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

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Abstract

Dark mode in mobile applications has drawn widespread attention in business, and many users choose to use dark mode in their mobile applications for different purposes. However, it is still an emerging field in the academic circle, as there are not many systematic studies on the definition and concept of dark mode. Besides, scarce are the scholarly inferences regarding contemporary investigative undertakings and future advancements concerning the dark mode. The pros and cons of dark mode are still debatable. In order to bridge this gap, this paper undertook a comprehensive evaluation of the scholarship concerning dark mode across diverse disciplines, with the aim of building a fundamental research process for studying the concept of dark mode and user experience to establish a more robust groundwork for further exploration of the correlation between dark mode and user experience. Based on the Scopus database, this paper searched and collected articles on dark mode research within the last 30 years via the two-step approach. Thirty-five articles were selected based on the inclusion and exclusion criteria. This paper first analysed the themes, background, theoretical foundations and research methods on dark mode. Then it classified and integrated the variable factors of dark mode research based on the Stimulus-Organism-Response (S-O-R) framework. It ultimately proposed a research framework explaining the more profound concept of dark mode and the relationship between variable factors, user experience, and their behaviours. In addition, this paper also identified existing gaps in the current document studies and outlined potential opportunities for future research on dark mode.

Keywords:Dark Mode, Two-stage Approach, S-O-R Framework, Bibliometric Analysis, User Experience (UX), Screen Display Technology

1. Introduction

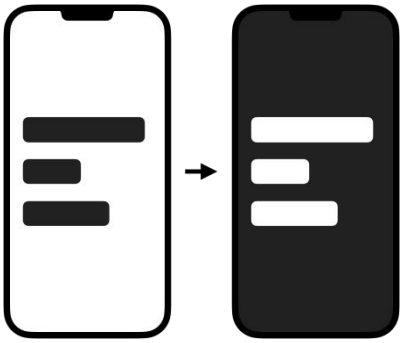
In IT and business, "dark mode" is a screen display technology that adjusts the interface of the screen to provide a comfortable viewing experience tailored for low-light environments with a dark colour palette and white text [1] (Techopedia, 2020). Dark mode was the only display technology in the first displays with white, green or amber text on a dark background [2] (Lunn, 2022). Related studies have also shown that dark mode is effective for people with vision difficulties who want to relieve visual fatigue [3] (Erickson et al., 2020). Meanwhile, it is true that using phones with dark mode enabled energy savings [4] (Xu et al., 2019). Youth today makes it a trend to adopt the dark mode in their electronic devices as means of creating a fashionable and cool design [5] (Pedersen et al., 2020). For various reasons, using dark mode is becoming increasingly common in our daily lives, and it has an evident impact on business and society [7] (Scaglione, 2022). From what is reviewed above, some scholars have researched dark mode, but not much attention has been paid to the professional and academic study on dark mode [8] (Henriette & Felix, 2020). Now there is neither a framework for research on dark mode nor a systematic review of the concepts, theoretical underpinnings, methods and final results of past research on dark mode [9] (Sethi & Ziat, 2022), and there is even controversy among the results of many different studies. [10] (Dobres, Chahine, Reimer, Gould, Mehler, et al., 2016; [11] Gao et al., 2021; [5] Pedersen et al., 2020; [12] Zlokazova & Burmistrov, 2017). Besides, the concept of the dark mode is often used in business, making it difficult for people to acquire the academic concept and relevant theory of the dark mode. Consequently, a common framework is needed across business domains, technical systems, theories and user experiences to explain the dark mode.

This paper provides a comprehensive, systematic review of prior research on dark mode. It closely scrutinises and deconstructs the selected corpus of literature, delving into the very essence of each publication, including the definition, theoretical underpinnings, research methodologies, and historical context of dark mode. This study is to have a better understanding of the dark mode and integrate the research on dark mode into a complete academic research framework to support future researches on the impact of the dark mode on people. Through a systematic review of current empirical research, the findings contribute to the understanding of dark mode and its user experience and identify best practices to study the features and experience of the dark mode. The paper is organised as follows: firstly, the definition of the dark mode and its related concepts are presented; Secondly, the search procedure for literature identification is described, and 35 screened research papers are analysed. Based on the S-O-R theory and the data from these papers, a research framework is developed which can be used as a systematic research framework and process to identify and integrate factors related to dark mode and its user experience; Finally, the paper discusses the theoretical and practical contributions of the study as well as future directions and priorities of the research on dark mode.

2. Definitions of Dark Mode and Related Concepts

Professionals and researchers of related industries have made certain definitions of dark mode from different perspectives. Some researchers define and contrast dark mode and the light mode from the perspective of contrast polarity, and propose that dark mode is negative contrast polarity that denotes the combination of light text on dark background. On the other hand, the light mode is a positive contrast polarity, and it refers to the dark-font text on a light background [13] (Budiu, 2020). Dark mode is a software option that makes the user interface darker. It changes light backgrounds to a dark colour and text from dark to light. The result is a pseudo-inverted interface that is primarily adorned in sombre shades [14] (Christensson, 2019). Some design experts in the tech industry interpret dark mode from the hue perspective and think dark mode is a colour style and trend that mainly uses dark colours. This is a design style that corresponds to the main popular style of default interfaces that mainly uses light tones [15] (Hoober, 2020). As shown in Figure 1, dark mode in the system design of the interface refers to a program or dark mode colour scheme that automatically adjusts the colour to protect the eyes of the users and make their eyes comfortable when staring at the screen for a long period, as well as reduce damage from excessive exposure to the light of a screen.

Figure 1. The comparison of the interface between dark and light mode



Academically, dark mode originally refers to a screen display technique and design. According to this definition, the visual effects of light text and content on a dark background are called " negative display polarity" or "negative contrast polarity" [16] (Dillon, 1992; [9] Sethi & Ziat, 2022). Also, Considering that dark mode becomes a trend in business in 2019 [8] (Henriette & Felix, 2020), and to have an understanding of the concept of dark mode and expand its scope, this paper not only refers to definitions of dark mode in the research literature but also draws on the terminology of dark mode from the authoritative commercial field. This extensive approach has also been validated as a useful research method [8] (Henriette & Felix, 2020). These key words include concepts that are closely related to dark mode, such as dark theme [17] (Android Developers, 2022), or the opposite terms of dark mode, such as light mode [18] (Moya, 2021). These two terms are often compared in research. Table 1 summarises dark mode definitions, concepts, synonyms and related words.

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. It also alters the colour of the text from dark to light. As if one were drawing the curtains or putting on sunglasses, dark mode engenders a marginally disruptive and robotic feeling.	[14], [19], [20] (Christensson, 2019; Developer of iOS, 2022; Goldberg, 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," which was suited to the programming tasks of the erudite few. However, as computing became more ubiquitous, a more approachable paper-like aesthetic emerged: white background with black text.	[2] (Lunn, 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. The dark theme effectively reduces the brightness emitted by the device screen and also satisfies the users' need for a minimum colour brightness at the same time.	[17], [21], [2] (Android Developers, 2022; Google developer, 2022; Lunn, 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, or any corresponding colour scheme, while night mode changes the colour emitted from the screen to a warmer colour.	[14], [22] (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.	[3], [23],[18] (Erickson et al., 2021; Koning & Junger, 2021; Moya, 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. Phosphorescence is usually a very dark colour that emits a bright light when struck by an electron beam. With the emergence of visual media, investigations were initiated to determine the optimal primary and secondary hues along with their combinations for this novel medium. Eventually it was found that cyan or yellow on black was the best.	[3] (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.	[8], [24] (Henriette & Felix, 2020; Piepenbrock et al., 2013b)
Negative display polarity	Negative polarity is a light character on a dark background.	(Henriette & Felix, 2020; Piepenbrock et al., 2013a)
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)

3. Research Methodology

3.1 Methodology Overview for Research

To integrate the previous researches on dark mode and its user experience, the two-stage approach was adopted to search and filter the literature. The two-stage approach was initially proposed by Heckman (1979) as a way to identify and mitigate a potential sample selection bias, and it consists of two consecutively applied stages. The first includes the selection of samples, and the second is to modify the sample selection bias and further focus on the core variables so that the results can be reliable (Heckman, 1979; Wolfolds & Siegel, 2019). Later, this approach was widely introduced into academic research and used as an effective way to modify samples to obtain core data and create research models (B. Kim et al., 2020; Papouskova & Hajek, 2019). Therefore, the two-stage approach is suitable for this paper. Since the dark mode does not have a unified academic concept and keywords, we adopt several associated keywords during the search to avoid missing relevant research data. Moreover, the two-stage approach also can identify articles on the same research topic published in different keywords (Gardner, 2022; Suh & Prophet, 2018). This method helps us retrieve a large sample of data in the first stage and allows us to exclude data that are not relevant to the research topic in the second stage through the restriction of core variables and screen out data truly consistent with the research, providing a good basis for creating a

variable centred model (Klyver et al., 2020; Tapia-Muñoz et al., 2022). In this paper, the first stage was to identify relevant articles through a keyword search on dark mode to obtain a large number of researches in the target database; the second stage set a limited scope and specific criteria to further screen the articles in the initial collection to exclude those which are ambiguous and deviate from the key words (the literature searching and screening process is shown in Figure 2). Next, we coded and categorised each of these data via the matrix method of literature review proposed by Klopper and others (Klopper, 2007; Lubbe et al., 2007) so that the findings could be analysed and summarised in an objective and quantitative approach. Finally, in accordance with the S-O-R theory (detailed discussed in Part 5), a framework for dark mode user experience research was constructed.

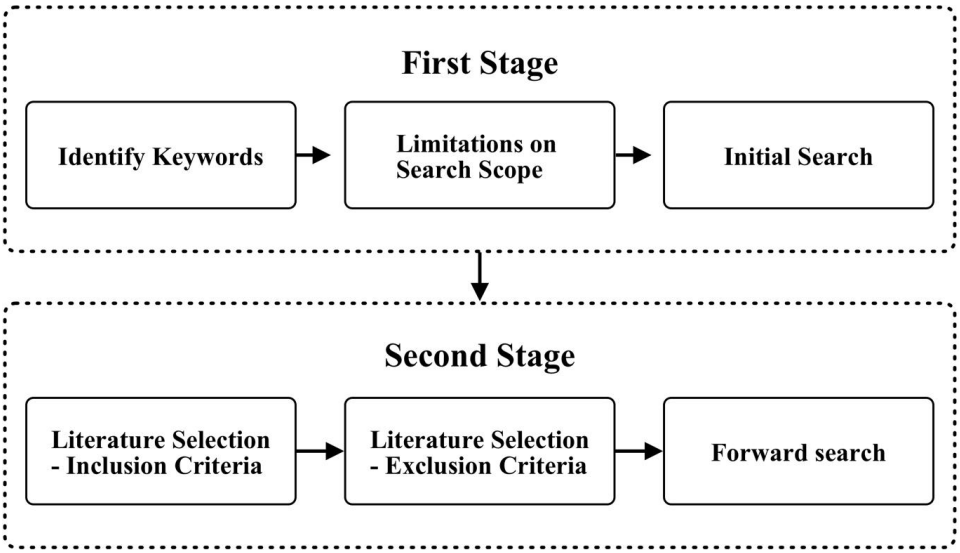


Figure 2. Two-stage approach process of the research

3.2 Study Design and Data Collection

As noted during the initial exploration, academic research on dark mode was limited in the first stage. This paper used The Scopus database as the collection source to obtain adequate data. Scopus database is the world's largest peer-reviewed abstract citation database, covering medical, natural science, social science, engineering and technology, arts and humanities and other disciplines. It has included a large number of journals, books and papers from more than 7,000 publishers worldwide. Searching in this encyclopedic database can ensure the data is reliable, quality, comprehensive, and maintain the consistency of the functions and algorithms (Morschheuser et al., 2017). As for the time range of searching and research, the critical review published by Dillon in 1992 defined the dark mode theoretically for the first time according to previous research findings (Dillon, 1992), and we want to learn about the empirical research on dark mode after it was defined academically, so the searching time for this paper is set to the last 30 years from 1992 to 2022. For the database search, broad key words such as “dark mode”, “black mode”, and “dark theme” were used based on the closely related words and synonyms for dark mode listed in the table above. Accordingly, 143386 relevant articles published between 1992 - 2022 were found. This paper aims to have a better understanding of dark-mode technology and user experience. Thus, in the first stage, empirical studies on dark pattern technology involving human factors or human life scenes were taken into consideration. Accordingly, the search for literature was targeted at related key subject areas of dark mode and user experience, including: computer science, social sciences, arts and humanities, health professions and nursing. In addition, the type of literature was limites to “Journal Article” and “Conference Paper”in order to ensure the research is rigorous and accurate. As a result, a total of 26,350 papers were screened under these 11 key words.

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:

a. The use of dark mode (techniques) as a study focus or as a closely related subject;

b. Relevant papers that have an impact on users.

The exclusion criteria were:

a. The topic of the research is not dark mode;

b. The meaning of dark mode in the article is ambiguous or contradictory to the actual definition of dark mode;

c. Other academic studies that are not related to the dark mode screen display technology studied in this paper.

Based on these criteria, 73 relevant articles were selected and exported in text after being filtered in accordance with the screen of subject, abstract and key words, and the detailed screening data for each term is shown in 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

Finally, by integrating searching results of 11 key words and removing duplicate articles, 35 papers and articles were sorted out. We then conducted a lookahead search based on these 35 papers to check whether there were any missing papers based on their relevant citations. We found no missing papers after a careful look ahead search. Data was collected from the 35 papers based 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 selected literature was then categorised and analysed via the matrix method of literature review mentioned in the research methodology. Finally, a summary was made on the themes, background, research methods, theoretical foundations and research trends in the dark mode literature.

4. Results

4.1 Overall Research and Publications

This paper made an overall review of the bibliometric data from 35 included papers. Figure 3 shows the publications on dark mode from 1992 to 2022. Although a preliminary academic definition of dark mode began in 1992, this did not attract much attention from researchers since then. As can be seen from the figure, empirical research on dark mode in the last 30 years began in 2005. Instead of using the term "dark mode", the former term "polarity display technique" was discussed and adopted (Chan & Lee, 2005). After that, dark mode began to enter the academic domain. However, the amount of literature published has been small and presents a tortuous pattern, with a peak in 2021. After a decline in publications from 2017 to 2018, it picked up in 2019, which may be related to the widespread release of dark mode by Apple and Android in business in 2019. Figure 4 shows the number of publications of academic research on dark mode. Computer Science ranked first with 12 papers, followed by 11 papers in Health Professions and then 7 papers in Engineering & Technology, indicating that research on dark mode is mainly related to computer science and technology.

Figure 3. Publications related to dark modes between 1992 and 2022

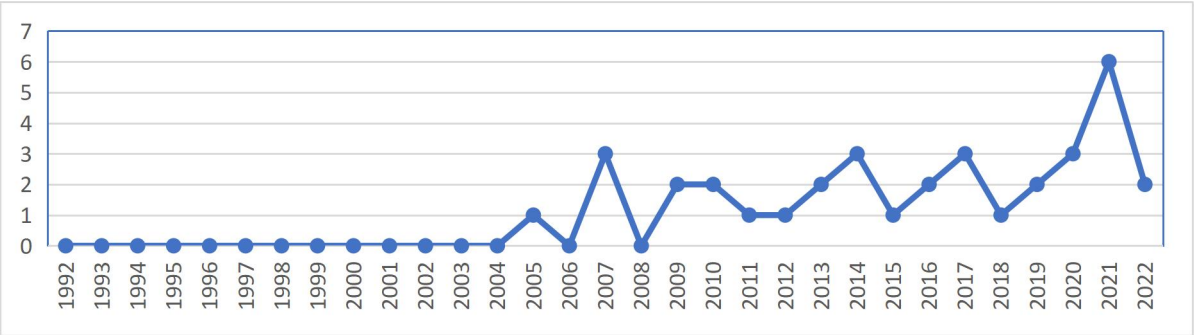
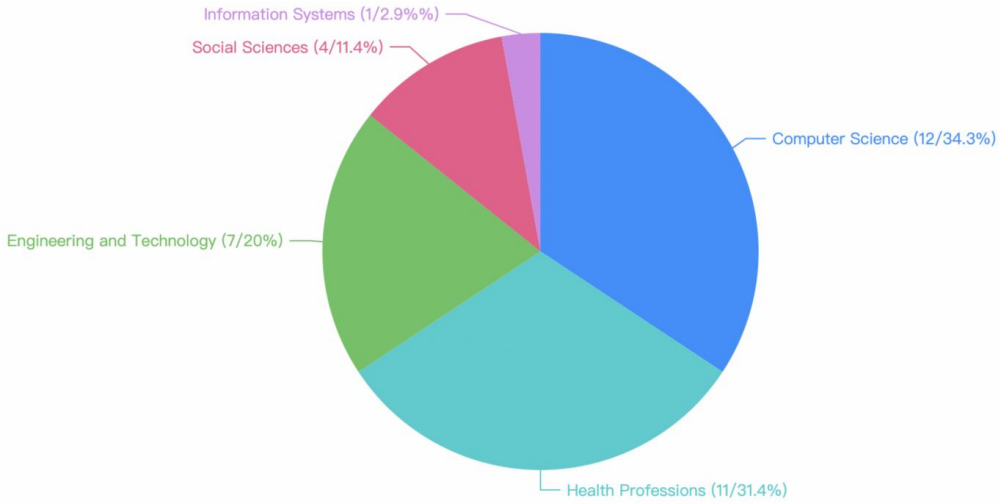


Figure 4. Quantity of Publications related to Dark Mode



The terminology of dark mode in business was developed in 2019 (Christensson, 2019), but from the analysis of the research and the literature, "dark mode" indeed belongs to the "negative polarity display technology" with white fonts on a black or dark background (Sethi & Ziat, 2022). There are three main schools in the study of dark mode. The first one studies the positive impact of this technique on user experience. They believe dark mode can enhance visual comfort and acuity (Erickson et al., 2020; Gao et al., 2021). promote an active circadian rhythm (Teran et al., 2020), and make the design of devices and apps more beautiful and fascinating (Pedersen et al., 2020). The second school, on the contrary, think that dark mode brings out some negative effects, for example,

diminishing the users' readability (Dobres, Chahine, Reimer, Gould, & Zhao, 2016; Piepenbrock et al., 2014b), hindering the accuracy of users' proofreading (Buchner & Baumgartner, 2007), and reducing their reading speed and efficiency (Chan & Lee, 2005). The third school holds a neutral attitude, claiming that dark mode is like a double sword for users and have both beneficial and detrimental impact on them under different circumstances. For example, the advantages and disadvantages of dark and light modes vary in the physical background and under different lighting circumstances and may also change among different users (Dobres, Chahine, Reimer, Gould, & Zhao, 2016; K. Kim et al., 2019). For example, the performances of the young and the elderly in dark mode are different in that the young can benefit from various aspects in both light and dark modes, while the elderly seem to experience a pronouncedly less visual fatigue in negative polarity displays (Lin & Yeh, 2010; Tomioka, 2007). It has also been shown that different monitors can lead to varying outcomes and effects of dark mode (Humar et al., 2014).

4.2 Methods in the Dark Mode Research

As shown in Table 3, various methods have been applied to dark mode research, including experiments, interviews, questionnaires, etc. Eleven articles adopted the single experiment approach, and twenty-four articles chose a mixed-method, with experiments and questionnaires the most commonly used one, a combination of which has been adopted in twenty-one articles. Most notably, experiments are proved to be the major research method since both single and mixed research methods are carried out on its basis. For example, experiments were conducted to explore users' visual acuity for dark mode (Gao et al., 2021) and to study users' proofreading performance together with pupillary changes in scenarios where dark mode is used (Piepenbrock et al., 2014b). Combining experiments and questionnaires, scholars have probed into some objectively unobservable data based on experimental data to obtain a further measurement of the user experience. For instance, they experimented with VR HMD devices to explore the data on users' vision usage and fatigue levels and evaluated the usability of the dark mode with short user experience questionnaires (UEQ-S).

Additionally, some other researchers have tested users' reading efficiency and proofreading ability in dark mode through text experiments and finally assessed their personal experience of dark mode in proofreading tasks with questionnaires (Piepenbrock et al., 2014a). According to the literature analysis, interviews are also effective methods to conduct research. Relatedly, researchers first measured the differences in productivity among users in the dark and light modes by inviting them to participate in an experiment with text copying tasks on a virtual keyboard. After that, brief interviews would be conducted to obtain data on users' preferences for the dark or light modes (Pedersen et al., 2020).

Table 3. Overview of research methods in the dark mode literature

Research Methods	**Total**	**Reference**
Experiment	10	(Buchner et al., 2009; Buchner & Baumgartner, 2007; Dobres et al., 2017; Erickson et al., 2020; Gao et al., 2021; Hong Chen & Muhamad, 2018; Kanda & Miyao, 2011; Mayr & Buchner, 2010; Piepenbrock et al., 2014b; Teran et al., 2020)
Questionnaire	1	(Zlokazova & Burmistrov, 2017)
Experiment & Case study	1	(Dash & Hu, 2021)
Experiment & Interview	2	(Pedersen et al., 2020)
Experiment & Questionnaire	20	(Bochud & Garbely, 2013; Chan & Lee, 2005; Dash & Hu, 2021; Dobres, Chahine, Reimer, Gould, Mehler, et al., 2016; Dobres, Chahine, Reimer, Gould, & Zhao, 2016; Erickson et al., 2021; Gattullo et al., 2015;

		Humar et al., 2014; Jeng et al., 2007; K. Kim et al., 2019; Li et al., 2022; Lin & Yeh, 2010; Löffler et al., 2017; Nissen & Riedl, 2021; Piepenbrock et al., 2013a, 2014a; Shen et al., 2009; Tomioka, 2007; Tsang et al., 2012; Xie et al., 2021)
Experiment & Questionnaire & Interview	1	(Sethi & Ziat, 2022; Vasylevska et al., 2019)

4.3 Theories Involved in the Dark Mode Research

This paper collates the theoretical or research frameworks involved in the thirty-one selected papers on dark mode (Table.4). It can be found that the vast majority of the papers are not based on any theory or framework. Instead, only a few theories have been cited as explanations of some concepts or as brief references without any detailed discussion. For example, 'Ego depletion theory' serves as the theoretical basis to elaborate that the dark mode increases the 'honesty' in users. 'Gestalt psychology' is used to illustrate how the dark mode, known as a form of negative polarity display, relates to the light mode (positive polarity display). Significantly, the UEQ theory and its framework were adopted in two different papers as a benchmark for a questionnaire to measure the usability (Erickson et al., 2020) and subjective preference (K. Kim et al., 2019) of dark mode. However, the six main aspects within the UEQ have not been investigated or discussed at length, nor have the findings and causes been explained. The "Signal processing theory" is used to explain the correlation and differences between positive and negative polarity and 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. Ego depletion theory can often be used in the construction of experimental control groups.	(Dang et al., 2021; Friese et al., 2019; Koning & Junger, 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 screen 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 (specifically Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation and Novelty), focusing on the 'Attractiveness'. The results of the UEO can reflect product quality in terms of user experience.	(Erickson et al., 2020; K. 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	(Bochud & Garbely, 2013; Köhler, 1967)

	underlying the dark background.	

4.4 Samples for Dark Mode Research

The samples used in the dark mode research have been summarised in Table 5. Participants' age in the thirteen papers are restricted to above 18 years old, whereas there is no explicit limit on the sample sources. As twelve papers selected this type of sample, university students were the most popular subject. Six papers are comparative studies on two different groups of subjects, four of which involved half youth and half elderly, while the other two papers both chose to include student groups and specialist teams. In particular, two articles conducted experiments on the devices rather than on human beings, and one other paper did not set any restrictions on participants. The studies with university students as subjects believed that this group was more familiar with the operation process of the dark mode (Pedersen et al., 2020). Researches selecting the elderly samples were designed to investigate whether elderly users would benefit from the display environment in dark mode (Lin & Yeh, 2010). Comparative studies of the young and the elderly intended to explore if the dark mode would exert different effects on them under the same conditions (Piepenbrock et al., 2013b). Researches with mixed sample groups of students and experts seek to obtain unbiased experimental results and thorough 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%

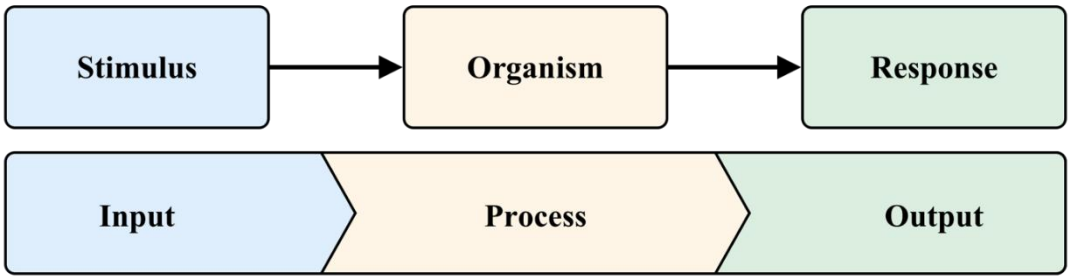
5. A Classification Framework for Dark Mode

Combining the S-O-R theory and research data, a more comprehensive research framework has been developed to facilitate subsequent research on the technologies, functions and content as well as user experience and behaviour related to the dark mode. It can theoretically help analyse and research the user experience processes of information technology and products (Teng & Bao, 2022). The theory covers primary aspects of user experience and behaviour, including not only the perceptual and affective reactions to the intense feelings that the surroundings and products may evoke (Wohlwill, 1976), but also the cognitive (learning ability, comprehension, etc.) and physiological reactions (Bitner, 1992). Additionally, explorations of product and technical features can also be conducted under the guidance. (J. Kim & Lennon, 2013). Therefore, S-O-R theory holds for investigating the factors and interrelationships between dark mode and user experience.

Furthermore, it has been widely used in the prediction of user behaviour when using information technology (Chen & Yao, 2018). With this multi-mediated mode, the relationship between the variable system of the dark model and the user experience has been adequately illustrated in this study. The theoretical framework consists of "stimulus", "organism", and "response". Thereinto, the "Stimulus" refers to the triggers, specifically in this study, those internal

and external elements that cause users' physiological, perceptual and cognitive changes in dark mode. Thus, all the variables in the research concerning dark mode have been extracted and categorised according to S-O-R theory for the purpose of exploring the correlations between them. "Organism" refers to the effect of the dark mode and its impact on the user, while "Response" refers to the result and behaviour of the user after using the dark mode. As such, the research process of the user experience in the dark mode is as follows: the internal and external factors (stimuli) of the dark mode have a perceptual, cognitive and physiological impact on users, which in turn prompts a positive or negative response of a desire or avoidance in the dark mode usage. Consequently, the S-O-R theory can be employed to establish an experiential framework for users of dark mode to elucidate the processes and reveal underlying rationales for their behaviour.

Figure 5. S-O-R Theoretical framework



5.1 The Stimuli in the Dark Mode

The advent of dark mode was driven by the objective of offering a colour-changing alternative that would render a unique visual experience. (Henriette & Felix, 2020). Research on dark mode shows that certain conditions, factors and features can elicit perceptual, cognitive and physiological reactions from users. The stimuli in this paper are divided into four categories per different research subjects. The first two categories, known as 'external factors', refer to factors that are beyond the control of the developers and designers. The latter two categories, defined as 'internal factors', are variables that can be adjusted internally by tech developers or the relevant product managers and designers. The first category is the ambient lighting of the dark mode, which is considered in several articles to be an important factor that may affect users (Erickson et al., 2021; Jeng et al., 2007). The second category is the main users of the dark mode, namely the sample subjects in the study, whose distinctions should be made clear in terms of age and physical condition as well as professional degree (Löffler et al., 2017; Piepenbrock et al., 2014a). The third category is devices that may bring about different user experience. For example, the display effects and product functions of the VR devices (Vasylevska et al., 2019).differ from that of computer screens (Pedersen et al., 2020). The fourth category is the internal components, that is, 'content', which includes texts (Chan & Lee, 2005), colours (Buchner & Baumgartner, 2007), graphics (Nissen & Riedl, 2021), images (Vasylevska et al., 2019), and luminance/contrast (K. Kim et al., 2019). These studies suggest that the 'content' factor is also key to stimulating the perceptual, cognitive and physiological reactions of dark mode users. Table 6 lists a variety of stimuli studied in the literature. Uncontrollable may the external factors be, the relevant technology and design practitioners can adapt the internal factors to suit the differences in external factors.

Table 6. Summary of stimuli in the dark mode

Stimulus	Classification	Reference

Ambient lighting	Dusky	(Buchner et al., 2009; Buchner & Baumgartner, 2007; Dobres, Chahine, Reimer, Gould, Mehler, et al., 2016; Dobres, Chahine, Reimer, Gould, & Zhao, 2016; Dobres et al., 2017; Erickson et al., 2020, 2021; Gattullo et al., 2015; Humar et al., 2014; Jeng et al., 2007; K. Kim et al., 2019; Koning & Junger, 2021; Löffler et al., 2017; Mayr & Buchner, 2010; Nissen & Riedl, 2021; Piepenbrock et al., 2013a, 2014a, 2014b; Sethi & Ziat, 2022; Shen et al., 2009; Tomioka, 2007; Xie et al., 2021)
	Bright	
Sample variation	Test subject • Involving human subjects • No human subject involved	(Dash & Hu, 2021; Dobres, Chahine, Reimer, Gould, Mehler, et al., 2016; Gattullo et al., 2015; Kanda & Miyao, 2011; Lin & Yeh, 2010; Löffler et al., 2017; Piepenbrock et al., 2013a; Sethi & Ziat, 2022; Teran et al., 2020; Tomioka, 2007; Vasylevska et al., 2019; Zlokazova & Burmistrov, 2017)
	Age • Young • Middle Age • Elderly	
	Health conditions • Normal vision • Eye disease	
	Level of expertise • Expert Team • General Users	
Equipment	Computer	(Chan & Lee, 2005; Dobres, Chahine, Reimer, Gould, Mehler, et al., 2016; Dobres, Chahine, Reimer, Gould, & Zhao, 2016; Gao et al., 2021; Humar et al., 2014; Koning & Junger, 2021; Löffler et al., 2017; Nissen & Riedl, 2021, 2021; Pedersen et al., 2020, 2020; Piepenbrock et al., 2013a, 2014a, 2014b; Sethi & Ziat, 2022; Tsang et al., 2012; Xie et al., 2021)
	Mobile phones	(Dash & Hu, 2021; Teran et al., 2020)
	Immersive equipment • VR • AR	(Erickson et al., 2020, 2021; Gattullo et al., 2015; K. Kim et al., 2019; Vasylevska et al., 2019)
	Display screens • OLED • LCD • CRT • TFT-LCD	(Buchner et al., 2009; Buchner & Baumgartner, 2007; Hong Chen & Muhamad, 2018; Li et al., 2022; Lin & Yeh, 2010; Mayr & Buchner, 2010)
	E-reader • E-Ink • Electronic paper	(Bochud & Garbely, 2013; Jeng et al., 2007; Kanda & Miyao, 2011; Shen et al., 2009)

Content	Text • Style • Size • Thickness • Line spacing	(Buchner & Baumgartner, 2007; Dobres, Chahine, Reimer, Gould, Mehler, et al., 2016; Dobres, Chahine, Reimer, Gould, & Zhao, 2016; Dobres et al., 2017; Gattullo et al., 2015; Hong Chen & Muhamad, 2018; Kanda & Miyao, 2011; Lin & Yeh, 2010; Piepenbrock et al., 2014a; Sethi & Ziat, 2022; Tomioka, 2007; Tsang et al., 2012; Zlokazova & Burmistrov, 2017)
	Colour • Saturation • Colourways	(Buchner & Baumgartner, 2007; Erickson et al., 2020; Gao et al., 2021; Hong Chen & Muhamad, 2018; Li et al., 2022; Löffler, 2017; Xie et al., 2021)
	Images • Clarity	(Erickson et al., 2021; K. Kim et al., 2019; Nissen & Riedl, 2021; Vasylevska et al., 2019)
	Graphics • Shape	(Hong Chen & Muhamad, 2018; Kanda & Miyao, 2011; Mayr & Buchner, 2010; Nissen & Riedl, 2021; Piepenbrock et al., 2013a; Sethi & Ziat, 2022)
	Contrast ratio • Low contrast ratio • Medium contrast ratio • High contrast ratio	(Bochud & Garbely, 2013; Erickson et al., 2020; Gao et al., 2021; Gattullo et al., 2015; Hong Chen & Muhamad, 2018; K. Kim et al., 2019; Li et al., 2022; Löffler et al., 2017; Mayr & Buchner, 2010; Piepenbrock et al., 2013a, 2014a; Tomioka, 2007; Tsang et al., 2012; Vasylevska et al., 2019; Xie et al., 2021; Zlokazova & Burmistrov, 2017)

5.2 The "Organism" in the Dark Mode

Within the ambit of this study, the term "organism" pertains to the subjective impressions and internal assessments of users while they interact with dark mode, specifically in terms of perception, cognition and physiology. The difference between perception and cognition is that perception is a state of feeling and emotion acquired directly from sensory experience, while cognition is an indirect, inferential and imperceptible process that affects thinking, understanding and learning ability after perception (Macpherson, 2011). The difference between perception and physiological reaction is that perception is an evaluative reaction psychologically manifested, whereas physiological reaction is a change that acts on the biological systems comprising the brain, the body and the internal organs (Bradley & Lang, 2000). It can be concluded from the previous analysis that the dark mode stimulates the visual senses mainly through visual elements, thus causing a perceptual and physiological reaction in the user and then influencing the cognitive reaction. As listed in Table 7, the main perceptual reactions regarding the dark mode include 'Attractive', 'Personalised', 'Fun' and so on, among which 'Fun', 'Sense of security' and 'Visual Aesthetics' are positive emotions and 'Depression' and 'Loss' are negative. This indicates that the same design pattern can also produce different perceptual reactions in different usage scenarios with different devices. For instance, dark mode promotes moral honesty as well as a sense of security (Koning & Junger, 2021). The variation in backgrounds also evokes a sense of pleasure. Besides, as dark scenes cause a feeling of losing contact with reality, the choices users make become more real that they choose hedonism over utilitarianism.

Moreover, the dark mode increases the enjoyment by making the choices more private (Huang et al., 2018; Pedersen et al., 2020). However, this colour mode can trigger depression in scenarios

like chat (Löffler, 2017) or in situations where the interface's colour is limited(Sethi & Ziat, 2022). Interestingly, due to previous long experience with light mode, users suffer from aesthetic fatigue and the potential psychological impact of excessive blue light exposure, developing a sense of contempt for light mode and considering its interface inferior. Switching to dark mode may sometimes create a sense of pride in users (Sethi & Ziat, 2022)

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. Many young users find dark modes more attractive than lighter ones.	(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 colors from light to dark, catering to uses' preference for changes. 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; K. 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. Also, the limited range of colours in the dark mode makes it dull.	(Löffler, 2017; Nissen & Riedl, 2021; Sethi & Ziat, 2022)
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. The minimum readable feature size at different distances is smaller in the dark mode.	(Erickson et al., 2020, 2021; Gao et al., 2021; J. Kim & Lennon, 2013)
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 & Ziat, 2022)
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. As such, it is safe to implement dark mode.	(Koning & Junger, 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	(Sethi & Ziat, 2022)

	pride in dark mode.	

Table 8 summarises the physiological states presented in the dark mode studies. The most frequent physiological reactions in the available studies were mostly vision-related. Accordingly, the advantageous low light in the dark mode restrains the prolonged visual stimulation caused by significant exposures to screen lights, especially the harmful blue light. Thanks to the decrease in the level of blue light, the inhibitory effect on melatonin can be reduced in dark mode, promoting better sleep for users who get used to using their mobile phones before bedtime (Teran et al., 2020). Low-light scenes lead to a lower visual burden, especially for the elderly who experience less visual fatigue in dark mode (Lin & Yeh, 2010). In addition to nighttime, the dark mode provides a more comfortable visual experience for those who spend long hours working or reading on computers and mobile phones (Erickson et al., 2020). However, some VR devices with little ambient light coordination, more time spent in the dim environment and dark screen displays can cause a state of physical stress leading to dizziness for some users (Vasylevska et al., 2019). Furthermore, using dark mode may cause glare to the eyes (Tsang et al., 2012), and the lower illumination of dark mode may lead to pupillary dilation , which introduces blurred vision (Dobres, Chahine, Reimer, Gould, Mehler, et al., 2016).

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., 2020, 2021; K. 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; K. Kim et al., 2019; Li et al., 2022; Lin & Yeh, 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.	(K. Kim et al., 2019; Lin & Yeh, 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	Researches show that some users may experience a motion sickness accompanied by salivation when wearing VR devices in	(Vasylevska et al., 2019)

	dark mode for long.	
Glare and reflection problems	Dark mode may leads to glare and reflection, as significantly worse lobe size and shape were presented in negative polarity conditions.	(Piepenbrock et al., 2014a; 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, Chahine, Reimer, Gould, Mehler, et al., 2016; Piepenbrock et al., 2014a; Tsang et al., 2012)

Table 9 lists the cognitive reactions towards dark modes. From this, we know that a set of studies link the significant cognitive reactions to the reading and comprehension ability which is affected by legibility, be it stemming from the fonts or texts presented on different screens or media. In general, the readability of a text is influenced by two factors: first, the difficulty of the textual material; second, the ease with which the text can be visually identified and processed. Thus, under the same test conditions, the length of reading reflects how easy it is for users to extract and understand information (Poole & Ball, 2006). For the same reading task, the readability is poor if the reading time is long; it also affects users' ability to process and understand information. Therefore, some researchers have argued that dark mode helps reading, based on the protective aspect of dark mode for the eyes, in terms of shorter reading time in dark mode (Bochud & Garbely, 2013). Others have argued that due to the pupil dilation effect (Dobres, Chahine, Reimer, Gould, & Zhao, 2016), the dark mode has a disadvantage in terms of luminance and recognition, leading to distractions and increased visual processing difficulties, making it more detrimental to reading than the light mode. In terms of usability, based on satisfying the use efficiency of the interface (readability, easy operation), the overall usability quality is higher because the dark mode has apparent advantages in the user's enjoyment when using the 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 & Garbely, 2013; Dobres, Chahine, Reimer, Gould, & Zhao, 2016; Erickson et al., 2021; Humar et al., 2014; Kanda & Miyao, 2011; K. 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.	(Buchner & Baumgartner, 2007; Chan & Lee, 2005; Dobres, Chahine, Reimer, Gould, &

	Conversely, at higher ambient light levels, lighter mode displays provide better readability.	Zhao, 2016; Hong Chen & Muhamad, 2018; Jeng et al., 2007; Piepenbrock et al., 2014a)
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; K. Kim et al., 2019, 2019; Schrepp et al., 2017)

5.3 The "Response" in the Dark Mode

In this study, 'response' refers to the outcome of using the dark mode and influences the user's response, which subsequently guides the choice of continuing or refusing to use the dark mode. Among the user responses to the dark mode, "comprehension", "task performance", "physical symptoms", and "intention to use " were commonly cited as response variables, and they were categorised into positive responses (Table 10) and negative responses (Table 11).

In terms of comprehension, as discussed in the previous section, reading length corresponds to readability and comprehension difficulty. In the negative responses, it has been shown that text reading in dark mode takes more time, has poor legibility and affects comprehension. Especially in LCD screen devices, the dark mode demonstrates poor legibility and increases the difficulty of reading and comprehension (Humar et al., 2014). Higher cognitive load using negative polarity also reflects increased search time and pupil diameter among elderly adults in bright environments. (Sethi & Ziat, 2022). However, positive responses indicated that dark mode in low-light environments promoted concentration and reading ability. Users who preferred dark mode were perceived as using and being proficient with computers for a long time, showing better reading and comprehension effects in dark mode (Pedersen et al., 2020). In addition, for CRT displays, the dark mode ranks highest in terms of legibility, promoting reading and comprehension (Humar et al., 2014)。

In task performance, visual acuity and usability are important factors in the accuracy of search operations and proofreading during the task. Some researchers have suggested that the dark mode performs better in low ambient light conditions, with shorter proofreading times and fewer error rates in task completion (Erickson et al., 2021). Other researchers have suggested that light-coloured patterns usually show higher brightness, resulting in stronger pupil contractions, which produces higher-quality projections on the retina, with sharper images and better perception of detail, and thus better collation. Conversely, dark mode shows more retinal image blurring due to lower luminance, poorer recognition and inferior proofreading performance, especially in low-contrast situations where colour elements affect the visualisation of contrast mechanisms in the ocular pathway, and dark mode shows poorer resolution and sensitivity effects and lower task completion rates. (Piepenbrock et al., 2014b)

From the point of view of "physical symptoms", positive reactions tend to outweigh negative ones. Since studies have proven that dark patterns can benefit vision and aid sleep, they are a good solution for people with eye problems and chronic use of electronic devices (Kanda & Miyao, 2011; Tomioka, 2007). However, it cannot be ignored that dark mode may cause muscle strain and back pain to the user (Piepenbrock et al., 2013a). Glare and blurred vision also occur due to the dilation of

the pupil caused by the dark background (Dobres, Chahine, Reimer, Gould, Mehler, et al., 2016; Piepenbrock et al., 2014a; Tsang et al., 2012). Furthermore, in head-mounted devices such as VR, there may be some stress on participants due to the dual stress of being in the device at low brightness and the dark mode without the adaptation of ambient brightness (Vasylevska et al., 2019).

Finally, in terms of 'intention to use', positive responses have reported a significant main effect of ambient lighting on overall preference. In weak ambient light, based on "easy to read", "perceptual performance", and "visual comfort", users will be more inclined to the dark mode, combined with the energy-saving effect of the dark mode in terms of visual aesthetics in perception and practical quality. Many researchers support users' preference for darker patterns (Erickson et al., 2020; K. Kim et al., 2019; Pedersen et al., 2020). Conversely, when it comes to negative reactions, many scholars believe that the white background mode is more similar to the reading scene of a book, as users have long been accustomed to reading black text on white paper, and white is closer to the natural environment. According to Gestalt psychology, a black background and white text is more like a reverse visual effect. Switching background colours causes visual unadaptation for the user, who needs to learn to use and adapt to the new visual display, and learning a new way of reading takes an effortful process. This is why dark mode can be rejected (Bochud & Garbely, 2013; Chan & Lee, 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.	(Erickson et al., 2020, 2021; Gao et al., 2021; Hong Chen & Muhamad, 2018; 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 & Buchner, 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; K. Kim et al., 2019; Li et al., 2022; Lin & Yeh, 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	(Dash & Hu, 2021; Erickson et al., 2020, 2021; K. Kim et al., 2019)

	important reasons for the preference.	

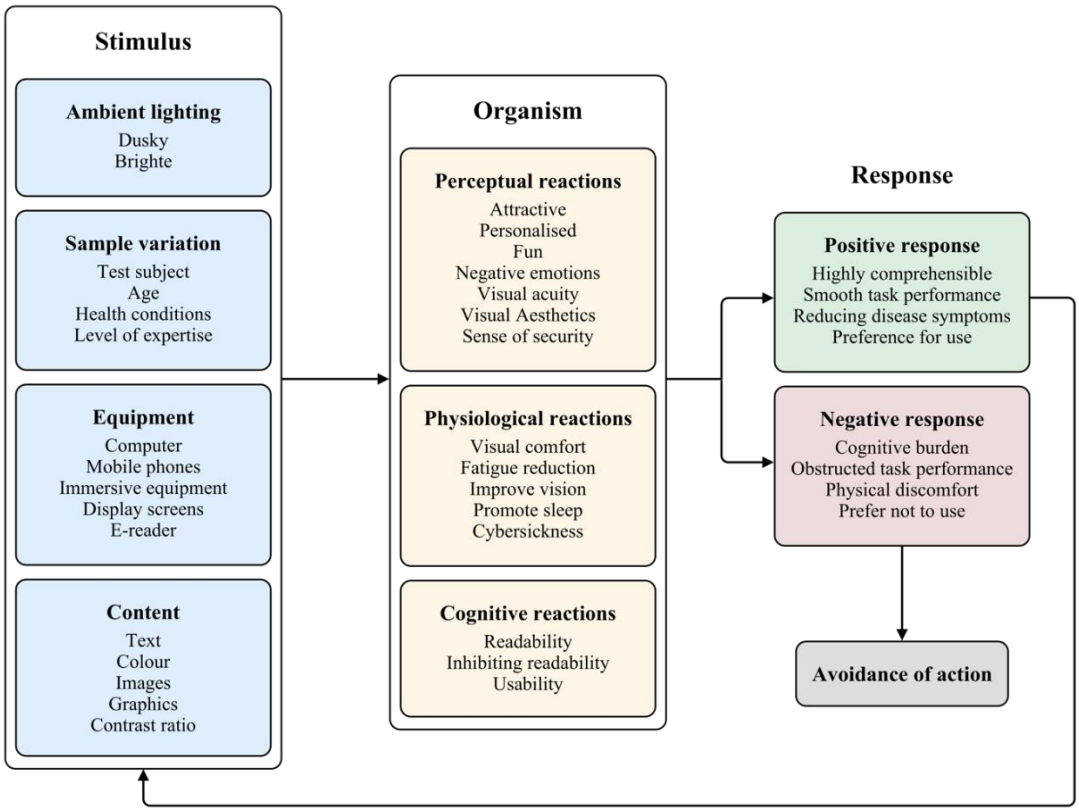
Table 11. Summary of Response in Dark Mode (Negative Outcomes)

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, Chahine, Reimer, Gould, & Zhao, 2016; Humar et al., 2014; Jeng et al., 2007; Piepenbrock et al., 2013a, 2014a; Sethi & Ziat, 2022)
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 & Baumgartner, 2007; Chan & Lee, 2005; Jeng et al., 2007; Kanda & Miyao, 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, Chahine, Reimer, Gould, Mehler, et al., 2016; Piepenbrock et al., 2013a, 2014a; 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 & Garbely, 2013; Chan & Lee, 2005; Piepenbrock et al., 2014b; Xie et al., 2021)

6. UX Research Framework for Dark Mode

The literature review reveals that although there are few papers on the emerging trend of dark patterns in the past, similar polarity techniques have been discussed much earlier. Current research findings show that there is a great deal of controversy in opinions on using dark mode, and most studies are inconsistent in focus, lack overall consideration, and do not have a holistic research framework to explore the relationships between these research variables and the reasons for these different findings. This paper proposes a comprehensive research framework for dark pattern research based on the S-O-R, as shown in Figure 6.

Figure 6. UX research framework for dark mode



The literature review analysis shows that the systemic components of the dark mode (external environment, research object, subject device and internal elements) influence the user's perceptual, cognitive and physiological responses. Research on the dark mode has produced diverse findings and research controversies. Therefore, the research framework summarised in this paper means that it is possible to comprehensively understand the differences and importance of stimuli caused by dark patterns in user perception and cognitive response and understand the user experience process related to dark patterns and how to lead to user behaviours ultimately. When researching and developing the dark mode, the combination of the external environment, the research subject, the subject device and the internal elements should be considered to examine the strengths, weaknesses and further refinement strategies of the dark mode rather than affirm or deny the overall system of the dark mode from one aspect of the research findings alone. Previous literature has not highlighted dark mode and the relationship between user experience and behaviour. However, it has been validated in many papers that stimuli from factors both internal and external to the dark mode system led to different user behaviours through the mediation of their perceptual, cognitive and physiological reactions. Therefore, this framework proposes that the systematic composition of dark patterns (stimuli) ultimately leads to outcomes that affect the user's use of dark patterns by influencing the user's perceptual, cognitive, and physiological responses (organisms) and, in turn, triggers the user's preferred behaviour (responses).

7. Discussion

Though the commercial field has given significant attention to the dark model, there is little research in the academic field on the dark model, and no research has systematically summarised and analysed the existing knowledge of the dark model, its concepts, its design systems and user experience processes. So, starting with dark mode as a screen display technology, this paper collects and analyses relevant research from the last 20 years; uses its nature (negative polarity display) and characteristics (dark or black background with light or white fonts) as a basis for extending the research data and integrate the various variables examined in dark mode research into a research framework. Therefore, it can provide a research reference for the study of dark mode, and researchers can use this research framework to understand, validate and develop further research on dark mode in future.

7.1 Theoretical Implications

This study analyses the current state of literature related to dark mode, including bibliometric information on dark patterns, research background, research methods, relevant theories and research trends, which make several important contributions to the academic field. Firstly, there is a lack of academic research into the dark mode based on developments in the commercial field, and no research provides a systematic literature review. Many researchers still need to learn more about the dark mode, and it is not easy for them to find a research direction. In fact, the negative polarity technique of dark mode has been studied and discussed long before dark mode received attention. However, the literature is not directly available in academic research as the commercial field has rebranded and improved the technique. This paper provides not only the most recent technical research data on the dark mode, but also supplements it with detailed research data and analysis of negative polarity techniques which is consistent with the nature and characteristics of the dark mode and the closely related positive polarity technology (light-coloured mode). This literature review can help the researcher to understand the situation of dark mode in terms of research topics, background, disciplines, theoretical basis, research methods and trends. Secondly, this paper develops a comprehensive research framework on the user experience of dark mode by integrating the factors related to dark mode together. Based on that, it can help subsequent researchers to develop new research theoretical models to explain the findings of dark mode user experience, analyse the system design of dark mode, and the interactions between dark mode and user experience. Finally, through summarising the literature, this paper finds the controversial issues and gaps in the research, and the research variables and factors integrated from the literature review can support future research from multiple directions.

7.2 Practical Implications

This study has practical significance for researchers involved in dark mode system developments and equipment vendors. This paper establishes a comprehensive and in-depth framework for research on the user experience in dark mode, involves dark mode systems (external environment and internal factors), user experience and ultimately user behaviour, which can explain the interactions between external environment, technology, content, individual users, perception, cognition, physiology and other factors that are closely related to dark mode to facilitate user decision-making behaviour further. Moreover, there are indeed both positive and negative aspects of user experience in dark mode, so system developers and designers involved in dark mode can refer to the dark mode experience framework and related factors presented in this study, compare the positive and negative effects, and focus on how to enhance the advantages of dark mode and reduce the negative responses of dark mode.

7.3 Future Research Agenda

(1) Methods for researching the user experience of dark mode should be diversified

The literature review analysis shows that experiments and questionnaires are the most widely used methods in dark mode research. Although quantitative methodology can provide objective empirical findings, there is much variation in the findings across a number of papers, even to the point where different papers present mutually exclusive views on the same aspect of the study. Many researchers have not explained the reasons for the user study results, which is a limitation of the research design. In addition, studies that use only a single experimental method may also affect the results of the study due to operational limitations and the accuracy of the data collected. Therefore, this paper proposed using mixed research methods for future research, expanding the diversity of research methods to provide more detailed research details and results. It is not only necessary to collect objective data to verify the accuracy of the research but also to collect detailed subjective data to support the credibility of the research results and further obtain adequate explanations. For example, in the research conducted by Pedersen (2020) he combined the experiment with interviews and concluded that although some users had negative reactions to the dark mode in the experiment, it was still found in the interviews that these users preferred to use the dark mode. Subjectively, these users focused more on the aesthetic appearance and comfort of the dark mode, rather than on the speed and errors of task completion in the dark mode. This explains why the experimental data contradicts the preference results.

(2) Incorporating more specific theoretical frameworks for research

In these literature reviews on the dark mode, it can be found that almost all of the studies have not been based on a systematic study of the theoretical framework but seek possible findings from the samples, devices or stimuli studied. Thus the findings do not yet encapsulate the complete user experience. In addition, most of the studies present an objective research result but lack insight into the theoretical basis and supporting reasons behind these findings, which are not deep and specific enough.

(3) Expanding the type of sample and enriching the context of the research subject

The bibliometric analysis shows that most studies have used 'students' as subjects to collect data. However, the student population only represents one type of population and experience, whereas the dark mode is already widely popular among different groups of people, and a single sample may inhibit the generalisability and applicability of the findings. Therefore, future research should include a broader range of user groups and consider different user backgrounds, and the sample should be less restrictive to address this problem.

(4) Understanding the negative consequences of the dark mode user experience and solutions for improvement

From the literature summary, it is clear that dark mode has a positive potential to enhance the user experience. However, using dark mode can also have negative consequences. Much of the research is based on discussing the positive effects of dark mode and lacks a dialectical view of the negative consequences of this technique. Negative reactions to dark patterns have been documented in other research, but further solutions have not been considered. In the future, the negative effects of dark mode should be improved by combining technology, objective data of user experience and subjective needs of users. For example, understanding the individual characteristics and suggestions from different users could be a potential solution to overcome the negative consequences of dark patterns.

8. Conclusion

The dark mode has become more common in daily life when display technology continues developing and users' needs diversify significantly. Thus, research and discussion on dark mode need to be further investigated. More empirical studies are needed in the future to validate the dark mode UX framework proposed in this study, advance a more comprehensive and systematic study based on the shortcomings of current research, as well as to propose practical solutions to the problems in the user experience of dark mode. This paper helps subsequent researchers understand the history, current status and focus of the dark mode, and provide a concrete research agenda for future research.

9. Limitations

Due to the limitations of the time scale and the scope of the database collection set in this study, the research in this paper can only summarise the empirical studies of dark mode in the Scopus database within the last 30 years, while other studies beyond the last 30 years are yet to be investigated and summarised. In addition, the search terms in this paper are limited to those listed in the table in the text, and search results beyond this range have not been explored and analysed in this paper.

As research on dark mode technology and its user experience continues to grow and develop, future research may present more new situations for researchers to investigate next.

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