DOCUMENT SUMMARY This 2024 paper provides a systematic review of academic research on **dark mode** interfaces. Using a two-stage approach to analyze 35 articles from the past 30 years, the authors find that the literature is divided, with some studies showing benefits (e.g., reduced visual fatigue, energy savings, aesthetic appeal), others showing drawbacks (e.g., decreased readability, impaired proofreading), and a third group finding that effects depend on context. To synthesize these conflicting findings, the paper proposes a comprehensive **User Experience (UX)** research framework based on the Stimulus-Organism-Response (S-O-R) model, categorizing the factors that influence a user's reaction to **dark mode** and outlining avenues for future research.

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FORMATTED CONTENT

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., https://www.google.com/search?q=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. 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.

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).

> **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).

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	(Christensson, 2019; Xie et al., 2021)

	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.	
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., https://www.google.com/search?q=2020; Piepenbrock et al., 2014a)
Negative display polarity	Negative polarity is a light character on a dark background.	(Eisfeld et al., https://www.google.com/search?q=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	(Buchner et al., 2009)

	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 c¼ (Lt7Lb)/(Lt Lb) becomes adversarial) or positive polarity of the text-background.
	Table 1: Definition of **Dark Mode** and Its Related Concepts.

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Research Methodology

Methodology Overview for Research

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.

For this paper, the initial step involved finding relevant articles by conducting a keyword search in

dark mode in a specific database. The next step was to narrow down the scope and establish specific criteria to carefully sift through the initial collection of articles.

Study Design and Data Collection

The paper utilised the Scopus database as the collection source. The search yielded a total of 143,386 articles from 1992 to 2022. A focused search was conducted in various subject areas such as computer science, social sciences, arts and humanities, health professions, and nursing. The literature was restricted to "journal articles" and "Conference Paper". A total of 11 specific search terms screened a total of 26,350 papers.

In the second stage, inclusion and exclusion criteria were set.

Inclusion 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.

Exclusion criteria:

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 criteria, a total of 73 articles were chosen. After integrating search results from 11 different keywords and eliminating duplicate articles, a total of 35 papers and articles were organised.

Results

Overall Research and Publications

Research on

dark mode has been conducted for the past 30 years, beginning in 2005. Instead of "

dark mode," early authors used the term "polarity display technique". The number of publications peaked in 2021. The research focus primarily revolves around computer science and technology. Computer Science had the most papers (12), followed by Health Professions (11), and Engineering and Technology (7).

There are three primary schools of thought in

dark-mode research:

* The initial study examines the favourable effects of this technique on

user experience. Some researchers suggested that

dark mode can enhance visual comfort and acuity.

* In contrast, the opposing viewpoint argues that

dark mode can have negative effects. Some researchers have found that it can decrease readability, hinder proofreading, and reduce reading speed.

* The third school maintains a neutral stance, asserting that

dark mode can have both positive and negative effects on users, depending on the circumstances. For instance, the way young people and elderly individuals respond to

dark mode differs.

Methods in the Dark Mode Research

Experiments and questionnaires are the predominant methods used in

dark mode research. Eleven articles used a single experiment approach, while twenty-four used a mixed-method approach, with the most common combination being experiments and questionnaires (21 articles).

A Classification Framework for Dark Mode

A comprehensive research framework was developed using the

S-O-R (Stimulus-Organism-Response) theory.

- **Stimulus**: Refers to triggers, both internal and external, that induce changes in users when using **dark mode**. These are categorized as external factors (ambient lighting, test subjects) and internal factors (equipment, content).
- **Organism**: Pertains to the influence of **dark mode** on the user's perception, cognition, and physiology.
- **Response**: Pertains to the user's subsequent actions and behavior following the use of **dark mode**, such as the intention to continue or discontinue use.

The "Organism" in Dark Mode: Perceptual, Physiological, and Cognitive Reactions

Perceptual Reactions:

- **Positive:** Reactions include finding **dark mode** 'Attractive', 'Personalised', and 'Fun'. It can also enhance 'visual aesthetics' and foster a 'sense of security' and 'pride'.
- **Negative: Dark mode** can also induce negative emotions like 'Depression' and 'Loss', especially in chat contexts or with limited color options.

Physiological Reactions:

- **Positive:** The most common reactions relate to vision.
  Dark mode can reduce visual stimulation from blue light, potentially improving sleep. It can reduce visual fatigue, especially for the elderly, and provide a more comfortable experience for those with prolonged screen time.
- **Negative:** It can also induce glare, pupillary dilation leading to blurred vision, and physical stress (cybersickness) in VR environments.

Cognitive Reactions:

- **Legibility Debate:** There is a significant debate on whether **dark mode** helps or hinders reading.
  - Some argue it aids reading by protecting the eyes, leading to shorter reading times.
  - Others suggest it may have drawbacks due to pupil dilation, which can reduce recognition and make visual processing more difficult.
- **Usability:** Despite legibility debates, **dark mode** shows clear advantages in enhancing the user's enjoyment and overall usability quality during interface interaction.

The "Response" in Dark Mode: Positive and Negative Outcomes

Positive Responses:

- **Comprehension:** Users in low-light environments may be more focused and have better comprehension.
- **Task Performance:** In low light, users may complete tasks more smoothly with fewer errors.
- **Health:** It can reduce disease symptoms by improving vision and promoting better sleep.
- **Preference:** Users often prefer **dark mode** in low light for ease of reading, comfort, energy-saving benefits, and aesthetics.

Negative Responses:

- **Cognitive Burden:** Text in **dark mode** can be harder to recognize and take more time to read, affecting comprehension, especially for older people in bright environments.
- **Task Performance:** Low illumination and **dark mode** can hinder task operation and reduce accuracy.
- **Physical Discomfort:** It can cause muscle strain, back pain, dizziness (in VR), glare, and blurred vision.
- **Preference:** Some users reject **dark mode**, preferring the familiar experience of reading black text on a white background, which mimics reading on paper.

Discussion

While commercially popular,

dark mode lacks sufficient academic research and a comprehensive literature review. Many studies show conflicting results and lack a holistic research framework. The

S-O-R framework presented in this paper aims to provide a structure for understanding the varied user responses by considering the different stimuli (external environment, user type, device, content) that influence them.

A significant portion of the research focuses on exploring the benefits of

dark mode while overlooking the potential drawbacks of this approach.

Future Research Agenda

1. **Diversify Research Methods:** Current research relies heavily on experiments and questionnaires. Future studies should use mixed methods, incorporating subjective data from interviews to explain why user preferences sometimes contradict performance data. As an illustration, Pedersen et al. cite_start 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.

2. **Incorporate Theoretical Frameworks:** Most studies lack a systematic theoretical framework, leading to findings that don't fully capture the entire **user experience**.
3. **Expand Sample Types:** The majority of studies use students as participants. Future research should include a wider array of user groups to improve generalizability.
4. **Understand and Solve Negative Consequences:** More research is needed not only to document the adverse effects of **dark mode** but also to explore potential solutions for improving them.

Conclusion

Further research is crucial to validate the proposed

dark mode UX framework and to address the limitations in current research. This paper aims to help future researchers understand the background and current state of

dark mode studies and provides a research agenda to guide future investigations.