# The Research into Dark Mode: A Systematic Review Using a Two-Stage Approach and the S-O-R Framework

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## Abstract

Dark mode in mobile applications has gained significant popularity in the business world, with many users opting to use it for various reasons. However, dark mode is still a relatively new area of study in academia, with limited research on its definition and concept. Moreover, there is a lack of academic research on current investigations and potential developments related to the dark mode. The advantages and disadvantages of dark mode are still a topic of debate. This paper conducted a thorough evaluation of the scholarship on dark mode across various disciplines. The goal was to establish a solid research process for studying the concept of dark mode and user experience. By doing so, it aims to lay a strong foundation for future investigations into the relationship between dark mode and the user

experience. This paper conducted a comprehensive search and collection of articles on dark mode research over the past 30 years using a two-step approach, according to the Scopus database. A total of thirty-five articles were chosen according to the specified criteria for inclusion and exclusion. This paper thoroughly examines the themes, background, theoretical foundations, and research methods surrounding dark mode. It organised and combined the different factors of dark mode research using the Stimulus-Organism-Response (S-O-R) framework. The research framework presented here delves into the intricate concept of dark mode and explores the interplay between various factors, user experience, and user behaviours. Furthermore, this paper also highlighted the deficiencies in the current document studies and presented potential avenues for future research on dark mode.

**Keyword:** Dark Mode, Two-stage Approach, S-O-R Framework, Bibliometric Analysis, User Experience (UX), Screen Display Technology, Systematic Review, Research Framework.

## Introduction

"Dark mode" in IT and business refers to a screen display technology that adjusts the screen's interface to provide a comfortable viewing experience, specifically tailored for low-light environments. This is achieved by using a dark colour palette and white text (Xie et al., 2021). In the early displays, the only option available was dark mode, where the text appeared in white, green, or amber against a dark background (Lunn & E, 2022). Past research has indicated that dark mode can be beneficial for individuals with vision impairments who seek to alleviate visual exhaustion (Erickson et al., 2021). Additionally, it is indeed a fact that using phones with dark mode activated can result in energy conservation (Xu et al., 2019). Many young people nowadays are embracing the dark mode feature on their electronic devices, seeing it as a stylish and trendy design choice (Pedersen et al., 2020). Using dark mode is becoming more prevalent in our daily lives for a variety of reasons, and it has a noticeable impact on business and society (Scaglione, 2022). The provided information suggests that despite some research on dark mode, professional and academic settings have not received enough attenti (Eisfeld & Kristallovich, 2020).

Currently, there is a lack of a comprehensive research framework and systematic review regarding dark mode. Previous studies on dark mode have not thoroughly

explored the concepts, theoretical foundations, research methods, and conclusive findings. Furthermore, there is ongoing debate and conflicting results among various studies. (Dobres et al., 2016b; Gao et al., 2021; Pedersen et al., 2020; Zlokazova & Burmistrov, 2017a) In addition, the widespread use of dark mode in various industries can pose challenges for individuals seeking to grasp the academic principles and theoretical framework behind it. Therefore, it is essential to establish a universal framework that encompasses various business domains, technical systems, theories, and user experiences in order to comprehensively understand the concept of dark mode.

This paper offers a thorough and methodical examination of previous studies on dark mode. The selected corpus of literature is thoroughly examined, analysing every aspect of each publication, such as its definition, theoretical foundations, research methods, and historical background of dark mode. This study aims to improve our understanding of the dark mode and integrate the research findings into a comprehensive academic research framework. This framework will serve as a valuable resource for future investigations on the effects of the dark mode on individuals. By conducting a thorough analysis of existing empirical research, this study enhances our comprehension of dark mode and its impact on user experience. It also highlights effective approaches to investigating dark mode's features and overall experience. The paper is structured as follows: First, we will discuss the definition of dark mode and its related concepts. We also outline the process of searching for relevant literature and conduct a thorough analysis on 35 carefully selected research papers. We have developed a research framework using the S-O-R theory and data from these papers. This framework can be utilised as a systematic research process to identify and integrate factors associated with dark mode and its impact on the user experience. Lastly, the paper explores the theoretical and practical contributions of the study, along with future directions and priorities for further research on dark mode.

## Definitions of Dark Mode and Related Concepts

Dark mode is a software option that alters the user interface to have a darker

appearance. This tool alters the appearance of light backgrounds to a darker colour and adjusts dark text to a lighter shade. The result is a pseudo-inverted interface, primarily adorned in subdued hues (Christensson, 2019). Some design experts in the tech industry view dark mode as a colour style and trend that primarily utilises darker hues. This design style aligns with the prevalent trend of default interfaces, characterised by its predominant use of light tones (Hoober & S, 2020). Figure 1 shows the interface's system design, which includes a dark mode feature. This feature automatically adjusts the colour scheme to protect users' eyes and make them more comfortable when looking at the screen for extended periods of time. Additionally, it aids in mitigating the potential harm resulting from prolonged exposure to screen light.

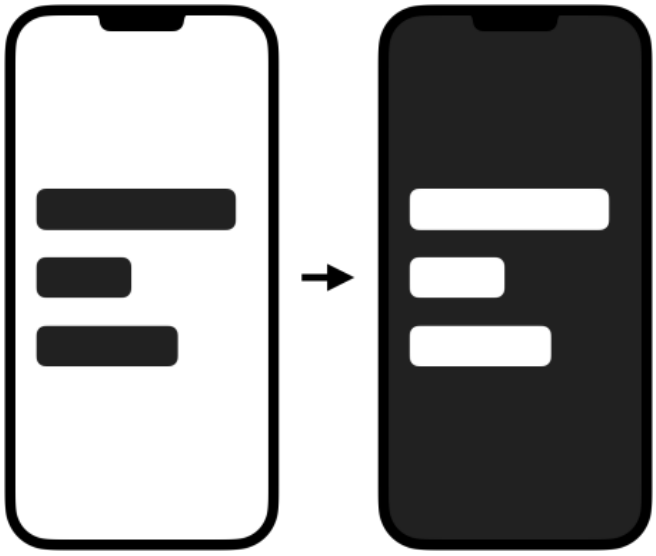

Figure 1: The Comparison of The Interface Between Dark and Light Mode.

Dark mode was originally a technique and design used for screen display in academia. The given definition refers to the visual effects of light text and content on a dark background as "negative display polarity" or "negative contrast polarity" (Dillon, 1992; Sethi & Ziat, 2023). In order to fully explore the concept of dark mode and its significance in the business world, this paper not only examines the definitions of dark mode in academic research, but also incorporates terminology from the commercial industry. These key words include concepts that are closely related to dark mode.

Table1: Definition of Dark Mode and Its Related Concepts.

| Concept | Definition | Reference |
|---|---|---|
| Dark mode | Dark mode is a software provision for websites and applications within an operating system that adumbrates the user interface. It transforms devices and applications that have conventionally possessed a light background with a ranging from grey to black. | (Christensson, 2019; Developer & iOS, 2022; Goldberg & D, 2021) |
| Black mode | Black mode is a digital feature that renders a transformative effect upon the user. Its philosophical underpinnings rest upon the principle of minimising screen-emitted light. Historically, cathode ray tube limitations compelled early computer screens to utilise a "black mode". | (Lunn et al., 2022) |
| Dark theme | Dark theme is a low-light user interface style that displays mainly dark surfaces. The dark theme displays dark surfaces in most user interfaces. It is designed as a complementary mode to the default (or light) theme. | (Developers, 2022; Google, 2022; Lunn et al., 2022) |
| Night mode | The functional objectives and techniques of Night Mode are largely the same as those of Dark Mode, i.e. dark backgrounds with light content to reduce eye strain. Dark mode can be used both during the day and at night; however, night mode is more recommended for nighttime use. Dark mode switches the background of the user interface to a darker shade, while night mode changes the colour emitted from the screen to a warmer colour. | (Christensson, 2019; Xie et al., 2021) |
| Light mode | Light mode is the default option for the interface of devices such as mobile phones and computers. In this setting, black or dark text sits on top of a white or light-coloured screen, simulating the appearance of ink on paper. | (Erickson et al., 2021; Koning & Junger, 2021; Moya & J, 2021) |
| Light-on-dark | Light-on-dark is a colour scheme that uses light text on a dark background, originally formed on CRTs for computer user interface images. | (Erickson et al., 2021) |
| Positive display polarity | Display polarity represents a variation in the relationship between light and dark. Positive polarity is black text on a light background. | (Eisfeld et al., 2020; Piepenbrock et al., 2014a) |
| Negative display polarity | Negative polarity is a light character on a dark background. | (Eisfeld et al., 2020; Piepenbrock et al., 2013) |
| Positive contrast polarity (light mode) | The phrase "contrast polarity" is employed to represent the difference between the text and its backdrop. When the text is seen against a light background, it is called positive contrast polarity or "light mode" and pertains to font that is dark in hue. | (Gao et al., 2021; Li et al., 2022);) |
| Negative contrast polarity (dark mode) | Negative contrast polarity, commonly known as dark mode, is achieved by displaying light-coloured text (e.g., white) on a dark-coloured background (e.g., black). | (Gao et al., 2021; Li et al., 2022) |
| Positive text-background polarity | The manifestation of sombre characters displayed against a luminescent backdrop is commonly denoted as negative contrast (due to the fact that if the radiance of the text Lt is lower than that of the background Lb, then the Michaelson contrast c ¼ (Lt7Lb)/(Lt þ Lb) becomes adversarial) or positive polarity of the text-background. | (Buchner et al., 2009) |

## Research Methodology

### Methodology Overview for Research

In order to incorporate existing research on dark mode and its impact on user experience, a two-stage approach was utilised to conduct a comprehensive search and filter through relevant literature. Heckman (1979) first introduced the two-stage approach as a method to address and reduce the potential impact of sample selection bias. It entails the sequential application of two stages. One aspect involves choosing appropriate samples, while the other is to address any biases in sample selection and prioritise key variables to ensure reliable results (Heckman, 1979; Wolfolds & Siegel, 2019). In the realm of scholarly investigation, this approach gained significant traction as a highly efficient method for manipulating samples to extract essential data and construct research models (Kim et al., 2019; Papouskova & Hajek, 2019). Thus, the two-stage approach is appropriate for this paper. Given the absence of a standardised academic framework or specific keywords for dark mode, we have incorporated various related terms in our search to ensure we capture all relevant research findings.

In addition, the two-stage approach can also identify articles on the same research topic published in different areas of study (Gardner, 2022; Suh & Prophet, 2018). This approach enables us to gather a substantial amount of data initially and then filter out irrelevant data in the subsequent stage by focusing on key variables. By doing so, we can identify data that aligns closely with our research, which lays a solid foundation for developing a model centred around variables (Klyver et al., 2020; Tapia-Muñoz et al., 2022). For this paper, the initial step involved finding relevant articles by conducting a keyword search in dark mode in a specific database. This helped gather a substantial amount of research material. The next step was to narrow down the scope and establish specific criteria to carefully sift through the initial collection of articles. The goal was to exclude any that were unclear or strayed from the main keywords (the literature searching and screening process is shown in Figure 2). Next, we meticulously

coded and categorised each piece of data using the matrix method of literature review proposed by Klopper and others (Klopper & Rugbeer, 2007). This allowed us to analyse and summarise the findings in an unbiased and quantitative manner. Lastly, we developed a framework for conducting research on the user experience of dark mode, following the S-O-R theory (thoroughly discussed in Part 5).

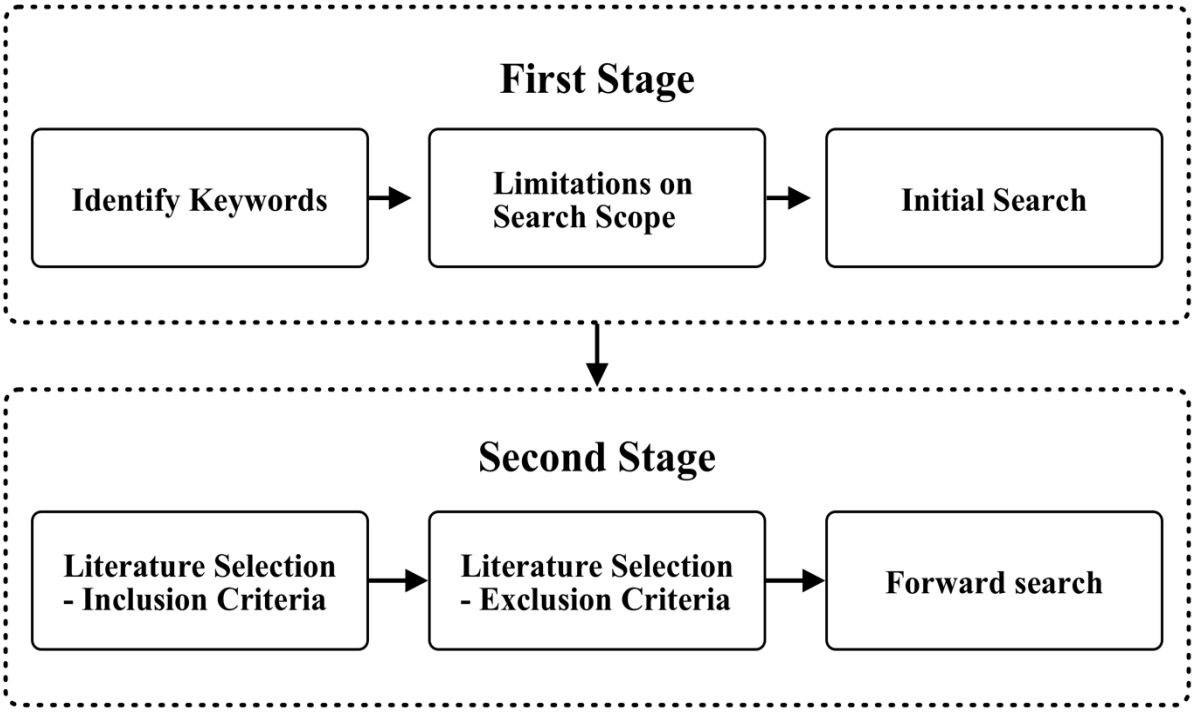


Figure 2: Two-Stage Approach Process of The Research.

**Study Design and Data Collection**

The initial exploration revealed a limited amount of research on dark mode in an academic context. This paper utilised the Scopus database as the collection source to gather sufficient data. The Scopus database is a comprehensive peer-reviewed abstract citation database that encompasses a wide range of academic disciplines, including medical, natural science, social science, engineering and technology, arts and humanities, and more. It has a wide range of journals, books, and papers. Using Scopus for research can help ensure the reliability, quality, and comprehensiveness of the data while also maintaining consistency in the functions and algorithms (Morschheuser et al., 2017). The initial exploration revealed a limited amount of research on dark mode in an academic context. This paper

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Using Scopus for research can help ensure the reliability, quality, and comprehensiveness of the data while also maintaining consistency in the functions and algorithms. The search yielded a total of 143,386 articles from 1992 to 2022. This paper seeks to gain a deeper understanding of dark-mode technology and its impact on the user experience. In the initial phase, we carefully examined empirical studies on dark pattern technology that focused on human factors and real-life scenarios. As part of the research, a focused search was conducted in various subject areas such as computer science, social sciences, arts and humanities, health professions, and nursing, to explore the connection between dark mode and user experience. Furthermore, the literature was restricted to "journal articles" and "Conference Paper" to maintain a high standard of research rigour and accuracy. These 11 specific terms screened a total of 26,350 papers.

In the second stage, inclusion and exclusion criteria were set to screen the closely related literature further.

The inclusion was based on the following criteria:

1. The use of dark mode (techniques) as a study focus or as a closely related subject.
2. Relevant papers that have an impact on users.

The exclusion criteria were:

1. The topic of the research is not dark mode.
2. The meaning of dark mode in the article is ambiguous or contradictory to the actual definition of dark mode.
3. Other academic studies that are not related to the dark mode screen display technology studied in this paper.

After applying the specified criteria, a total of 73 articles were chosen and exported as text. These articles were carefully filtered based on their subject, abstract, and keywords. For more information on the screening process, please refer to Figure 2.

Figure 2: The Searching Results of Keywords.

| Keywords | Number of initial searches | Stage 1 Screening | Stage 2 Screening |
|---|---|---|---|
| Dark mode | 11030 | 1373 | 12 |
| Black mode | 14480 | 2405 | 0 |
| Dark theme | 1040 | 712 | 1 |
| Night mode | 4197 | 1088 | 3 |
| Light mode | 110307 | 20429 | 4 |
| Light-on-dark | 116 | 27 | 4 |
| Positive display polarity | 321 | 55 | 19 |
| Negative display polarity | 338 | 62 | 13 |
| Positive contrast polarity | 779 | 85 | 8 |
| Negative contrast polarity | 774 | 111 | 7 |
| positive text-background polarity | 4 | 3 | 2 |

After integrating search results from 11 different keywords and eliminating duplicate articles, a total of 35 papers and articles were organised. Afterwards, we conducted a comprehensive search using the 35 papers as a reference to guarantee the inclusion of all relevant citations. After a thorough examination, we did not discover any papers that were unaccounted for. Information was gathered from the 35 papers, focusing on the following aspects: (a) bibliometric information (including author, publication date, academic discipline, etc.), (b) study topic, (c) study methodology, (d) theory involved (framework), and (e) study sample. The literature that was chosen was categorised and analysed using the matrix method of literature review, as described in the research methodology. At last, a comprehensive summary was created that covers the themes, background, research methods, theoretical foundations, and research trends in the literature on dark mode.

## Results

### Overall Research and Publications

This paper provides a comprehensive analysis of the bibliometric data from the 35 included papers. Figure 3 displays the publications in dark mode from 1992 to 2022. Despite an initial exploration of dark mode in 1992, it has not garnered significant interest from researchers since then. The provided figure clearly indicates that researchers have been conducting research on dark mode for the past 30 years, commencing in 2005. Instead of using the term "dark mode," the authors discussed and adopted the term

"polarity display technique" (Chan & Lee, 2005). Subsequently, dark mode started making its way into the academic sphere. Nevertheless, the quantity of literature published has been limited and follows a convoluted pattern, reaching its highest point in 2021. Following a decrease in publications from 2017 to 2018, there was an increase in 2019, possibly due to the widespread adoption of dark mode by Apple and Android in the business sector. Figure 4 displays the number of academic publications on dark mode research. Computer Science took the top spot with 12 papers, closely followed by Health Professions with 11 papers. Engineering and Technology also made a significant contribution with seven papers. These findings suggest that the focus on dark mode primarily revolves around computer science and technology.

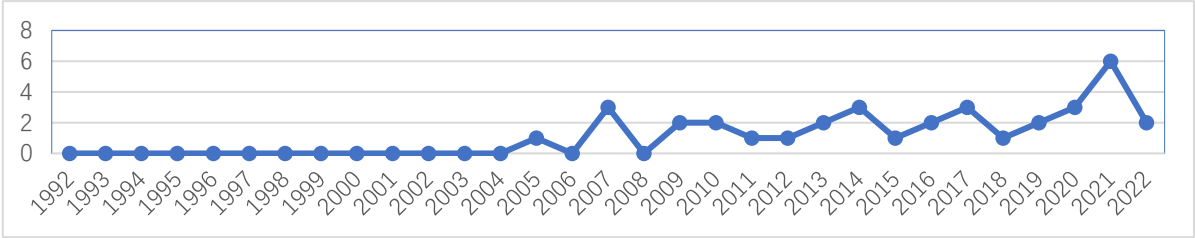


Figure 3: Publications Related to Dark Modes Between 1992 and 2022.

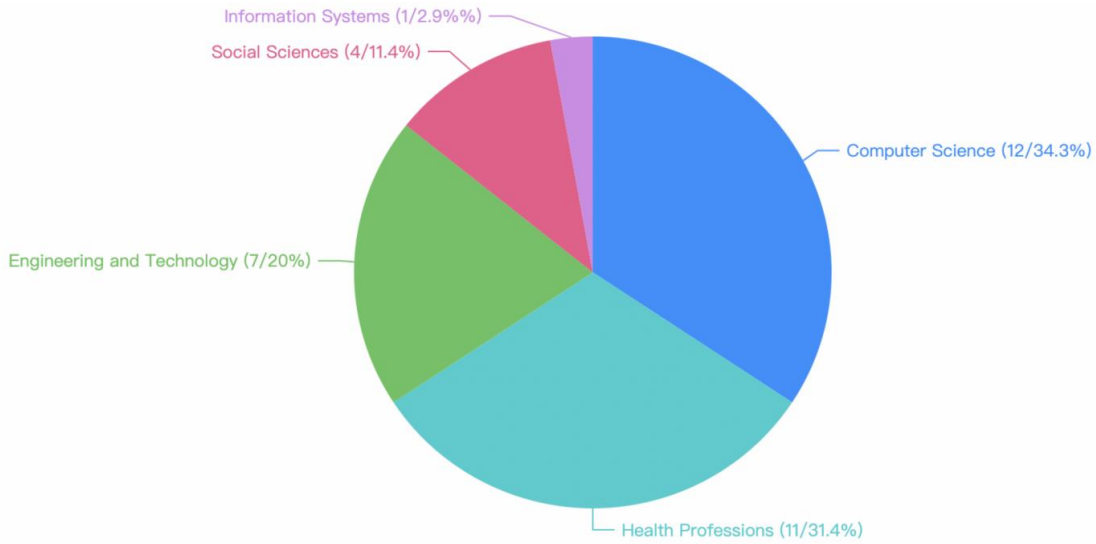


Figure 4: Quantity 0f Publications Related To Dark Mode.

The concept of dark mode in business emerged in 2019 (Christensson, 2019). However, based on research and literature analysis, it is evident that "dark mode" falls under the category of "negative polarity display technology," which involves

using white fonts on a black or dark background (Sethi et al., 2023). There are three primary schools in the field of dark-mode research. The initial study examines the favourable effects of this technique on user experience. Some researchers have suggested that using dark mode can enhance visual comfort and acuity (Erickson et al., 2021; Gao et al., 2021). It is also believed to have a positive impact on circadian rhythm (Teran et al., 2020).

Additionally, Pedersen et al. (2020) claim that dark mode contributes to more aesthetically pleasing and captivating designs for devices and apps. In contrast, the opposing viewpoint argues that dark mode can have negative effects. Some researchers have found that it can decrease readability (Dobres et al., 2016b; Piepenbrock et al., 2013), hinder users' ability to proofread accurately (Buchner & Baumgartner, 2007), and reduce reading speed and efficiency (Chan et al., 2005). The third school maintains a neutral stance, asserting that dark mode can have both positive and negative effects on users, depending on the circumstances. Take into consideration that the benefits and drawbacks of dark and light modes can differ depending on the physical background and lighting conditions. Additionally, these factors may also vary among different users, as noted by Dobres et al. (2016b) and Kim et al. (2019). For instance, the way young people and elderly individuals respond to dark mode differs. Young people can enjoy several advantages in both light and dark modes, whereas the elderly tend to experience significantly less visual fatigue when using negative polarity displays (Lin & Yeh, 2010; Tomioka, 2007). When using dark mode, different monitors can result in different outcomes and effects, according to research (Humar et al., 2014).

**Methods in the Dark Mode Research**

Table 3 displays the different approaches utilised in dark mode research, such as experiments, interviews, questionnaires, and more. A total of eleven articles utilised the single experiment approach, while twenty-four articles opted for a mixed-method approach. Among the mixed-method articles, a combination of experiments and

questionnaires was the most frequently employed. This particular combination was utilised in twenty-one articles. Experiments are widely recognised as a primary research method, as they encompass both single and mixed research approaches. Researchers conducted two studies to investigate the effects of dark mode on users. Gao et al. (2021) examined users' visual acuity, while Piepenbrock et al. (2013) studied users' proofreading performance and pupillary changes in dark mode scenarios. Scholars have used a combination of experiments and questionnaires to investigate objectively unobservable data derived from experimental data in order to obtain additional measurements of user experience. The researchers conducted experiments on VR HMD devices to investigate users' vision usage and fatigue levels. Short user experience questionnaires were also used to assess the usability of the dark mode (UEQ-S).

Furthermore, other researchers have conducted text experiments to evaluate users' reading efficiency and proofreading ability in dark mode. They then used questionnaires to assess participants' personal experience with dark mode in proofreading tasks (Piepenbrock et al., 2014a).

Table 3: Overview of Research Methods in The Dark Mode Literature.

| Research Methods | Total | Reference |
|---|---|---|
| Experiment | 10 | (Buchner et al., 2007; Buchner et al., 2009; Dobres et al., 2016b; Erickson et al., 2021; Gao et al., 2021; Hong Chen & Muhamad, 2018; Kanda & Miyao, 2011; Mayr & Buchner, 2010; Piepenbrock et al., 2013; Teran et al., 2020) |
| Questionnaire | 1 | (Zlokazova & Burmistrov, 2017b) |
| Experiment & Case study | 1 | (Dash & Hu, 2021) |
| Experiment & Interview | 2 | (Pedersen et al., 2020) |
| Experiment & Questionnaire | 20 | (Bochud & Garbely, 2013; Chan et al., 2005; Dash et al., 2021; Dobres et al., 2016a; Dobres et al., 2016b; Erickson et al., 2021; Gattullo et al., 2014; Humar et al., 2014; Jeng et al., 2007; Kim et al., 2019; Li et al., 2022; Lin et al., 2010; Löffler, 2017; Nissen & Riedl, 2021; Piepenbrock et al., 2014a; Piepenbrock et al., 2013; Shen et al., 2009; Tomioka, 2007; Tsang et al., 2012; Xie et al., 2021) |
| Experiment & Questionnaire & Interview | 1 | (Sethi et al., 2023; Vasylevska et al., 2019) |

## Theories Involved in The Dark Mode Research

This paper presents a compilation of the theoretical and research frameworks utilised in the thirty-one selected papers on dark mode (Table 4). The

majority of papers lack a theoretical or conceptual framework. A limited number of theories, often lacking extensive analysis or discussion, serve as explanations for certain concepts. We use the 'Ego depletion theory' to explain how the dark mode can enhance users' 'honesty'. The concept of 'Gestalt psychology' is employed to demonstrate the relationship between dark mode (a form of negative polarity display) and light mode (a positive polarity display). The UEQ theory and its framework were utilised as a benchmark for measuring the usability and subjective preference of dark mode in two separate papers (Erickson et al., 2021; Kim et al., 2019). The "signal processing theory" explains the correlation and differences between positive and negative polarity, as well as light and dark modes (Erickson et al., 2021).

Table 4: Overview of Research Theories in The Dark Mode Literature.

| Related Theories | Definition | Reference |
|---|---|---|
| Ego depletion theory | Ego depletion theory states that participants' self-regulation ability is wakened after completing a task requiring self-control and unable to exert the same level of it on subsequent tasks, which results in worse performances. | (Dang et al., 2021; Friese et al., 2019; Koning et al., 2021) |
| Signal processing theory | Signal processing theory can not only measure the ratio between the spread and sum of two luminance levels but also be used to explain the differences between these two positive and negative contrast screens displays for dark and light modes. | (Michelson, 1995; Xie et al., 2021) |
| UEQ | The UEQ is a theoretical framework that measures user experience across six distinct dimensions, focusing on the 'Attractiveness'. The results of the UEO can reflect product quality in terms of user experience. | (Erickson et al., 2021; Kim et al., 2019; Rauschenberger et al., 2013; Schrepp et al., 2017) |
| Gestalt psychology | Negative polarity display refers to the inversion of colours between texts and backgrounds. As demonstrated in Gestalt psychology, the visual discrimination is referred to as figure-ground perception. In that case, the brightness of the text is then closer to its surroundings and seems to be 'enclosed' by the dark background, as if the text were underlying the dark background. | (Bochud et al., 2013; Köhler, 1967) |

**Samples for Dark Mode Research**

The samples utilised in the investigation of dark mode have been consolidated and presented in Table 5. The age of participants in the thirteen papers is limited to those above 18 years old, while there are no specific restrictions on the sources of the

samples. University students were the most popular subject among the twelve papers that selected this type of sample. Six papers conducted comparative studies on two distinct groups of subjects. Among these, four papers examined a combination of youth and elderly individuals, while the remaining two papers focused on student groups and specialist teams. Specifically, two articles conducted experiments on devices instead of human subjects, while another paper did not impose any restrictions on participants. According to Pedersen et al. (2020), university students, as participants in their studies, demonstrated a higher level of familiarity with the dark mode operation process. The selection of elderly participants in the studies aimed to examine the potential benefits of using dark mode in the display environment for this age group (Lin et al., 2010). Piepenbrock et al. (2014a) conducted comparative studies to investigate the potential differential effects of dark mode on young and elderly individuals under identical conditions. Studies that include a variety of student and expert samples aim to achieve unbiased experimental findings and comprehensive research data from both professional staff and regular users (Vasylevska et al., 2019).

Table 5: Study Sample and Proportions.

| Study Sample | Number of articles | Total percentage |
|---|---|---|
| University students | 12 | 34.3% |
| Staff | 1 | 2.9% |
| Youth & Elderly | 4 | 11.4% |
| Student & Specialist | 2 | 5.7% |
| No restriction on sample sources above 18 years old | 13 | 37.1% |
| No restriction on age or source of sample | 1 | 2.9% |
| Non-human subjects | 2 | 5.7% |

## A Classification Framework for Dark Mode

A comprehensive research framework has been developed by integrating the S-O-R theory and research data. This framework aims to facilitate further research on technologies, functions, content, user experience, and behaviour associated with the dark mode. Theoretical analysis and research of user experience processes in information technology and products can be facilitated (Teng & Bao, 2022). The theory encompasses key elements of user experience and behaviour, which include

perceptual and affective responses to the intense emotions that may be evoked by the environment and products (Wohlwill, 1976). It also addresses cognitive factors such as learning ability and comprehension, as well as physiological reactions (Bitner, 1992). Hence, the S-O-R theory is applicable for examining the factors and relationships between dark mode and user experience.

Moreover, it has been extensively employed in forecasting user behaviour in the context of information technology (Chen & Yao, 2018). This study effectively illustrates the relationship between the dark model's variable system and the user experience in a multi-mediated mode. The theoretical framework comprises the elements of "stimulus," "organism," and "response." The term "stimulus" in this study refers to the triggers, both internal and external, that induce physiological, perceptual, and cognitive changes in users when using dark mode. The variables related to dark mode in the research have been extracted and categorised based on the S-O-R theory to investigate their correlations. The term "organism" pertains to the influence of dark mode on the user, whereas "response" pertains to the user's subsequent actions and behaviour following the use of dark mode. The research process regarding user experience in dark mode involves examining the perceptual, cognitive, and physiological effects of internal and external factors on users. These effects can elicit either positive or negative responses, leading to a desire to use or avoid dark mode. The S-O-R theory can be used to create an experiential framework for users of dark mode, allowing for the analysis of their behaviour and the identification of underlying reasons.

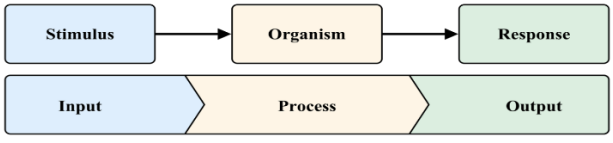


Figure 5: S-O-R Theoretical Framework.

**The "Stimuli" in the Dark Mode**

The introduction of dark mode was motivated by the goal of providing a color-changing option that would create a distinct visual experience. (Eisfeld et al., 2020). Studies on dark mode have found that specific conditions, factors, and features can

trigger perceptual, cognitive, and physiological responses in users. The stimuli in this study are categorised into four groups based on the research subjects. The first two categories, referred to as 'external factors', pertain to factors beyond the control of developers and designers. The latter two categories, referred to as 'internal factors', are variables that can be internally adjusted by tech developers or relevant product managers and designers. The impact of ambient lighting on users in dark mode is a significant factor, as highlighted in various articles (Erickson et al., 2021; Jeng et al., 2007). The second category consists of the primary users of dark mode, specifically the study participants.

Table 6: Summary of Stimuli in The Dark Mode.

| Stimulus | Classification | Reference |
|---|---|---|
| **Ambient lighting** | Dusky | (Buchner et al., 2007; Buchner et al., 2009; Dobres et al., 2017; Dobres et al., 2016a; Dobres et al., 2016b; Eisfeld et al., 2020; Erickson et al., 2021; Gattullo et al., 2014; Humar et al., 2014; Jeng et al., 2007; Kim et al., 2019; Koning et al., 2021; Löffler et al., 2017; Mayr et al., 2010; Piepenbrock et al., 2014a, 2014b; Piepenbrock et al., 2013; Sethi et al., 2023; Shen et al., 2009; Tomioka, 2007; Xie et al., 2021) |
| | Bright | |
| **Sample variation** | Test subject.<br>• Involving human subjects<br>• No human subject involved<br>Age<br>• Young<br>• Middle Age<br>• Elderly<br>Health conditions<br>• Normal vision<br>• Eye disease<br>Level of expertise<br>• Expert Team<br>• General Users | (Dash et al., 2021; Dobres et al., 2016b; Gattullo et al., 2014; Kanda et al., 2011; Lin et al., 2010; Löffler et al., 2017; Piepenbrock et al., 2013; Sethi et al., 2023; Teran et al., 2020; Tomioka, 2007; Vasylevska et al., 2019; Zlokazova et al., 2017b) |
| **Equipment** | Computer | (Chan et al., 2005; Dobres et al., 2016a; Dobres et al., 2016b; Gao et al., 2021; Humar et al., 2014; Koning et al., 2021; Löffler et al., 2017; Nissen et al., 2021; Pedersen et al., 2020; Piepenbrock et al., 2014b; Piepenbrock et al., 2013; Sethi et al., 2023; Tsang et al., 2012; Xie et al., 2021) |
| | Mobile phones | (Dash et al., 2021; Teran et al., 2020) |
| | Immersive equipment<br>• VR<br>• AR | (Erickson et al., 2021; Gattullo et al., 2014; Kim et al., 2019; Vasylevska et al., 2019) |

| | | |
|---|---|---|
| **Content** | Display screens.<br>• OLED<br>• LCD<br>• CRT<br>• TFT-LCD | (Buchner et al., 2007; Buchner et al., 2009; Hong Chen et al., 2018; Li et al., 2022; Lin et al., 2010; Mayr et al., 2010) |
| | E-reader<br>• E-Ink<br>• Electronic paper | (Bochud et al., 2013; Jeng et al., 2007; Kanda et al., 2011; Shen et al., 2009) |
| | Text<br>• Style<br>• Size<br>• Thickness<br>• Line spacing | (Buchner et al., 2007; Dobres et al., 2017; Dobres et al., 2016a; Dobres et al., 2016b; Gattullo et al., 2014; Hong Chen et al., 2018; Kanda et al., 2011; Lin et al., 2010; Piepenbrock et al., 2014b; Sethi et al., 2023; Tomioka, 2007; Tsang et al., 2012; Zlokazova et al., 2017b) |
| | Colour<br>• Saturation<br>• Colourways | (Buchner et al., 2007; Chen & Muhamad, 2018; Erickson et al., 2021; Gao et al., 2021; Li et al., 2022; Löffler et al., 2017; Xie et al., 2021) |
| | Images<br>• Clarity | (Erickson et al., 2021; Kim et al., 2020; Nissen et al., 2021; Vasylevska et al., 2019) |
| | Graphics<br>• Shape | (A Chen et al., 2018; Kanda et al., 2011; Mayr et al., 2010; Nissen et al., 2021; Piepenbrock et al., 2013; Sethi et al., 2023) |
| | Contrast ratio.<br>• Low contrast ratio<br>• Medium contrast ratio<br>• High contrast ratio | (Bochud et al., 2013; A Chen et al., 2018; Erickson et al., 2021; Gao et al., 2021; Gattullo et al., 2014; Kim et al., 2019; Li et al., 2022; Löffler et al., 2017; Mayr et al., 2010; Piepenbrock et al., 2014b; Piepenbrock et al., 2013; Tomioka, 2007; Tsang et al., 2012; Vasylevska et al., 2019; Xie et al., 2021; Zlokazova et al., 2017b) |

It is important to clarify their age, physical condition, and professional degree (Löffler et al., 2017; Piepenbrock et al., 2014a). The third category comprises devices that can result in varied user experiences. The display effects and product functions of VR devices (Vasylevska et al., 2019) differ from those of computer screens (Pedersen et al., 2020). The fourth category pertains to the internal components, specifically the 'content'. This encompasses texts (Chan et al., 2005), colours (Buchner et al., 2007), graphics (Nissen et al., 2021), images (Vasylevska et al., 2019), and luminance/contrast (Kim et al., 2019). The studies indicate that the "content" factor plays a crucial role in eliciting perceptual, cognitive, and physiological responses in users of dark mode.

### The "Organism" in Dark Mode

This study focuses on the subjective impressions and internal assessments of users while interacting with dark mode. The term "organism" refers to the aspects of perception, cognition, and physiology. The distinction between

perception and cognition lies in their respective characteristics. Perception involves the direct acquisition of feelings and emotions from sensory experiences, whereas cognition is an indirect and imperceptible process that influences thinking, understanding, and learning abilities after perception (Macpherson, 2011). Perception and physiological reaction differ in that perception is a psychologically manifested evaluative reaction, while physiological reaction refers to changes in the biological systems of the brain, body, and internal organs (Bradley & Lang, 2000).

The previous analysis suggests that dark mode primarily stimulates visual senses through visual elements, leading to perceptual and physiological reactions in users, which in turn influence cognitive reactions. The main perceptual reactions towards the dark mode, as indicated in Table 7, include positive emotions such as 'Attractive', 'Personalised', and 'Fun', as well as negative emotions such as 'Depression' and 'Loss'. Additionally, 'fun','sense o of security', and 'visual aesthetics' are identified as positive emotions. This suggests that the same design pattern can elicit varying perceptual responses in different usage scenarios and with different devices. Researchers have found that dark mode enhances moral honesty and fosters a sense of security (Koning et al., 2021). The diversity of backgrounds also elicits pleasure. In addition, dark scenes can lead to a sense of detachment from reality, resulting in users prioritising hedonism over utilitarianism.

In addition, the use of dark mode enhances privacy by making choices more discreet (Huang et al., 2018; Pedersen et al., 2020). However, this colour mode has been found to potentially induce depression in contexts such as chat (Löffler et al., 2017) or when the interface's colour options are restricted (Sethi et al., 2023). Users who have had extensive experience with light mode may experience aesthetic fatigue and psychological effects from excessive blue light exposure. As a result, they may develop a contempt for the light mode and perceive its interface as inferior. Switching to dark mode can evoke a sense of pride in users (Sethi et al., 2023).

Table 7: Summary of Perceptual Reactions in Dark Mode

| Perceptual reactions | Description and definitions | Reference |
|---|---|---|
| Attractive | Colour choices and design elements in dark mode can create visually appealing interfaces, especially on social media, and can even promote greater engagement. | (Hakobyan & Saha, 2021; Pedersen et al., 2020) |
| Personalised | The colour scheme of dark modes is in contrast to that of the widely used black-on-white one. The uniqueness offers an alternative for users to display their individuality and to gain the focus of attention. | (Pedersen et al., 2020) |
| Fun | Pleasure may sprout from the shifting background colours from light to dark. The secrecy of dark mode encourages the user to freely choose hedonism over utilitarianism and thus increases the sense of enjoyment. | (Erickson et al., 2021; Huang et al., 2018; Kim et al., 2019; Pedersen et al., 2020) |
| Negative emotions | Colour can measure the pleasantness and arousal of the emotional experience. In normal ambient light, the atmosphere in dark mode can lead to depression and loss in the user's emotional perception. | (Löffler, 2017; Nissen et al., 2021; Sethi et al., 2023) |
| Visual acuity | In low-light physical environments and against complex backgrounds, the dark mode improves visual acuity, making it easier for users to identify characters or visual details. | (Erickson et al., 2021; Gao et al., 2021; Kim & Lennon, 2013; Kim et al., 2019) |
| Visual Aesthetics | The uniformity of a dark background is visually better on the whole, and bright text on it produces a aesthetically delectable visual effect. | (Gao et al., 2021; Li et al., 2022; Sethi et al., 2023) |
| Sense of security | Dark mode promotes user honesty. In the long-run experiments, users are prone to display more honesty in dark mode which also motivates positive ethical behaviours. | (Koning et al., 2021) |
| Pride | Due to previous experience with light mode, users suffer from aesthetic fatigue and excessive blue light exposure, thus developing a sense of contempt for the light mode but a pride in dark mode. | (Sethi et al., 2023) |

Table 8 provides a summary of the physiological states observed in the studies on dark mode. The most common physiological reactions observed in the studies were primarily related to vision. The dark mode's low light is beneficial as it reduces prolonged visual stimulation from excessive screen exposure, particularly the harmful blue light. The reduction of blue light in dark mode can decrease the inhibitory effect on melatonin, potentially improving sleep for users who habitually use their mobile phones before bedtime (Teran et al., 2020). According to Lin et al. (2010), low-light scenes reduce the visual burden, particularly for the elderly, who experience less visual fatigue in dark mode. The dark mode offers a more comfortable visual experience for individuals who spend extended periods working or reading on computers and mobile phones, in addition to nighttime (Erickson et al., 2021). According to Vasylevska et al. (2019), certain VR devices that lack proper coordination with ambient light, prolonged exposure to dim environments,

and dark screen displays can induce physical stress and result in dizziness among users (Tsang et al., 2012). Moreover, the use of dark mode has been found to potentially induce glare and pupillary dilation, resulting in blurred vision (Dobres et al., 2016a).

Table 8: Summary of Physiological Reactions in Dark Mode.

| Physiological reactions | Description and definitions | Reference |
|---|---|---|
| Visual comfort | Long-term users of electronic devices prefer darker modes, which resulted in a higher degree of visual comfort with less light stimulation and thus prolonged the working and reading time. | (Erickson et al., 2021; Kim et al., 2019; Pedersen et al., 2020) |
| Fatigue reduction | Studies reveal a positive effect of dark mode on the visual fatigue level. The visual fatigue grown out of electronic devices usage at night can be reduced in the dark mode by means of higher blink rates and papillary accommodation. | (Erickson et al., 2021; Kim et al., 2019; Li et al., 2022; Lin et al., 2010; Xie et al., 2021) Pedersen7 |
| Improve vision | The ANOVA showed that only the polarity effect was significant in terms of visual acuity measurement. While both the elderly and youth reported a decrease of visual acuity when utilising light mode, participants demonstrated significantly enhanced visual acuity under dark mode as contrasted with the light one. | (Kim et al., 2019; Lin et al., 2010) |
| Promote sleep | The disturbance of the circadian cycle caused by prolonged smartphone use before bedtime and the effect of light sources on melatonin may be reduced through the dark mode display technology. | (Teran et al., 2020; Vasylevska et al., 2019) |
| Cybersickness | Research show that some users may experience a motion sickness accompanied by salivation when wearing VR devices in dark mode for long. | (Vasylevska et al., 2019) |
| Glare and reflection problems | Dark mode may lead to glare and reflection, as significantly worse lobe size and shape were presented in negative polarity conditions. | (Piepenbrock et al., 2014b; Tsang et al., 2012) |
| Blurred vision | The low-luminance properties of the dark mode trigger pupillary dilation, resulting in restricted depth of field, greater spherical aberration, diminished retinal imaging quality, which ultimately introduces blurred vision. | (Dobres et al., 2016b; Piepenbrock et al., 2014b; Tsang et al., 2012) |

Table 9 displays the cognitive reactions to dark modes. The studies presented provide evidence of a correlation between cognitive responses and reading comprehension, which can be affected by legibility. Factors such as fonts and the presentation of text on different screens or media can impact legibility. The readability of a text is typically assessed based on two factors: the complexity of the content and the ease of visual identification and processing. The length of reading, in identical test conditions, reflects the ease with which users can extract and comprehend information (Poole & Ball, 2006). Long reading times negatively impact readability and hinder users'

information processing and comprehension. Some researchers argue that dark mode aids reading because it protects the eyes, resulting in shorter reading time (Bochud et al., 2013). Some researchers have suggested that the dark mode may have drawbacks in terms of luminance and recognition due to the pupil dilation effect (Dobres et al., 2016b). This can lead to distractions and increased visual processing difficulties, making it potentially more detrimental to reading than the light mode. The overall usability quality is higher when considering the interface's use efficiency, which includes factors such as readability and ease of operation. Dark mode offers clear advantages in enhancing the user's enjoyment during interface interaction (Erickson et al., 2021).

Table 9: Summary of Cognitive Reactions in Dark Mode.

| Cognitive reactions | Description and definitions | Reference |
|---|---|---|
| **Legibility** | In low light conditions, the dark mode offers shorter reading times and higher legibility than the light mode, which is particularly effective for users with reduced visual function (e.g. the elderly / users with cataracts). Dark mode provides better legibility for finer characters and in darker environments. | (Bochud et al., 2013; Dobres et al., 2016b; Erickson et al., 2021; Humar et al., 2014; Kanda et al., 2011; Kim et al., 2019; Li et al., 2022; Siegenthaler et al., 2011) |
| **Inhibiting legibility** | In dark mode, the pupil dilates on the incomplete surface of the eye, introducing sensory distortions that hinder visual processing and thus reduce visual acuity in dark mode. Conversely, at higher ambient light levels, lighter mode displays provide better readability. | (Buchner et al., 2007; Chan et al., 2005; A Chen et al., 2018; Dobres et al., 2016a; Jeng et al., 2007; Piepenbrock et al., 2014b) |
| **Usability** | Dark mode significantly improved the overall usability (smoother and more enjoyable to use) of the AR text annotations. The results of availability quality (utility quality and hedonic quality) of dark mode in low light environment show that dark mode has significant main effect on overall availability. | (Erickson et al., 2021; Kim et al., 2019; Schrepp et al., 2017) |

## The "Response" in Dark Mode

The term 'response' in this study pertains to the outcome resulting from the use of dark mode and its impact on the user's subsequent decision to continue or discontinue its use. The user responses to the dark mode were categorised into positive (Table 10) and negative responses (Table 11), with commonly cited response variables including "comprehension," "task performance," "physical symptoms," and "intention to use".

As previously mentioned, reading length is linked to readability and comprehension difficulty. The negative responses indicate that reading text in dark

mode results in increased reading time, reduced legibility, and impaired comprehension. The legibility of dark mode is particularly poor on LCD screen devices, leading to increased difficulty in reading and comprehension (Humar et al., 2014). Elderly adults in bright environments experience increased search time and pupil diameter when exposed to negative polarity, indicating a higher cognitive load (Sethi et al., 2023). Positive feedback suggests that dark mode enhances concentration and reading ability in low-light environments. According to Pedersen et al. (2020), users who preferred dark mode were perceived as having extensive experience with computers and demonstrated improved reading and comprehension outcomes when using dark mode. Dark mode is the most legible and effective display option for CRT displays, as it enhances reading and comprehension (Humar et al., 2014).

Visual acuity and usability significantly impact the accuracy of search operations and proofreading task performance. Erickson et al. (2021) have proposed that dark mode is more effective in low ambient light conditions, resulting in shorter proofreading times and lower error rates in task completion. Prior studies have proposed that light-coloured patterns generally exhibit increased brightness, leading to more pronounced pupil contractions. This, in turn, yields higher-quality projections on the retina, resulting in sharper images, improved perception of detail, and ultimately enhanced collation. Due to reduced luminance, dark mode causes increased retinal image blurring. It also leads to diminished recognition and inferior proofreading performance, particularly in low-contrast scenarios where colour elements impact the visualisation of contrast mechanisms in the ocular pathway. Additionally, dark mode demonstrates lower resolution and sensitivity effects, as well as decreased task completion rates (Piepenbrock et al., 2014b).

Positive reactions generally outweigh negative ones in terms of physical symptoms. Dark patterns have been shown to have positive effects on vision and sleep, making them a viable option for individuals with eye problems and prolonged use of electronic devices (Kanda et al., 2011; Tomioka, 2007). Nevertheless, it is important to acknowledge that dark mode has the potential to induce muscle strain and back pain in users (Piepenbrock et al., 2013). Glare and blurred vision can result from pupil dilation induced by a dark background (Dobres et al., 2016a; Piepenbrock et al., 2014a;

Tsang et al., 2012). In head-mounted devices like VR, participants may experience stress due to the combination of being in a low brightness environment and the absence of ambient brightness adaptation (Vasylevska et al., 2019).

Regarding 'intention to use', positive responses have indicated a significant main effect of ambient lighting on overall preference. In low lighting conditions, users tend to prefer dark mode due to its ease of reading, enhanced perceptual performance, and visual comfort. Additionally, dark mode offers energy-saving benefits and is aesthetically pleasing, enhancing both perception and practical quality. Several researchers endorse users' inclination towards darker patterns (Erickson et al., 2020; Kim et al., 2019; Pedersen et al., 2020). On the other hand, in terms of negative reactions, experts in the field argue that the white background mode resembles a book's reading experience. People associate reading black text on white paper with the natural environment. Based on Gestalt psychology, a black background with white text creates a reverse visual effect. Changing the background colours can be challenging for users as they have to adjust to the new visual display and learn a different way of reading, which requires effort and adaptation. Here are some reasons why users might not prefer the dark mode (Bochud et al., 2013; Chan et al., 2005).

Table 10: Summary of Response in Dark Mode (Positive Outcomes).

| Positive response | Description and definitions | Reference |
|---|---|---|
| Highly comprehensible | Dark mode users in low-light environments were more focused, read more effectively and understood better. Participants with a preference for dark mode showed higher performance in all conditions, reading faster on darker backgrounds and better-facilitating comprehension. | (A Chen et al., 2018; Erickson et al., 2020; Erickson et al., 2021; Gao et al., 2021; Pedersen et al., 2020) |
| Smooth task performance | Experimental comparisons revealed that in low light conditions, using the dark mode, users were able to complete significantly more tasks with fewer errors overall, and that users took less time to complete the tests. | (Erickson et al., 2021; Mayr et al., 2010; Vasylevska et al., 2019) |
| Reducing disease symptoms | The dark mode helps to reduce the visual load, especially for low-light scenes where the use of dark mode reduces the damage caused by electronic devices to people's eyes which improves vision, promotes circadian rhythms at night, and helps to get to sleep. | (Erickson et al., 2021; Kim et al., 2019; Li et al., 2022; Lin et al., 2010; Teran et al., 2020; Vasylevska et al., 2019; Xie et al., 2021) |
| Preference for use | In low light conditions, users tend to prefer darker colours. In addition to the fact that dark mode saves power and increases the length of time the device is used, the unique visual style and attractive personalisation of dark mode are also important reasons for the preference. | (Dash et al., 2021; Erickson et al., 2020; Erickson et al., 2021; Kim et al., 2019) |

Table 11: Summary of Response in Dark Mode (Negative Outcomes).

| Negative response | Description and definitions | Reference |
|---|---|---|
| Cognitive burden | The font form and text information displayed in dark mode is more difficult to recognise and read than in light mode. Text in dark mode takes more time to read, is less readable and affects comprehension. For elder people, it takes more mental efforts to use a negative polarity search task in a bright environment. | (Dobres et al., 2016a; Humar et al., 2014; Jeng et al., 2007; Piepenbrock et al., 2014a; Piepenbrock et al., 2013; Sethi et al., 2023) |
| Obstructed task performance | Ambient illumination has a significant effect on the duration of the search task, which decreases with increasing brightness. Higher ambient illumination, with lighter colour patterns, provides greater accuracy; conversely, low illumination and dark mode hinder task operation and reduce the accuracy of task completion. | (Buchner et al., 2007; Chan et al., 2005; Jeng et al., 2007; Kanda et al., 2011; Piepenbrock et al., 2014b; Shen et al., 2009; Vasylevska et al., 2019) |
| Physical discomfort | Young users suffer muscle strain and back pain during studies in dark and light modes, while elder users experienced that after studies in dark mode and may experience dizziness after using dark mode for a long time inside the head-mounted VR device. In addition, it was found in the study that dark colour mode may result in glare and blurred vision | (Dobres et al., 2016a; Piepenbrock et al., 2014a; Piepenbrock et al., 2013; Tsang et al., 2012; Vasylevska et al., 2019) |
| Prefer not to use | Subjects showed a higher preference for lighter mode and subjectively rejected darker mode. This may be related to their usage habits, where users are used to reading white and black text on a daily basis and are not used to dark background formats. | (Bochud et al., 2013; Chan et al., 2005; Piepenbrock et al., 2014b; Xie et al., 2021) |

## UX Research Framework for Dark Mode

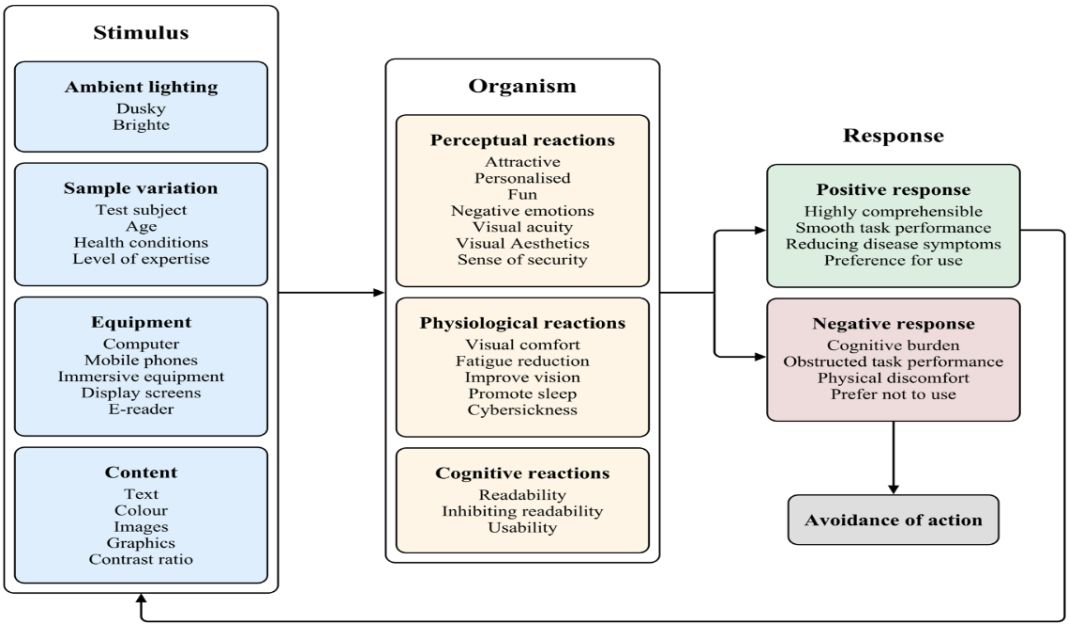


Figure 6: UX Research Framework for Dark Mode.

The literature review indicates that there has been a limited amount of research on the emerging trend of dark patterns in the past. However, earlier discussions have focused on similar techniques with contrasting viewpoints. Recent research indicates that there is significant debate surrounding the use of dark mode. Many studies lack consistency, comprehensive analysis, and a holistic research framework to fully understand the relationships between various research variables and the reasons behind differing findings. This paper presents a thorough research framework for dark pattern research, utilising the S-O-R model as illustrated in Figure 6.

The analysis of the literature review reveals that the various components of the dark mode have an impact on the user's perceptual, cognitive, and physiological responses. These components include the external environment, research object, subject device, and internal elements. Studies on the dark mode have yielded a wide range of results and sparked debates among researchers. Thus, the research framework presented in this paper allows for a comprehensive understanding of the variations and significance of stimuli resulting from dark patterns in user perception and cognitive response. It also sheds light on the user experience process associated with dark patterns and how they ultimately influence user behaviours. When conducting research and development in dark mode, it is important to consider the external environment, the research subject, the subject device, and the internal elements. This will allow for a comprehensive examination of the strengths, weaknesses, and potential refinement strategies of dark mode.

It is crucial to avoid making definitive judgements about the overall system of dark mode based solely on one aspect of the research findings. Prior research has not extensively explored the impact of dark mode on user experience and behaviour. Nevertheless, numerous studies have confirmed that various stimuli, originating from both internal and external sources of the dark mode system, can elicit distinct user behaviours by influencing their perceptual, cognitive, and physiological responses. Thus, this framework suggests that the deliberate arrangement of certain design elements can have a significant impact on how users interact with them, influencing their thoughts, feelings, and physical reactions, ultimately leading to desired user behaviour (responses).

## Discussion

While the commercial field has shown great interest in the dark model, there is a noticeable lack of academic research on this topic. Surprisingly, no research has thoroughly examined and analysed the existing knowledge of the dark model, including its concepts, design systems, and user experience processes. This paper focuses on dark mode as a screen display technology. It gathers and analyses research from the past 20 years, using its unique characteristics such as a negative polarity display and a dark background with light fonts. Based on this, the paper extends the research data and integrates various variables examined in dark mode research into a comprehensive research framework. Thus, this research can serve as a valuable reference for studying dark mode, enabling researchers to utilise this framework to gain a deeper understanding, validate findings, and pursue further investigations in the future.

## Theoretical Implications

This study examines the current state of literature on dark mode, encompassing bibliometric information on dark patterns, research background, research methods, relevant theories, and research trends. It offers significant contributions to the academic field. Firstly, there is a noticeable lack of extensive research on the dark mode's relationship to commercial sector advancements, and a comprehensive literature review remains unconducted. Researchers may encounter challenges in determining their research focus, as there is still much to discover about the dark mode. Interestingly, the dark mode's negative polarity technique has been a subject of study and discussion for quite some time, predating the recent attention it has received. Nevertheless, the literature is not readily accessible in scholarly research due to the fact that the commercial sector has revamped and enhanced the method. This paper presents the most recent technical research data on the dark mode, as well as detailed research and analysis of negative polarity techniques that align with the nature and characteristics of the dark mode and its closely related positive polarity technology (light-coloured mode).

This literature review provides valuable insights into the current state of research

on dark mode. It covers a wide range of topics, including background information, disciplinary perspectives, theoretical foundations, research methodologies, and emerging trends. Additionally, this paper presents a thorough research framework on the user experience of dark mode by consolidating the factors associated with dark mode. Considering this, it can assist future researchers in constructing fresh theoretical models to elucidate the observations of dark mode user experience, examine the system design of dark mode, and explore the interactions between dark mode and user experience. After carefully reviewing the literature, this paper identifies contentious issues and areas where further research is needed. The research variables and factors gathered from the literature review can serve as a foundation for future studies in various directions.

## Practical Implications

This study has practical implications for researchers working on dark mode systems and equipment vendors. This paper presents a thorough framework for studying the user experience in dark mode. It explores various aspects such as dark mode systems, user experience, and user behaviour. By examining the interactions between the external environment, technology, content, individual users, perception, cognition, physiology, and other related factors, this framework aims to enhance user decision-making behaviour. Furthermore, there are both positive and negative aspects of the user experience in dark mode. Therefore, system developers and designers working on dark mode can consult the dark mode experience framework and related factors discussed in this study. They can analyse the positive and negative effects and concentrate on improving the benefits of dark mode while minimising its negative impact.

## Future Research Agenda

### Methods for Researching the User Experience of Dark Mode Should be Diversified

Based on the analysis of the literature review, it is evident that experiments and questionnaires are the predominant methods utilised in dark mode research. While quantitative methodology can yield objective empirical findings, it is important to note

that there is considerable variation in the results among different papers. In fact, some papers may even present conflicting views on the same aspect of the study. Several researchers have failed to provide explanations for the user study's results, which is a drawback of the research design. Furthermore, the use of a solitary experimental method in studies may impact the study's findings as a result of operational constraints and the precision of the gathered data. This paper proposes the use of mixed research methods for future studies, broadening the range of research approaches to produce more comprehensive and precise findings. Collecting objective data is crucial for verifying the accuracy of research findings. However, it is equally important to gather detailed subjective data to bolster the credibility of the results and gain comprehensive explanations. As an illustration, Pedersen et al. (2020) conducted research that involved a combination of experiments and interviews. The findings revealed that, despite some users expressing negative reactions to the dark mode during the experiment, it was still evident in the interviews. Thus, these users opted for the dark mode. From a subjective standpoint, the users placed greater emphasis on the visual appeal and comfort of the dark mode rather than the speed and accuracy of completing tasks in this mode. This explains why the experimental data differs from the preference results.

**Incorporating More Specific Theoretical Frameworks for Research**

These literature reviews on the dark mode reveal that most studies have not approached the topic from a systematic theoretical framework. Instead, they focus on extracting potential findings from the samples, devices, or stimuli examined. Therefore, the findings do not yet fully capture the entire user experience. Furthermore, many of the studies provide research results that are objective, but they fail to delve into the theoretical foundation and supporting rationale behind these findings, which lack depth and specificity.

**Expanding the Type of Sample and Enriching the Context of the Research Subject**

It is worth noting that the majority of studies have utilized ‘students" as participants for data collection purposes. Nevertheless, it is important to consider that the student

population is just one segment of the overall population, and their experiences may not fully reflect those of other groups. On the other hand, dark mode has gained significant popularity across various demographics, and relying on a single sample may limit the generalizability and practicality of the results. Hence, it is recommended that future research incorporate a wider array of user groups and consider diverse user backgrounds. Additionally, in order to effectively address this issue, the sample should be less exclusive.

### Understanding the Negative Consequences of the Dark Mode User Experience and Solutions for Improvement

Based on the literature summary, it is evident that dark mode has the potential to significantly improve the user experience. Nevertheless, using dark mode can also result in adverse effects. A significant portion of the research focuses on exploring the benefits of dark mode while overlooking the potential drawbacks of this approach. While other studies have documented negative reactions to dark patterns, they have not explored potential solutions. In the future, it would be beneficial to enhance the negative effects of dark mode by integrating technology, objective user experience data, and addressing users' subjective needs. For instance, gaining insights into the unique traits and recommendations of various users may offer a possible remedy to mitigate the adverse effects of dark patterns.

## Conclusion

In recent years, the prevalence of dark mode has grown as display technology advances and user preferences become more varied. Therefore, it is crucial to conduct further research and engage in discussions regarding dark mode. This study requires further research to validate the dark mode UX framework. We should adopt a more comprehensive and systematic approach to address the limitations of current research and provide practical solutions to the user experience issues in dark mode. This paper aims to assist future researchers in gaining a comprehensive understanding of the dark mode, including its historical background, current state, and primary areas of focus. Additionally, it presents a well-defined research agenda to guide future investigations in this field.

## Limitation

Given the constraints of time and the database used, this study provides a summary of empirical studies on dark mode in the Scopus database over the past 30 years. However, this research may have overlooked other relevant studies beyond this time frame. Furthermore, the scope of this paper is confined to the search terms specified in the table, and any search results outside of this range have not been examined or analysed in this study.

As the field of dark mode technology and user experience research expands, future studies may uncover new areas for investigation.

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