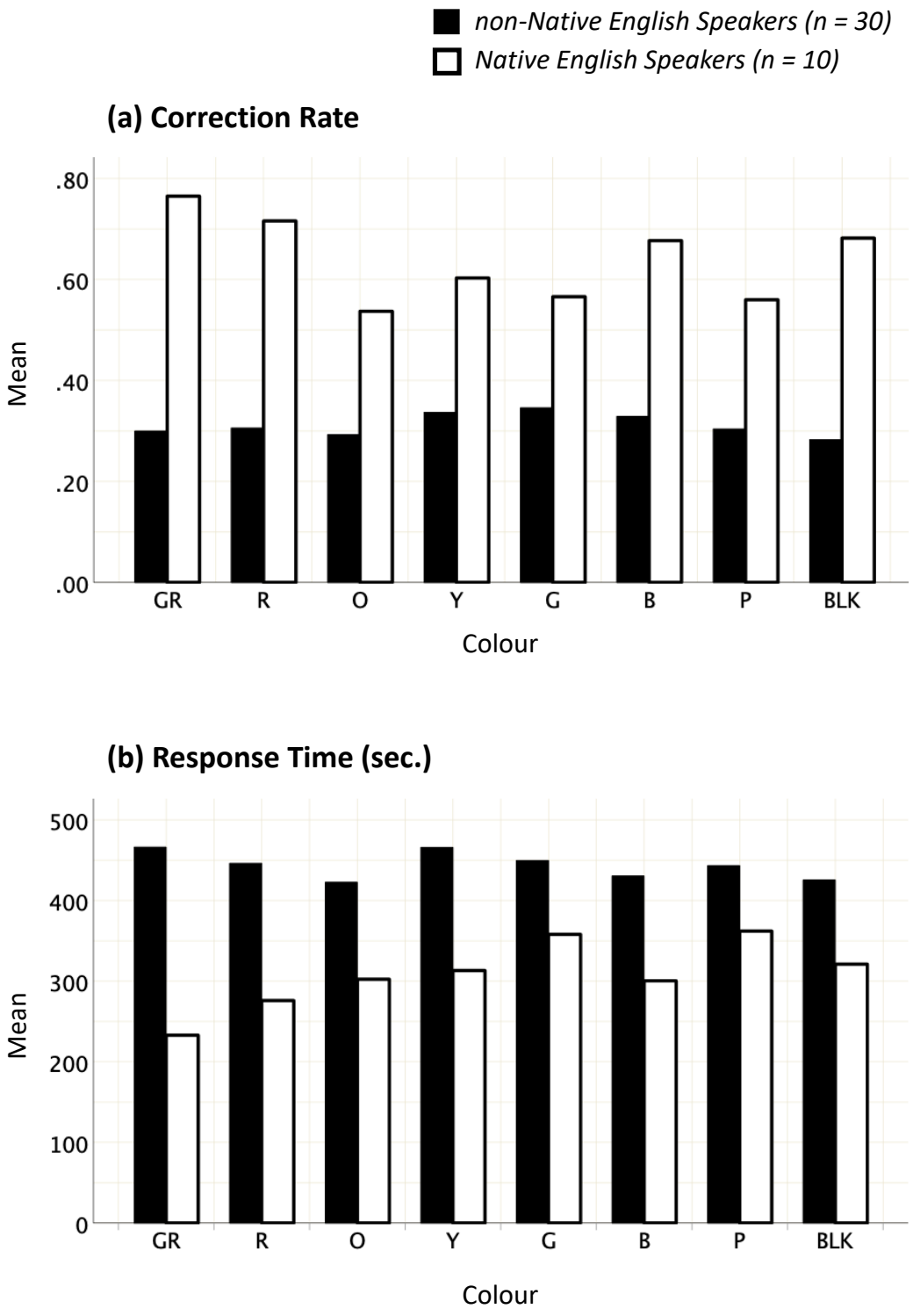



**Figure 4.3** Correction Rate and Response Time Mean Comparison in the group of Native and Non-Native English speakers.

Figure 4.1 (b) presents the average response time in two distinct groups exposed to eight different background materials of various Colours. Irrespective of the background Colour, it was observed that the non-native English speakers' group exhibited longer average response times compared

to the native English speakers' group. Notably, the discrepancy was most pronounced in the grey Colour condition, where the mean value was nearly twice as significant as that of the other group. The distribution of response time data generally aligns with Figure 4.1 (a), wherein the non-native English speakers' group displayed a relatively concentrated distribution within the 400–500 second range. Conversely, the data for the native English speakers' group demonstrated a wider range, with a difference of approximately 130 seconds between the maximum and minimum values. Analysing the data pertaining to the native English speakers' group, two Colours, namely Grey (M: 232.98; SD: 168.72) and Red (M: 276.01, SD: 197.20), stood out as superior, with average completion times below 300 seconds. This indicates that participants took less time to complete the test under these two Colour conditions. In contrast, for the non-native English speakers' group, the Colour that yielded the poorest performance was Grey (M: 466.12; SD: 267.78). On the other hand, the Colours orange (M: 422.71; SD: 272.31) and black (M: 425.50; SD: 227.77) demonstrated relatively better performance, with average response times only slightly lower than the other Colour conditions, without a distinct advantage.

In summary, the grey colour condition showed the best overall performance in the native English speakers' group, with the highest percentage of correct test responses and the shortest response times.

#### 4.4.2.2 The Correlation Between Response Time and Correction

Figure 4.2 shows the relationship between the mean response time (X-axis) and the average percentage of correctness (Y-axis) for different colours. The coloured points on the graph represent the distribution of different colours and the dotted line represents the overall trend line encompassing all the points.

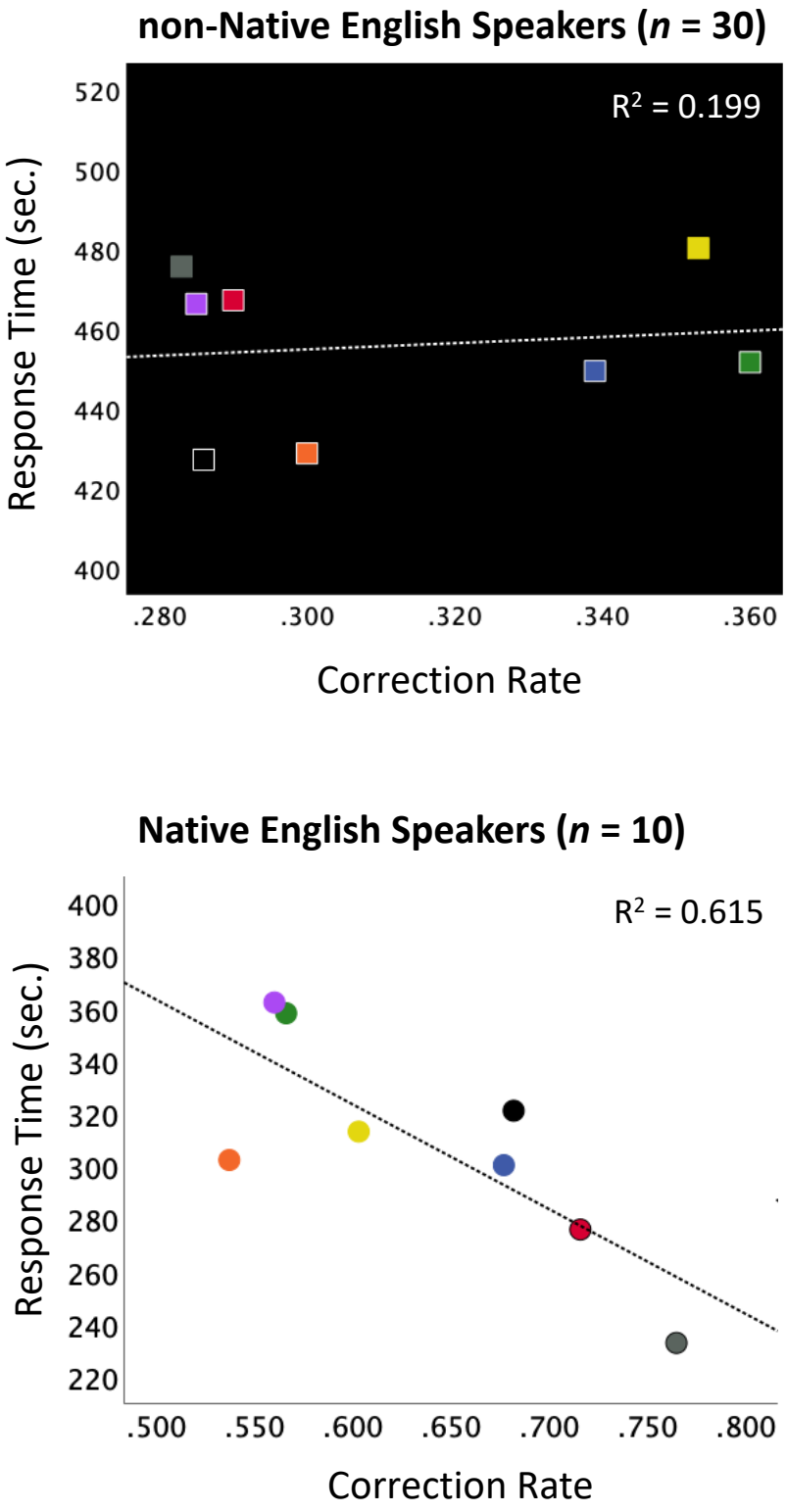



**Figure 4.4** Variable Correlation Line Diagram in the Non-native and Native.

In the non-native speaker group, the coefficient of determination ($R^2$) is calculated to be 0.199, indicating that the correlation between response time and correction rate is approximately 20%. This suggests that changes in one dimension (response time) do not strongly determine the changes observed in the other dimension (correction rate) in this group. In other words, there is a relatively weak relationship between the two variables. On the contrary, the relationship between response time and correction rate in the native English speaker group is markedly different. The $R^2$ value for this group is 0.615, significantly higher than that of the non-native speaker group. The overall data in this group exhibit a positive correlation, indicating a consistent pattern across different Colour conditions. Specifically, participants who took less time to complete the tests tended to achieve higher correction rates, and vice versa.

These findings highlight the contrasting nature of the relationship between response time and correction rate in the two groups. While the correlation is relatively weak in the non-native speaker group, the native English speaker group shows a stronger and more consistent association. These observations provide valuable insights into how the interplay between response time and correction rate differs based on language proficiency and cultural background. English group.

#### 4.4.2.3 Preference, Legibility, Readability

Figure 4.3 shows the results of the preference, legibility and readability scores on the comprehension tests on eight different colour backgrounds between the native English group and the non-native English group.

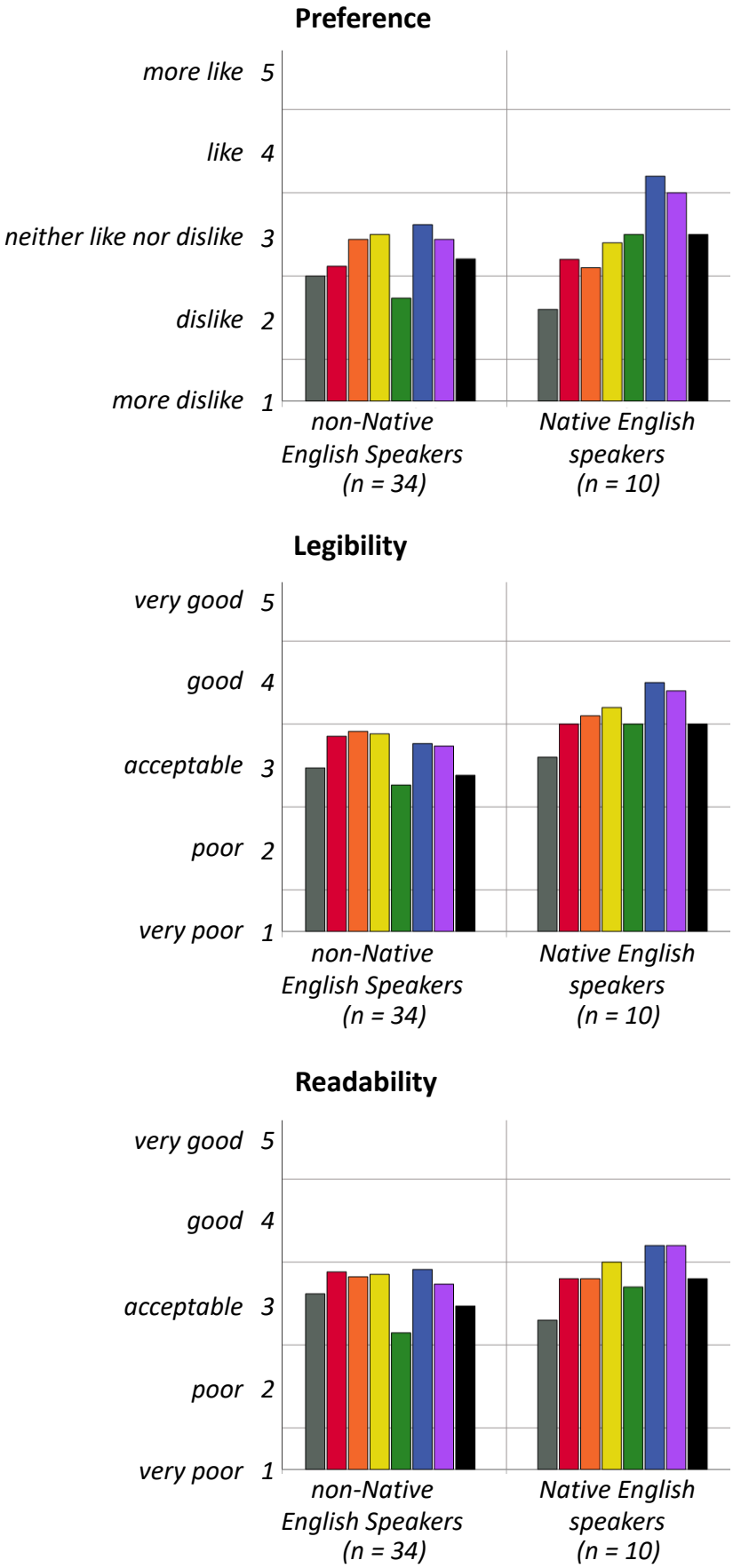



**Figure 4.5** Results of Online Questionnaire.

Regardless of learners' cultural backgrounds, the most preferred colour for the background of digital learning materials is consistently blue with means of 3.12 (SD: 1.15) for non-native English and 3.70 (SD: 1.16) for native English speakers. However, there is a clear distinction in the least preferred colour, with non-native English speakers least favouring green (M: 2.24; SD: 0.99), and native English speakers least choosing grey (M: 2.10; SD: 0.74). Interestingly, although grey was the least preferred colour among native English speakers, the previous data showed that they performed the best in the grey colour condition. This implies that participants' comprehension ability is not necessarily related to colour preference. Comprehension of text-based information was not necessarily better in the preferred colour condition. For instance, within the native English speaker group, preferences for red and orange were similar, yet the difference in performance between the two Colour conditions was significant, with red significantly outperforming orange. The non-native English speakers generally rated most colour preferences in the middle range, with no clear likes or dislikes, except for the clear dislike of green.

When it comes to legibility and readability for different font and background colour combinations, there was no significant difference in the evaluative scores between them. For example, in the non-native English speakers group, green had the lowest mean value for legibility (M: 2.76; SD: 1.13) and readability (M: 2.65; SD: 1.13). Grey had the lowest mean values for legibility and readability scores among the native English speakers group, with means and standard deviations of (M: 2.97; SD: 0.94) and (M: 3.12; SD: 0.95).

The relationship between colour preference, legibility, and readability is highly consistent for certain colours, for both groups. Blue consistently was shown as the most preferred colour for the background of digital learning materials and also as the most appropriate colour for legibility and readability (although there was an exemption for non-native English speakers' legibility score). The second preferred colour in the non-native English speakers group was purple, consistently ranking second and achieving the same highest mean as blue in the readability (M: 3.70), with slightly different standard deviations, blue (SD: 1.16) and purple (SD: 1.06). These colours exhibit distinct trends. However, when considering the experimental data, blue, despite excelling in several aspects such as preference, legibility, and ease of reading, did not yield the best performance among participants in the blue colour condition within the native English speakers group and fell only

within the upper-middle-range among the eight colours. Grey remained the unquestionably best colour.

## 4.5 Conclusions

In summary, two important conclusions could be drawn from the main experiment. First, the impact of colour on comprehension ability was more prominent in the non-native English speakers' group. No statistically significant association was observed in the native English speaker group. This suggests that participants' primary language, particularly English being their second language rather than their mother tongue, played a significant role in influencing comprehension in different colour backgrounds. The data indicates that cultural background had a greater impact on participants' comprehension than the effect of colour itself, especially in the non-native English speaker group. These findings highlight that comprehension is hindered when individuals are tested in a second language, overshadowing the influence of Colour on cognition. Therefore, in this specific group, the effect of Colour on comprehension was negligible compared to the influence of cultural background. Second, the results underscore the importance of considering participants' prior knowledge and language proficiency as they significantly impact the outcomes across all recorded dimensions. It is crucial to acknowledge that participants were not tested at the same difficulty level due to the primary factor of the language barrier. Consequently, when conducting experiments to assess the potential influence of Colour on comprehension, it is vital to ensure a balance between participants' abilities and the difficulty of the test questions. The questions should neither be excessively easy, eliminating any challenge, nor overly difficult, causing participants to primarily focus on understanding the questions themselves and losing sight of the potential effect of Colour.

These findings emphasise the significance of cultural background, particularly language proficiency, concerning comprehension abilities in different colour backgrounds. The results underscore the need to consider participants' language capabilities when investigating the impact of Colour on cognition. By addressing language barriers and ensuring an appropriate balance in the experimental design, future research can more accurately assess the effect of Colour on comprehension in diverse populations. Based on the conclusions of this research, the following conditions should be met to optimise comprehension in digital materials:

1. Legibility and readability: It is crucial to ensure that digital materials have high legibility and readability. This can be achieved by maintaining a contrast ratio of around 7:1 between the text and background Colour. This contrast ratio ensures that the text stands out clearly, making it easier to read and comprehend.
2. Text-based information: The research findings specifically apply to text-based information. It is important to note that the conclusions may not necessarily extend to other forms of content, such as images or multimedia elements. Further research is needed to explore the impact of Colour on comprehension in those contexts.
3. Higher education population without language barriers: The conclusions are derived from studying a higher education population without any language barriers. The participants were assumed to have a strong command of the language in which the information was presented. The findings may not be directly applicable to populations with language limitations or individuals with limited proficiency in the language used in the study.

Regarding specific Colours, the research identifies grey as the most effective Colour for presentation. Under the tested conditions, grey resulted in the highest correct rate on the psychometric comprehension test and the shortest completion time. Additionally, the study reveals that both grey and black, despite lacking specific Colour tendencies, performed similarly in terms of contrast. The font used in the grey background condition was black, while the font in the black background condition was reference grey, with the two combinations reversed. This implies that the light background with a dark font condition generally yielded better comprehension of textual information compared to the dark background with light text.

In conclusion, adhering to the identified conditions and employing a grey background for text-based information can optimize comprehension. However, it is important to consider that the conclusions pertain to the specific conditions and variables tested in the study. Further research is needed to explore the applicability and generalizability of these findings in different contexts and populations.

# Chapter 5
# Discussions and Conclusions

## 5.1 Introduction

The 5.2 discussions revolve around the intricate relationship between colour perception and its effects on human comprehension ability. It delves into how the pandemic shapes colour role and learners' experiences in the virtual learning environment, gathers learners' colour preferences, highlights the impact of colour in material design on information comprehension, explores cross-cultural interpretations of colour influenced by primary language, and evaluates study limitations while proposing avenues for future research. Next, the 5.3 conclusions draw these discussions together, emphasizing the significance of colour's role in designing materials' background colour in the digital learning environment. It underscores the need for a comprehensive, multidisciplinary approach to grasp its implications.

## 5.2 Discussions, Limitations, and Further Research

### 5.2.1 COVID-19 Impact and Colour's Role

The online focus group revealed that the COVID-19 pandemic significantly increased the acceptance and frequency of online learning among contemporary learners. However, the study indicated that colour is often overlooked as a crucial element in the digital educational environment. Notably, high-frequency vocabulary analysis showed a lack of colour-related keywords, highlighting the underappreciation of colour in educational materials.

This study aimed to understand contemporary online learners‘ experience in the virtual learning environment (VLE) with digital learning materials. A web-based survey was conducted in 2020. The study found that contemporary learners have shown a significant increase in the frequency and acceptance of online/distance education compared to before 2019. Due to the factors of the pandemic, The main findings of this study focus on the changes in contemporary learners' learning habits and the advantages and disadvantages of the digital learning materials they encounter during their learning process, it was observed that colour is often overlooked as a crucial element in the digital educational environment.

These findings are alien to studies of Rashid and Yadav (2020) and Aristovnik *et al.* (2020) researches result. They affirm the importance of online learning, the COVID-19 outbreak impacted the global economy and higher education. The pandemic revealed shortcomings in higher education and emphasized the need for digital technology training for educators. In the future, eLearning and virtual education may become integral to higher education, requiring institutions to plan post-pandemic education strategies to maintain learning outcomes and quality (Rashid and Yadav, 2020). From an overall perspective, the changes are not only limited to the quality of teaching but also extend to students' lifestyles, hygienic behaviours, and their satisfaction with the support from teaching staff and universities during the transition to online learning (Aristovnik *et al.*, 2020).

### 5.2.2 Material Design and Comprehension

In the pre-experiments, the effectiveness of experimental materials was tested on a smaller scale. Findings indicated flaws in the material design, specifically limited question types and variations. Participants were found to answer questions correctly without fully comprehending the content, compromising the accuracy of their responses. Moreover, the selection of test materials varied across participants' educational backgrounds, leading to differing levels of understanding across different sections.

The pre-experiments, aimed to test the effectiveness of experimental materials on a small scale. However, the results highlighted flaws in the material design, particularly in the limited variety of question types, which allowed participants to answer correctly without fully understanding the content. The selection of test materials from different disciplines and the varying educational backgrounds of participants further influenced their understanding of the content.

To assess a person's comprehension, in most cases, there are the following types of questions single-choice, multiple-choice, fill-in-the-blank ( cloze), and others on re-tells (Fletcher, 2006). However, many tests rely almost entirely on one of these question types, early research identified that reading comprehension involved multiple components that would appear depending on the formats used to present the material to be read and how the person was asked to indicate their understanding of it, as summarized by Pearson and Hamm (2005). Furthermore, as demonstrated in the article by Cutting and Scarborough (2006), the inferences made about how well a person

comprehends written material vary depending on how it is assessed. The articles stress the need for diagnostic tests to assess reading comprehension, providing insights for targeted interventions. Limited samples and lack of diversity call for larger studies. A comprehensive assessment should go beyond traditional methods, considering reader-text interaction. Observational techniques involving teachers' input can be beneficial. Integrating research and using a multimethod approach allow for assessing a wide range of latent variables and understanding their relations.

### 5.2.3 Primary Language and Colour Effects

The online questionnaires and main experiments compared data from native English speakers and non-native English speakers. Regardless of the group, blue emerged as the participants' favourite colour, followed by purple. When combining different colour backgrounds with text, similar trends were observed in terms of readability and legibility. However, language proficiency had a more significant impact on comprehension than colour. Among native English speakers, the grey colour condition yielded the best performance, with shorter response times and higher accuracy.

It utilised an online questionnaire and main experiments, comparing data from native English speakers and non-native English speakers. Regardless of the group, participants favoured blue and purple as their favourite colours. Readability and legibility trends were consistent within each group when considering different combinations of background colours and text. Considering language barriers, participants' native language had a more significant impact on comprehension than colour. However, after eliminating language influence, native English speakers performed best under the grey colour condition, exhibiting shorter response times and higher accuracy. One interesting aspect is that, in the study, black text was presented on a grey background, and in contrast, grey text was presented on a black background. Both combinations are achromatic colour combinations, and participants were exposed to nearly identical colour conditions with no other chromatic interventions. However, within the same group (English native speakers), the data from the two colour conditions showed a significant difference. Participants' comprehension of textual information was much better in the grey background condition than in the black background condition. This may suggest a pattern where participants perform better with light-coloured backgrounds and dark-coloured foregrounds compared to dark-coloured backgrounds and light-coloured foregrounds.

The findings of this study contribute to the field of knowledge by shedding light on the preferences and performance of contemporary learners in the virtual learning environment. The preference for blue and purple colours indicates a potential for incorporating these colours in educational materials to enhance engagement and readability. The results of this study show a remarkable resemblance to previous research findings, including data collected from the tertiary education population. In both the online experimental environment and the laboratory experimental environment, participants' preference scores ranked blue as the highest (26% for online, 31% for laboratory), followed by red (21% for online, 23% for laboratory), orange (16% for online, 13% for laboratory), yellow (13% for online and laboratory), purple (12% for online, 13% for laboratory), and green (12% for online, 7% for laboratory) (Yu *et al.*, 2021). Another example, in Hanafy and Sanad's (2015) study, they found that educational background plays a significant role in shaping personality traits, which in turn influence individual colour preferences. The research involved collecting questionnaires from 80 participants, including students from the graphic design and information technology departments, both at the beginning and end of their studies. The participants were asked to choose their preferred colour for clothing and living room settings. Among the total subjects, "Blue" emerged as the most preferred colour for clothing, selected by 15% of the participants. Even at different age stages, 8-9-year-old children's colour preferences show surprising similarities to those of adults (Brooker and Franklin, 2016).

The research also suggests that colour design in digital learning materials can have an impact on comprehension, particularly among native English speakers. In addition to colour preferences, the study conducted by Brooker and Franklin(2016) highlights a significant difference in cognitive performance based on colours. Performance is notably worse in the presence of red compared to grey. The effect of colour remains consistent across different tasks. These findings provide evidence that colour can influence children's cognitive performance, with red specifically having a detrimental effect. In contrast to the findings of this study, Elliot and Aarts (2011) reported different results. In their research, participants' performance on aspects related to movement, such as maximum force, mean force over time (N), and slope toward maximum force (N/sec), was not ideal under the condition of grey colour compared to equally bright and chromatic red and blue colours.

Regardless of the group, the performance in the grey colour condition was inferior to that in the red and blue conditions, with red being the most favourable. From these research results, an alternative interpretation could be considered, suggesting that while the grey colour condition may not optimize individuals' movement and strength performance, it might be more suitable for activities that are entirely different, such as static or learning environments. Furthermore, a mounting body of contemporary research suggests that colour can influence cognitive task performance. Specifically, the presence of the colour red appears to negatively impact adults' cognitive performance compared to other colours (Elliot and Maier, 2014).

### 5.2.4 Limitations and Further Research

Specific limitations should be acknowledged during the initial phases of research design, which encompass activities like online focus groups and pre-experiments. In the context of focus groups, potential constraints arise from relatively modest sample sizes and the potential for participants to influence each other's responses. Similarly, pre-experiments unveiled limitations by highlighting inconsistencies in participant comprehension. The design of materials exhibited shortcomings, resulting in diverse question types that yielded accurate responses devoid of genuine comprehension. Variations in reading speed and the complexity of themes surfaced among passages, consequently affecting participants' understanding. It's essential to note that this form of comprehension assessment is constrained, prompting inquiries into its efficacy in gauging participants' grasp of the subject matter.

Some limitations of the final study. The sample size may not fully represent the entire higher education population. The experimental design involved participants completing two different questions under each colour condition, with time taken and correctness scores recorded separately. The statistical analysis relied on a multiplied sample size of 2 for the same colour condition, considering the number of participants. However, drawing conclusions with higher confidence would have been possible if participants had completed more questions within each colour condition. Alternatively, increasing the participant pool would have bolstered the credibility of the findings.

Utilizing the relative luminance formula, the contrast between the foreground and background was managed within a tight interval, explicitly ranging from 7.31 to 7.39. In theory, participants' acceptance of legibility and readability

across varying coloured backgrounds should have demonstrated uniformity, yet they highlighted visual distinctions among the diverse colour combinations. The study maintained a consistent contrast ratio of around 7.3:1 between fonts and background colours, following the belief that higher contrast ratios enhance legibility and readability. However, the selected contrast ratio of 7.3:1 is just one of the viable options for acceptable ratios. Further investigation is necessary to determine whether participants' comprehension would be optimized or diminished with an even higher contrast ratio.

It is important to acknowledge that all the results are based on the higher education population, which already possesses a higher level of learning and understanding compared to other education levels. Consequently, the impact of colour on the learning process may be relatively minor within this specific group. To gain a more comprehensive understanding, it would be valuable to apply the same experimental method to different age groups or individuals with varying educational backgrounds, as the effect of colour could potentially be more significant in those contexts. The selection of test materials could have introduced bias.

Additionally, the study primarily focused on text-based comprehension, and other factors such as multimedia elements were not extensively explored.

Further research is recommended to address these limitations and expand the understanding of colour design's impact on comprehension in digital learning materials. Future studies could explore the effects of multimedia elements, consider a broader range of disciplines and educational backgrounds, and investigate the preferences and performance of non-native English speakers.

In terms of practice and policy recommendations, educational institutions and designers should consider incorporating grey in digital learning materials, as the colour may not align with learners' preferences. However, further research is needed to determine optimal colour combinations and their impact on comprehension in various contexts. Designers should also focus on creating diverse question types to ensure comprehensive understanding and accurate assessment of learners' knowledge and skills.

In conclusion, this study provides valuable insights into the potential of different background colours in digital educational materials for enhancing comprehension in the virtual learning context. It highlights the importance of considering learners' preferences and suggests areas for further research

and recommendations for practice and policy in colour design for higher education.

## 5.3 Conclusions

This chapter discusses the findings and implications of three studies conducted to explore the impact of colour design on comprehension in digital learning materials within the virtual learning environment (VLE). Study 1 aimed to understand contemporary online learners' experiences in the VLE with digital learning materials. It revealed a significant increase in the acceptance of online education due to the pandemic. Despite this, the importance of colour in the digital educational environment was often overlooked. Study 2, involving pre-experiments, identified flaws in material design, impacting participants' understanding of the content. The study highlighted the need for diverse question types in comprehensive reading comprehension assessment. Study 3 utilised an online questionnaire and main experiments to compare data from native English speakers and non-native English speakers. Participants favoured blue and purple as their preferred colours and comprehension performance was best under the grey background condition for native English speakers. In conclusion, the chapter emphasizes the role of colour in cognitive performance and offers practice and policy recommendations. It suggests incorporating grey in digital materials while considering diverse question types and conducting further research to optimise colour combinations for different contexts.

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## List of Abbreviations

1. The abbreviation "SOI" stands for "Signalling, Organizing, and Integrating." In the context of Mayer's SOI model of meaningful learning, it refers to a framework that emphasizes the importance of incorporating signalling cues, organizing information, and integrating new material with prior knowledge to promote effective learning and comprehension.
2. CL: Cognitive Load
3. CLT: Cognitive Load Theory
4. CTML: the Cognitive Theory of Multimedia Learning
5. CATLM: the Cognitive Affective Theory of Learning with Media
6. aCLT: the augmented Cognitive Load Theory
7. ICALM: The integrated Cognitive Affective Model of Learning with Multimedia
8. CASTLE: the Cognitive-Affective-Social Theory of Learning Environment
9. ICBT: The online Ishihara Colour Blindness Test

# Appendix A
## Data analysis of the main experiment psychometric test- word changes test

### A.1 Mean, Number and Standard Deviation of correction rate in the group of native English speakers and non-native speakers of English (accurate to three decimal places)

**Report**

| Cultural_Backgrounds | | S_Grey | S_Red | S_Orange | S_Yellow | S_Green | S_Blue | S_Purple | S_Black |
|---|---|---|---|---|---|---|---|---|---|
| non-English | Mean | .299 | .305 | .293 | .336 | .346 | .328 | .303 | .282 |
| | N | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| | Std. Deviation | .324 | .299 | .297 | .308 | .315 | .315 | .266 | .289 |
| English | Mean | .765 | .716 | .537 | .603 | .565 | .676 | .560 | .681 |
| | N | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| | Std. Deviation | .342 | .360 | .364 | .347 | .334 | .347 | .377 | .374 |
| Total | Mean | .415 | .408 | .354 | .403 | .400 | .415 | .367 | .382 |
| | N | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 |
| | Std. Deviation | .384 | .361 | .330 | .336 | .332 | .355 | .316 | .355 |

S: Correction Rate

## A.2 Mean, Number and Standard Deviation of response time in the group of native English speakers and non-native speakers of English (accurate to three decimal places)

**Report**

| Cultural_Backgrounds | | T_Grey | T_Red | T_Orange | T_Yellow | T_Green | T_Blue | T_Purple | T_Black |
|---|---|---|---|---|---|---|---|---|---|
| non-English | Mean | 466.115 | 446.206 | 422.705 | 465.888 | 449.661 | 430.510 | 443.293 | 425.499 |
| | N | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| | Std. Deviation | 267.775 | 328.925 | 272.308 | 298.935 | 308.908 | 274.903 | 298.967 | 227.770 |
| English | Mean | 232.978 | 276.008 | 302.400 | 313.178 | 358.073 | 300.446 | 362.185 | 321.100 |
| | N | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| | Std. Deviation | 168.716 | 197.204 | 196.118 | 221.217 | 331.643 | 228.859 | 342.030 | 230.456 |
| Total | Mean | 407.831 | 403.656 | 392.629 | 427.711 | 426.764 | 397.994 | 423.015 | 399.399 |
| | N | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 |
| | Std. Deviation | 265.927 | 309.281 | 259.572 | 287.986 | 315.137 | 268.791 | 310.061 | 231.491 |

T: Response Time

# Appendix B
## Data analysis of the main experiment- online questionnaire

### B.1 The 5-point Likert Scale data analysis in three dimensions preference, legibility and readability

**Report**

| Language | | P_Grey | P_Red | P_Orange | P_Yellow | P_Green | P_Blue | P_Purple | P_Black |
|---|---|---|---|---|---|---|---|---|---|
| non-English | Mean | 2.50 | 2.62 | 2.94 | 3.00 | 2.24 | 3.12 | 2.94 | 2.71 |
| | N | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 |
| | Std. Deviation | 1.080 | 1.181 | 1.127 | 1.128 | .987 | 1.149 | 1.153 | 1.338 |
| English | Mean | 2.10 | 2.70 | 2.60 | 2.90 | 3.00 | 3.70 | 3.50 | 3.00 |
| | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | Std. Deviation | .738 | 1.059 | 1.075 | 1.197 | 1.414 | 1.160 | 1.434 | .943 |
| Total | Mean | 2.41 | 2.64 | 2.86 | 2.98 | 2.41 | 3.25 | 3.07 | 2.77 |
| | N | 44 | 44 | 44 | 44 | 44 | 44 | 44 | 44 |
| | Std. Deviation | 1.019 | 1.143 | 1.112 | 1.131 | 1.127 | 1.164 | 1.228 | 1.255 |

P: Preference

**Report**

| Language | | L_Grey | L_Red | L_Orange | L_Yellow | L_Green | L_Blue | L_Purple | L_Black |
|---|---|---|---|---|---|---|---|---|---|
| non-English | Mean | 2.97 | 3.35 | 3.41 | 3.38 | 2.76 | 3.26 | 3.24 | 2.88 |
| | N | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 |
| | Std. Deviation | .937 | .917 | .925 | 1.129 | 1.130 | 1.082 | 1.017 | 1.387 |
| English | Mean | 3.10 | 3.50 | 3.60 | 3.70 | 3.50 | 4.00 | 3.90 | 3.50 |
| | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | Std. Deviation | .994 | 1.080 | 1.075 | .949 | 1.269 | 1.054 | .738 | 1.179 |
| Total | Mean | 3.00 | 3.39 | 3.45 | 3.45 | 2.93 | 3.43 | 3.39 | 3.02 |
| | N | 44 | 44 | 44 | 44 | 44 | 44 | 44 | 44 |
| | Std. Deviation | .940 | .945 | .951 | 1.088 | 1.189 | 1.108 | .993 | 1.355 |

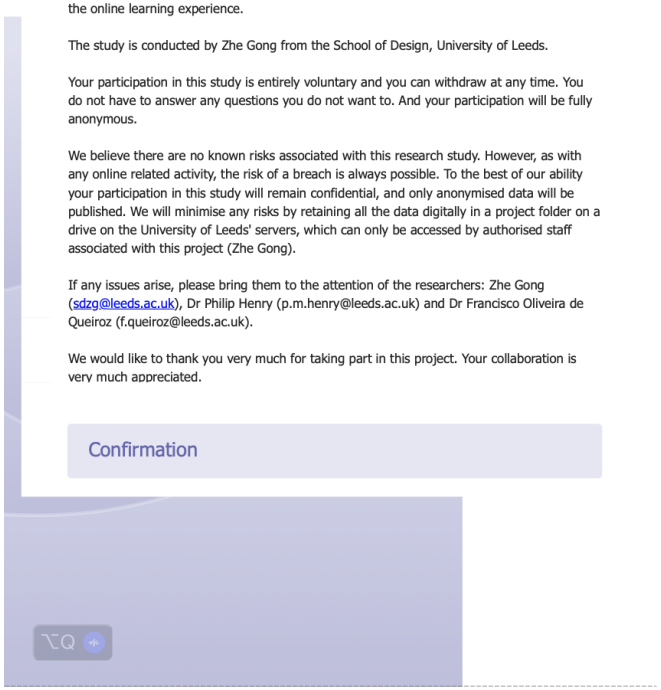
L: Legibility

**Report**

| Language | | R_Grey | R_Red | R_Orange | R_Yellow | R_Green | R_Blue | R_Purple | R_Black |
|---|---|---|---|---|---|---|---|---|---|
| non-English | Mean | 3.12 | 3.38 | 3.32 | 3.35 | 2.65 | 3.41 | 3.24 | 2.97 |
| | N | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 |
| | Std. Deviation | .946 | .985 | .976 | 1.098 | 1.125 | 1.131 | 1.156 | 1.337 |
| English | Mean | 2.80 | 3.30 | 3.30 | 3.50 | 3.20 | 3.70 | 3.70 | 3.30 |
| | N | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| | Std. Deviation | 1.033 | 1.160 | .949 | 1.269 | 1.549 | 1.160 | 1.059 | .949 |
| Total | Mean | 3.05 | 3.36 | 3.32 | 3.39 | 2.77 | 3.48 | 3.34 | 3.05 |
| | N | 44 | 44 | 44 | 44 | 44 | 44 | 44 | 44 |
| | Std. Deviation | .963 | 1.014 | .959 | 1.125 | 1.236 | 1.131 | 1.140 | 1.257 |

R: Readability

# Appendix C
# The online questionnaire_ Learners' online educational experience



## Learners' online educational experience

The survey will take approximately 7 minutes to complete. You are being invited to participate in a research study conducted to explore the potential effect of colour design on the online learning experience.

The study is conducted by Zhe Gong from the School of Design, University of Leeds.

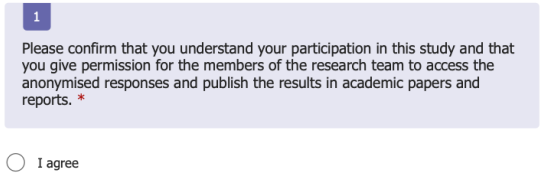
Your participation in this study is entirely voluntary and you can withdraw at any time. You do not have to answer any questions you do not want to. And your participation will be fully anonymous.

We believe there are no known risks associated with this research study. However, as with any online related activity, the risk of a breach is always possible. To the best of our ability your participation in this study will remain confidential, and only anonymised data will be published. We will minimise any risks by retaining all the data digitally in a project folder on a drive on the University of Leeds' servers, which can only be accessed by authorised staff associated with this project (Zhe Gong).

If any issues arise, please bring them to the attention of the researchers: Zhe Gong (sdzg@leeds.ac.uk), Dr Philip Henry (p.m.henry@leeds.ac.uk) and Dr Francisco Oliveira de Queiroz (f.queiroz@leeds.ac.uk).

We would like to thank you very much for taking part in this project. Your collaboration is very much appreciated.

Confirmation



1

Please confirm that you understand your participation in this study and that you give permission for the members of the research team to access the anonymised responses and publish the results in academic papers and reports. *

○ I agree

## A. Participant Information

2

What is your age? *

3

What is your gender? *

- Male
- Female
- Non-binary
- Prefer not to say
- Other

4

What is your nationality? *

5

What is your primary Language? *

6

What is your programme of study? *

7

What is your current year of study? *

## B. Online learning experience

**8**

What would be your preferred mode of study in most cases? *

- ◯ Traditional face-to-face classroom learning
- ◯ Online/distance learning
- ◯ Blending learning (both online and traditional face-to-face classroom learning)

**9**

How knowledgeable do you think you are with distance/online learning? *

| | Very good | Good | Acceptable | Poor | Very poor |
|---|---|---|---|---|---|
| Knowledge | ◯ | ◯ | ◯ | ◯ | ◯ |

**10**

How often did you experience distance/online learning **BEFORE** pandemic? *

| | All the time | Usually | About half the time | Seldom | Never |
|---|---|---|---|---|---|
| Frequency | ◯ | ◯ | ◯ | ◯ | ◯ |

**11**

How often did you experience distance/online learning **DURING** pandemic? *

| | All the time | Usually | About half the time | Seldom | Never |
|---|---|---|---|---|---|
| Frequency | ◯ | ◯ | ◯ | ◯ | ◯ |

**12**

Are you satisfied with the quality of your online learning? *

| | Very satisfied | Satisfied | Neither satisfied nor dissatisfied | Dissatisfied | Very dissatisfied |
|---|---|---|---|---|---|
| Satisfaction | ◯ | ◯ | ◯ | ◯ | ◯ |

13

What main DIFFICULTIES have you faced during online/distance learning? (choose as many answers as you need) *

- [ ] Actively participated
- [ ] Access to online materials
- [ ] Ability to learn on own space (self-discipline)
- [ ] Comfortable surrounding
- [ ] Reduced interaction with instructor and others
- [ ] Social isolation
- [ ] Technical problems
- [ ] Too challenging eLearning materials
- [ ] Other

14

How much do you agree that it is difficult to concentrate and more easily distracted when doing online education? *

| | Strongly agree | Agree | Neither agree nor disagree | Disagree | Strongly disagree |
|---|---|---|---|---|---|
| Agreement | ○ | ○ | ○ | ○ | ○ |

15

Do you think online instructional material is essential to help you learn effectively and understand the content of the online courses more easily? *

| | Strongly agree | Agree | Neither agree nor disagree | Disagree | Strongly disagree |
|---|---|---|---|---|---|
| Agreement | ○ | ○ | ○ | ○ | ○ |

16

What educational materials do/did you use frequently in online/distance learning? (you can choose more than one) *

- [ ] Live lecture slide presentation
- [ ] Lecture recordings
- [ ] Podcasts
- [ ] Videos
- [ ] Animation
- [ ] Interactive materials
- [ ] Polls and quizzes
- [ ] Live chat and discussions
- [ ] Digital textbooks
- [ ] Online tests and exams
- [ ] Online workshops and labs
- [ ] Other

17

Do you usually download online/distance learning slides? *

| | All the time | Usually | About half the time | Seldom | Never (I read them online) |
|---|---|---|---|---|---|
| Frequency | ○ | ○ | ○ | ○ | ○ |

18

Do you think the slides you have used or are using have any barriers in terms of content delivery? *

| | Very difficult | Difficult | Neutral | Easy | Very easy |
|---|---|---|---|---|---|
| Difficulty | ○ | ○ | ○ | ○ | ○ |

19

Do you agree that colour is essential for online learning materials design? *

| | Strongly agree | Agree | Neither agree nor disagree | Disagree | Strongly disagree |
|---|---|---|---|---|---|
| Agreement | ○ | ○ | ○ | ○ | ○ |

20

What device(s) do you usually use for online courses? (You can choose more than one) *

- [ ] Laptop
- [ ] Mobile phone
- [ ] Tablet
- [ ] Other

21

What is the environment in which you regularly do your online learning? *

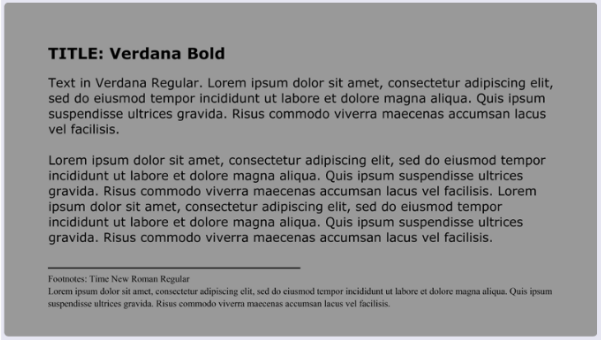
- [ ] Indoor - good lighting conditions (bright environment)
- [ ] Indoor- poor lighting conditions (dark environment)
- [ ] Outdoor- natural light
- [ ] Other

## Online Learning Materials' Background Colour Preference, Legibility & Readability

**Legibility**- The degree to which glyphs (individual characters) in text are understandable or recognizable based on appearance.
**Readability**- This refers to how easy it is to read and understand large passages of text. It can often be confused with legibility, which refers to the recognition of individual characters, not whole words or paragraphs.

22

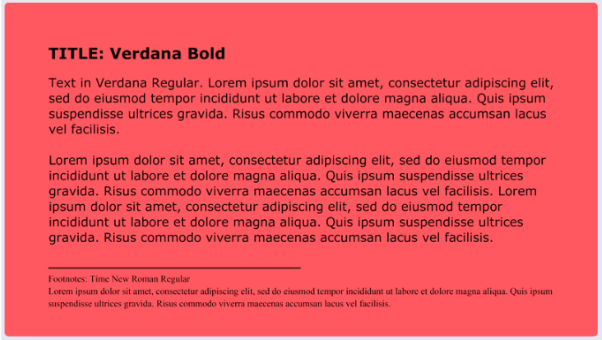
If the online learning material (slide) you're using has the following background colour, what extent do you think it's appropriate based on your preferences?
Please also rate the online learning material below in descending order from left to right regarding legibility and readability.




| | Very good | Good | Acceptable | Poor | Very poor |
|---|---|---|---|---|---|
| Preference | ○ | ○ | ○ | ○ | ○ |
| Legibility | ○ | ○ | ○ | ○ | ○ |
| Readability | ○ | ○ | ○ | ○ | ○ |

23

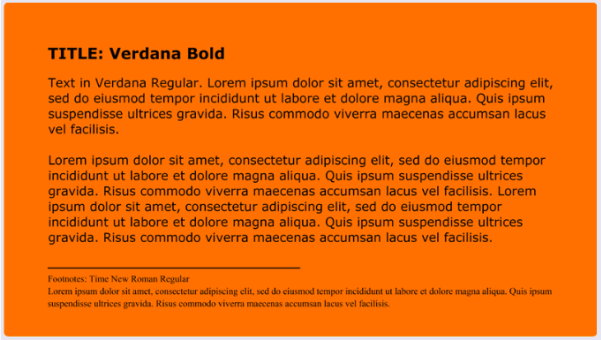
If the online learning material (slide) you're using has the following background colour, what extent do you think it's appropriate based on your preferences?
Please also rate the online learning material below in descending order from left to right regarding legibility and readability.




| | Very good | Good | Acceptable | Poor | Very poor |
|---|---|---|---|---|---|
| Preference | ○ | ○ | ○ | ○ | ○ |
| Legibility | ○ | ○ | ○ | ○ | ○ |
| Readability | ○ | ○ | ○ | ○ | ○ |

24

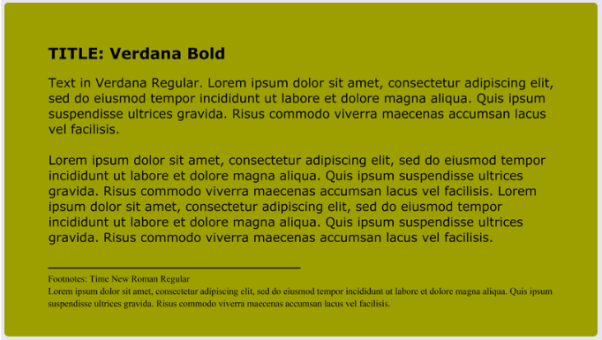
If the online learning material (slide) you're using has the following background colour, what extent do you think it's appropriate based on your preferences?
Please also rate the online learning material below in descending order from left to right regarding legibility and readability.




| | Very good | Good | Acceptable | Poor | Very poor |
|---|---|---|---|---|---|
| Preference | ○ | ○ | ○ | ○ | ○ |
| Legibility | ○ | ○ | ○ | ○ | ○ |
| Readability | ○ | ○ | ○ | ○ | ○ |

25

If the online learning material (slide) you're using has the following background colour, what extent do you think it's appropriate based on your preferences?
Please also rate the online learning material below in descending order from left to right regarding legibility and readability.




| | Very good | Good | Acceptable | Poor | Very poor |
|---|---|---|---|---|---|
| Preference | ○ | ○ | ○ | ○ | ○ |
| Legibility | ○ | ○ | ○ | ○ | ○ |
| Readability | ○ | ○ | ○ | ○ | ○ |

26

If the online learning material (slide) you're using has the following background colour, what extent do you think it's appropriate based on your preferences?
Please also rate the online learning material below in descending order from left to right regarding legibility and readability.


| | Very good | Good | Acceptable | Poor | Very poor |
|---|---|---|---|---|---|
| Preference | ◯ | ◯ | ◯ | ◯ | ◯ |
| Legibility | ◯ | ◯ | ◯ | ◯ | ◯ |
| Readability | ◯ | ◯ | ◯ | ◯ | ◯ |

27

If the online learning material (slide) you're using has the following background colour, what extent do you think it's appropriate based on your preferences?
Please also rate the online learning material below in descending order from left to right regarding legibility and readability.


| | Very good | Good | Acceptable | Poor | Very poor |
|---|---|---|---|---|---|
| Preference | ◯ | ◯ | ◯ | ◯ | ◯ |
| Legibility | ◯ | ◯ | ◯ | ◯ | ◯ |
| Readability | ◯ | ◯ | ◯ | ◯ | ◯ |

28

If the online learning material (slide) you're using has the following background colour, what extent do you think it's appropriate based on your preferences?
Please also rate the online learning material below in descending order from left to right regarding legibility and readability.


| | Very good | Good | Acceptable | Poor | Very poor |
|---|---|---|---|---|---|
| Preference | ○ | ○ | ○ | ○ | ○ |
| Legibility | ○ | ○ | ○ | ○ | ○ |
| Readability | ○ | ○ | ○ | ○ | ○ |

29

If the online learning material (slide) you're using has the following background colour, what extent do you think it's appropriate based on your preferences?
Please also rate the online learning material below in descending order from left to right regarding legibility and readability.


| | Very good | Good | Acceptable | Poor | Very poor |
|---|---|---|---|---|---|
| Preference | ○ | ○ | ○ | ○ | ○ |
| Legibility | ○ | ○ | ○ | ○ | ○ |
| Readability | ○ | ○ | ○ | ○ | ○ |