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Analyzing The Effect of Theory-Based User Interface Design in Mobile Learning Application on PSTI Students' Extraneous Cognitive Load

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ABSTRACT

The limited screen size of mobile devices can increase users' Extraneous Cognitive Load (ECL), hindering effective Self-Regulated Learning (SRL) in digital environments. This study aims to design a mobile learning application (MLA) interface integrating User Interface Design (UID) principles with SRL theory and to evaluate its impact on learners' ECL. Adopting DBR, a prototype was developed and evaluated by 144 respondents using an ECL questionnaire and open-ended feedback. Descriptive statistics revealed that the interface successfully minimized cognitive load, with all dimensions categorized as low. The Aesthetic and Minimalist Design dimension recorded the lowest mean score (2.55). However, thematic analysis revealed issues such as reading fatigue from dense text and subtle navigation cues. Consequently, a design iteration was executed to implement micro-learning content chunking, centralize navigation, and enhance visual signaling. The findings highlight that minimizing ECL through strict UID compliance is essential to support SRL. This research contributes an empirical study by integrating UID principles and SRL theory within a DBR approach to systematically reduce extraneous cognitive burdens.

1. Introduction

Mobile phone usage in Indonesia has demonstrated a significant upward trend in recent years, reflecting society's growing reliance on mobile devices for daily routines. Projections indicate that the number of mobile phone users in Indonesia will reach 239 million by 2026, an increase from 228 million in the previous year (Statista, 2024). This surge was further catalyzed by the COVID-19 pandemic, during which digital technology played a pivotal role in sustaining vital sectors, such as banking, industry, and public services to prevent national economic decline. In the educator sector, the pandemic compelled universities and educational institutions to transition from face-to-face to online learning, resulting in the massive adoption of mobile phones as learning media. Various studies have shown that the integration of digital interactive media and innovative learning models, such as game-based platforms, simulations, and animated videos can significantly enhance students' cognitive outcomes (Rosyida et al., 2022; Khayyirah et al., 2024; Faza et al., 2024). These findings underscore the critical role of well-designed digital tools in achieving pedagogical goals across different educational levels and subjects (Dewi et al., 2024; Utami et al., 2025). Mobile technology enables educational institutions to leverage various advantages, including flexibility, affordability, and portability, making it a potent instrument for supporting teaching and learning activities in the new digital era (Briz-Ponce et al., 2017).

These conditions align with the emergence of a new educational paradigm, mobile learning (Goksu, 2021). Mobile learning is defined as a learning process (Sattarov & Khaitova, 2019) that offers exclusive opportunities to bridge learners' experiences across formal and informal contexts (Joo et al., 2016) using personal mobile devices (Kinash et al., 2012; Rossiter et al., 2024), such a smartphones, smartwatches, tablets, and digital audio players (Kumar & Sharma, 2020; Kumar et al., 2020). This learning model allows students to access information anytime and anywhere, engaging in authentic learning activities relevant to their daily lives (Martin & Ertzberger, 2013). Furthermore, mobile learning supports real-time collaboration among learners through discussion forums, group projects, and shared documents (Hernando et al., 2014), thereby fostering peer-to-peer learning, teamwork, and knowledge exchange without the constraints of physical location (Hug, 2015).

Despite its inherent flexibility, the implementation of mobile learning faces several challenges, particularly regarding the comfort and effectiveness of the learning experience. Learning through mobile devices is often considered less optimal compared to desktop-based-a-learning (Elkhair & Mutalib, 2019). A primary factor contributing to this issue is the relatively small screen size (Alasmari, 2020). This limited visual space makes interface navigation, such as using keypads and buttons, more difficult and restricts the amount of information that can be displayed simultaneously. This phenomenon is known as the peephole effect, where users are forced to continuously scroll to maintain information context, which can subsequently trigger an increase in cognitive workload (Nielsen, 2011).

Within this context, user interface design plays a crucial role in ensuring effective interaction between learners and mobile learning applications. According to a study by Septiadi et al. (2025), an intuitive interface in educational applications is essential as it enables learners to access information more easily and execute learning activities more effectively. Conversely, a poorly designed interface restricts users' ability to utilize application features, triggering click errors and navigational frustration. Such poor UI design ultimately imposes an irrelevant mental burden on students' cognitive systems, known as Extraneous Cognitive Load (Curum & Khedo, 2021; Suartama et al., 2019; Li & Heng, 2021; Chu, 2013). ECL is an ineffective cognitive load because it does not directly contribute to the learning process, rather, it arises from poor, disorganized, and distracting information presentation (Sweller, 1994). When a screen layout is complex and unintuitive, learners exhaust their working memory trying to figure out how to use the application, instead of focusing on processing the core learning materials (Feng et al., 2018). Therefore, to minimize ECL, user interfaces must be systematically designed (Darejeh et al., 2024), adhering to established UI design guidelines and frameworks (Galitz, 2007; Wilson & Johnson, 1996).

Aligning with these principles, Faudzi et al. (2023) developed a conceptual framework explaining how UID principles can serve as a foundation for designing mobile learning environments capable of reducing learners' ECL. However, because this framework was constructed upon a synthesis of literature and cognitive load theory, the causal relationship between UID principles and ECL reduction remains largely hypothetical. In other words, there is a lack of empirical evidence comprehensively examining the extent to which the integration of interface design theory and learning regulation within a mobile learning interface actually reduces users' ECL. To bridge this gap in the literature, this study aims to design the user interface of a mobile learning application based on SRL theory and subsequently evaluate the students' ECL levels resulting from the designed interface. This research is expected to provide theoretical contributions to the development of mobile learning interface design, as well as practical contributions to optimizing the quality of digital learning experiences.

2. Methodology

This study employed a DBR approach to build the Pixelio mobile learning application, integrating the cyclical phases of SRL proposed by Zimmerman (2002), namely forethought, performance, and self-reflection into its user interface. The DBR method was selected as it inherently supports a theory-driven development process. In its initial phase, DBR requires the formulation of a robust theoretical framework to guide the design of practical solutions, accordingly, this study is grounded in the deliberate integration of UID principles and SRL theory. Furthermore, DBR perfectly accommodates the need for an iterative and transformative process. Through this approach, theoretical constructs are translated into specific UI features, which are then empirically tested and continuously refined through successive cycles based on direct user feedback.

By employing DBR, this research moves beyond merely observing a phenomenon, instead actively developing and improving a pedagogical solution to address the complex challenge of ECL in mobile learning environments. Consequently, the final interface is not only theoretically grounded at its inception but also practically optimized through repeated evaluation in real-world contexts (Amiel & Reeves, 2008). The development approach refers to the model proposed by Amiel & Reeves (2008), which consists of four phases: (1) analyzing practical problems, (2) developing solutions guided by SRL and UI principles, (3) iterative cycles of testing and refinement of solutions in practice, and (4) reflecting to produce final design principles. The overall research flow of this study is represented in Figure 1.

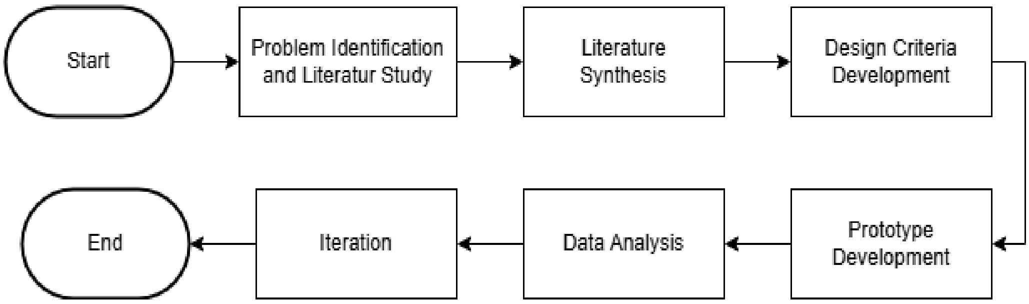

Figure 1. Research Flow Diagram

The sample consisted of 144 Information Systems and Technology Education (PSTI) students (42 males and 102 females) at UPI campus in Purwakarta. These participants were selected because of their strong academic background in educational technology and user interface design. Consequently, they are not only accustomed to using Learning Management Systems, online learning resources, and AI-based tools in their academic activities, but they also have the critical knowledge required to provide in-depth, informed evaluations regarding interface design and its impact on cognitive load compared to general users.

Data were collected using a random sampling technique to ensure representativeness and minimize selection bias. The evaluation instrument utilized an ECL questionnaire with a ten-point Likert scale. This questionnaire was adapted from the NASA-Task Load Index (Hart and Staveland, 1988) by Faudzi et al. (2024). While the original tool evaluates general perceived workload, this adapted version specifically measures ECL triggered by user interfaces. The questionnaire comprised 29 statements across six UID indicators adopted from Faudzi et al. (2023), namely Content Organization (CO), Navigation (Nav), Signaling/Cue (SC), Aesthetic and Minimalist Design (AM), Font (Ft), and Graphic Complexity (GC). To ensure the credibility and accuracy of the gathered data, the adapted ECL questionnaire was subjected to rigorous validity and reliability assessments prior to distribution.

Content and construct validity were established to confirm that the items accurately measured the intended cognitive load dimensions. Furthermore, the instrument demonstrated a high level of internal consistency, as evidenced by a Cronbach's Alpha coefficient exceeding the acceptable threshold of 0.70. This rigorous validation guarantees that the empirical findings derived from the usability testing are scientifically trustworthy. Additionally, open-ended questions were included to capture qualitative feedback on usability obstacles. Procedurally, participants interacted with the Pixelio prototype via the Maze platform. This testing was conducted through both face-to-face moderated sessions in a classroom with 68 students to ensure data reliability and online unmoderated sessions with 76 students to provide user flexibility (Khayyatkhosnevis et al., 2022).

A mixed methods approach was employed for data analysis, systematically combining descriptive statistics and thematic analysis. Descriptive statistics were utilized to calculate the mean and standard deviation of the quantitative ECL responses for each UI indicator. Concurrently, a thematic analysis was conducted to systematically code and categorize the qualitative feedback from the open-ended questions into the six UID criteria. This qualitative procedure aimed to uncover specific interface frictions, explain the quantitative scores, and provide an empirical foundation for the researchers to execute the subsequent prototype redesign iteration.

3. Results and Discussion

Interface Integration with SRL

The development of the Pixelio was initiated by addressing the inherent constraints and usability challenges of mobile learning environments. As highlighted by Alasmari (2020), the limited screen size of mobile devices can significantly increase students' cognitive load, as small displays restrict the amount of information that can be processed at once and often lead to visual fatigue. Furthermore, Kumar et al. (2020) emphasized that many mobile learning applications struggle with usability hurdles such as small typography, complex layouts, and inconsistent navigation. To overcome these limitations, the design of Pixelio was grounded in User Interface Design principles specifically aimed at minimizing ECL.

According to Faudzi et al. (2023), the UI criteria that directly influence learners' ECL encompass content organization, navigation, signaling/cues, aesthetic and minimalist design, font, and graphic complexity. To systematically implement these theoretical principles, a design system as presented in Figure 2 was established prior to the prototyping phase. The typography, SF Pro, was selected due to its high legibility and clean anatomical structure on small digital screens. The baseline font size was strictly set to a minimum 16px for body text. Additionally, the color palette employs a minimalist aesthetic with a high-contrast ratio. A clean background (predominantly white) paired with dark typography maximizes text visibility. Furthermore, a primary accent color, blue, was strategically used as signaling cues to highlight interactive elements and Call-to-Action (CTA) buttons.

Built upon this foundational Design System, the interface was further structured to facilitate the SRL framework proposed by Zimmerman (2002). This framework consists of three phases designed to foster users' independent learning, the forethought, performance, and self-reflection phase. The forethought phase occurs before the learning process begins, encompassing task analysis and self-motivation beliefs. To facilitate this phase, the Pixelio UI integrates several features, such as learning personalization, learning stats, streaks, course and learning path lists.

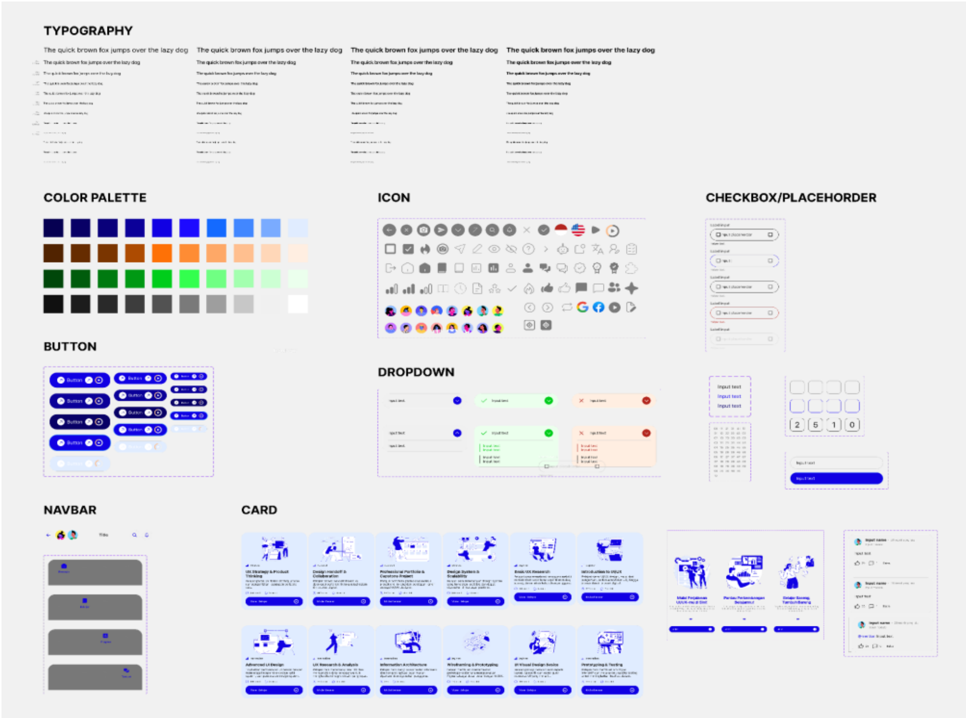

Figure 2. Design System

Through the learning personalization feature, users are encouraged to establish clear learning directions by defining their learning goals (Figure 3), interests (Figure 4), target skills (Figure 5), and study time targets (Figure 6). The learning stats and streak features on the homepage (Figure 7) reinforce users' self-efficacy and learning commitment. The course and learning path list (Figures 8, 9, 10, 11) support strategic planning, enabling users to select materials aligning with their needs based on difficulty levels and estimated study durations.

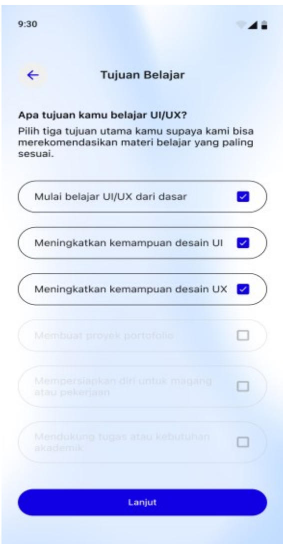

Figure 3. Learning Goals

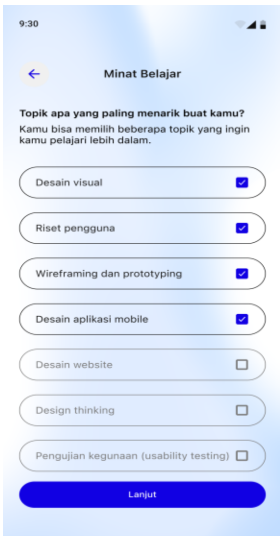

Figure 4. Interests

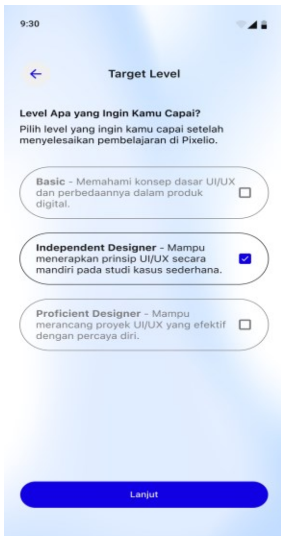

Figure 5. Target Skills

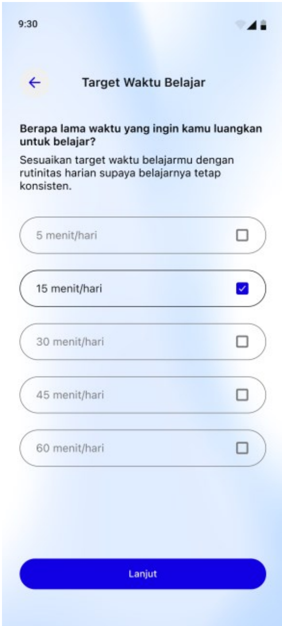

Figure 6. Study Time Targets

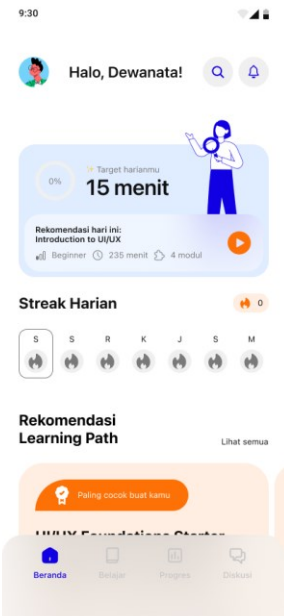

Figure 6. Learning Stats and Streak Features

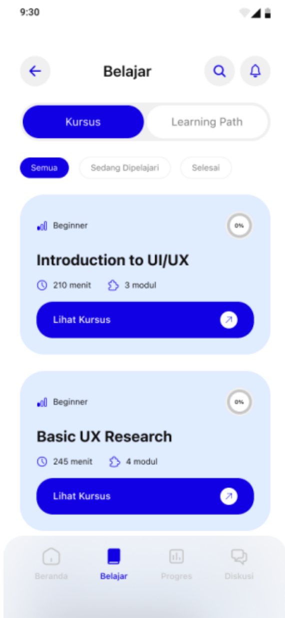

Figure 8. Course List

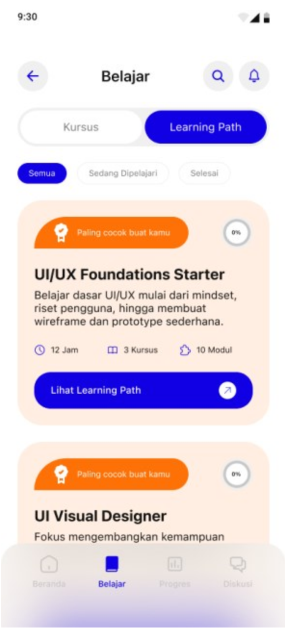

Figure 9. Learning Path List

Figure 10. Course Detail

Figure 11. Learning Path Detail

The performance phase occurs during the learning activity and is divided into self-control and self-observation. These needs are accommodated through the material and quiz features. The material interfaces (Figure 12) serve as a space for users to implement cognitive strategies. Meanwhile, the quiz feature (Figures 13 and 14) supports self-control by providing opportunities for periodic comprehension assessment. Aligning with Zimmerman's (2002) assertion that self-regulated learners are proficient in time management, the inclusion of a timer feature (Figures 14) assists users in regulating their pace. Additionally, the progress bar (Figures 12 and 14) plays a crucial role in supporting self-observation by allowing users to track their learning milestones.

Figure 12. Material Page

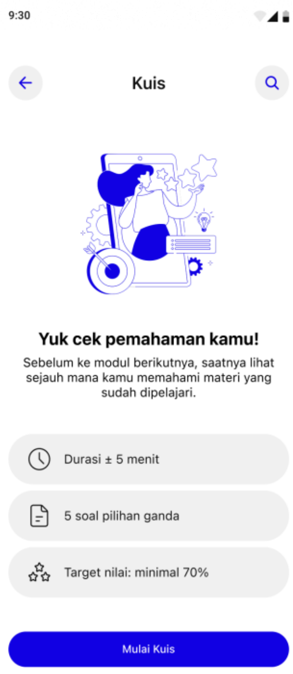

Figure 13. Quiz Introduction Page

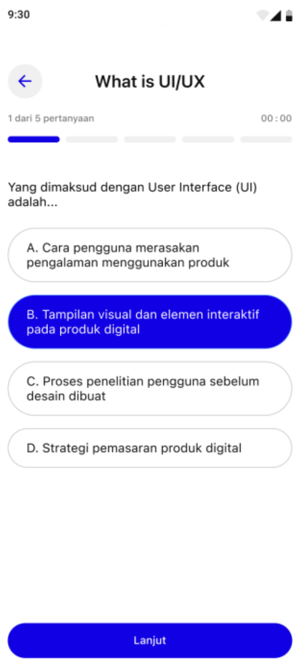

Figure 14. Quiz Page

The self-reflection phase takes place after the learning process is completed. This phase involves self-judgement and self-reaction. The features implemented include quiz summaries, learning analytics, and discussion forums. The quiz summary (Figure 15) presents scores, error insights, and answer reviews, facilitates self-judgement by allowing users to understand the causes of their learning outcomes. The learning analytics feature and the 'change learning plan' option (Figure 16) enable users to adaptively adjust their strategies and targets based on empirical progress data. The discussion feature (Figures 17 to 20) further complements this by providing a platform for users to seek clarification and feedback.

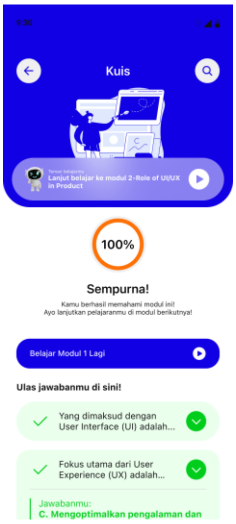

Figure 15. Quiz Summary Page

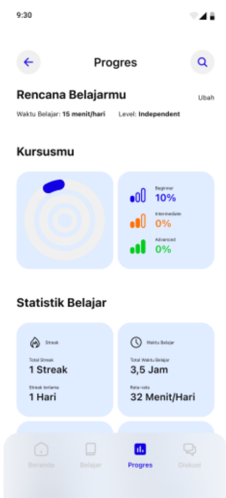

Figure 16. Learning Progress Page

Figure 17. Discussion Topic

Figure 18. Discussion Forum

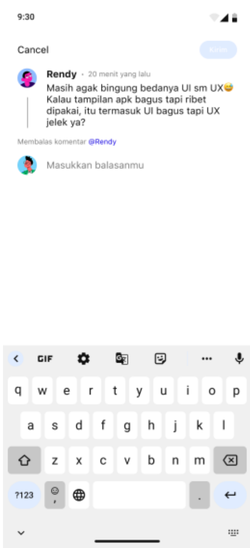

Figure 19. Reply to Comment Feature

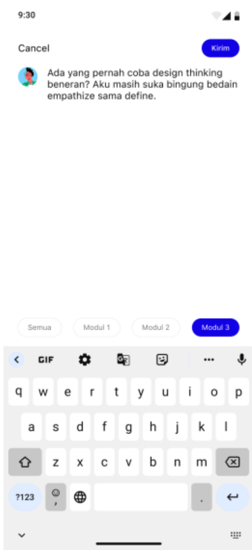

Figure 20. Commenting Feature

Evaluation of Users' ECL

To ensure that the integration of the UID Theory and SRL did not inadvertently increase mental friction, this study empirically evaluated the interface's impact on users' ECL. This measurement determined the extent to which the developed UI minimized unnecessary cognitive burdens. An ECL questionnaire, adapted from Faudzi et al. (2024), was distributed to 144 respondents following a usability testing session via the Maze platform. The data underwent a normalization process (reverse scoring) to ensure directional consistency, where higher scores (closer to 10) indicate higher cognitive load (poor design). The data were analyzed using descriptive statistics based on an interval scale, 1-3 for low, 4-6 for moderate, 7-10 for high categories. The descriptive analysis results in Table 2 demonstrate that the developed UI successfully minimized users' ECL. All evaluated dimensions fell within the "Low" Category. The Aesthetic and Minimalist Design dimension recorded the lowest score (Mean = 2.55), indicating that the clean visual design effectively suppressed ECL. Conversely, the Font (Mean = 3.79) and Graphic Complexity (Mean = 3.78) dimensions exhibited relatively higher cognitive loads. These quantitative findings were corroborated by qualitative feedback from the open-ended questions. Regarding typography, numerous users reported that the certain text sizes were too small. For graphic complexity, users highlighted the need for content simplification, noting that text density required excessive scrolling.

Table 2. Descriptive Statistics

UID Criteria	Mean	Standard Deviation	ECL Category
Content Organization (CO)	3.44	1.22	Low
Navigation (Nav)	3.09	1.49	Low
Signaling/Cues (SC)	2.77	1.47	Low
Aesthetic & Minimalist Design (AM)	2.55	1.35	Low
Font (Ft)	3.79	0.92	Low
Graphic Complexity (GC)	3.78	1.52	Low

To formulate actionable guidelines for the subsequent DBR iteration, a thematic analysis was conducted on the open-ended responses. The results, detailing specific user feedback and design recommendations, are presented in Table 3. The thematic analysis highlights that interface friction, specifically high text density and subtle navigation cues, acts as a primary cognitive bottleneck. When learners expend their working memory processing small fonts or searching for hidden features, their cognitive capacity is significantly depleted. This observation perfectly corroborates the heuristic evaluation framework for mobile learning applications proposed by Kumar et al. (2020), which asserts that predictable navigation, consistency, and high visibility of system status are critical to minimizing learners' memory load. How the redesign addresses this is rooted in the concept of cognitive offloading. By systematically enforcing visual hierarchy, enhancing CTA contrast, and aligning menus with established mental models, the interface passively guides the user, thereby freeing mental resources strictly for intrinsic learning tasks.

Table 3. Thematic Analysis Results

UID Criteria	Feedback	Recommendation
Content Organization (CO)	Users reported that the learning materials are too text-dense, requiring excessive vertical scrolling, and lack multimedia variety.	Chunk lengthy text into bit-sized micro-learning modules and integrate interactive multimedia (e.g., short videos) to reduce reading fatigue.
Navigation (Nav)	Users experienced difficulties	Relocate user-specific settings

	locating specific features, such as the settings for extending study time.	('Ubah Rencana Belajar') to a centralized, easily accessible 'Profile' or 'Settings' menu to align with common user mental models.
Signaling/Cues (SC)	Primary CTA buttons, such as the button to proceed to the next module, are often overlooked due to poor visibility.	Apply high-contrast-colors and distinct visual highlights to primary action buttons to ensure they instantly draw the user's attention.
Aesthetic & Minimalist Design (AM)	Some users suggested improvements in color combination and gradients to make it visually appealing.	Implement a strict UI kit to ensure absolute consistency in harmonious color palettes.
Font (Ft)	Several users complained that the text sizes, especially on navigation menus is too small	Increase the baseline typography scale to guarantee effortless legibility on mobile screens.
Graphic Complexity (GC)	Users felt certain areas were visually cluttered by long text labels.	Replace lengthy, space consuming action texts with universally recognizable icons to simplify the layout.

Guided by these theoretical insights, the subsequent DBR iteration eliminated the identified frictions (Figures 21 to 24). The core transformation involved restructuring text-heavy modules into micro-learning chunks enriched with multimedia, centralizing the learning plan CTA into a standard profile menu, and amplifying visual cues for essential buttons. This iteration demonstrates that adherence to strict UID principles is not merely an aesthetic enhancement, but a pedagogical necessity for effectively operationalizing SRL features. Furthermore, these refinements ensure that learners can allocate their cognitive resources more efficiently toward processing learning content rather than navigating the interface.

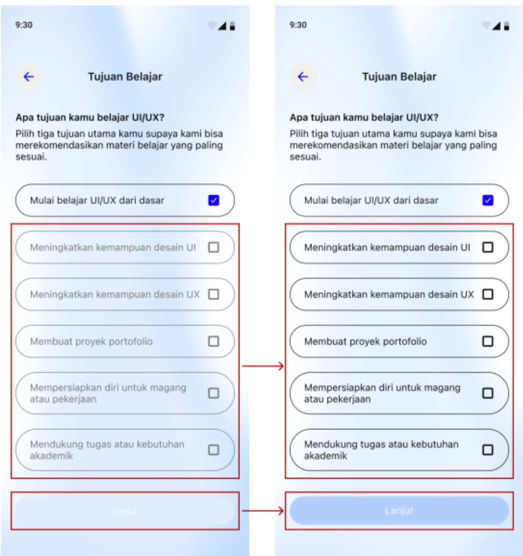

Figure 21. Enhanced Color Contrast on Checkbox and CTA Buttons

Figure 22. Improved Visibility of Navigation Bar Menu Items

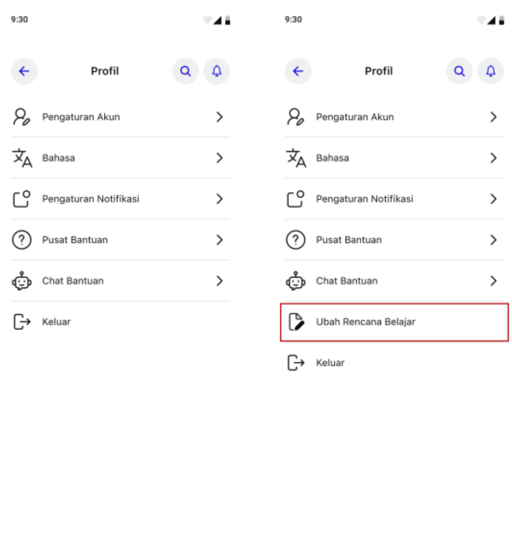

Figure 23. Centralized 'Ubah Rencana Belajar' Menu within the Profile Page

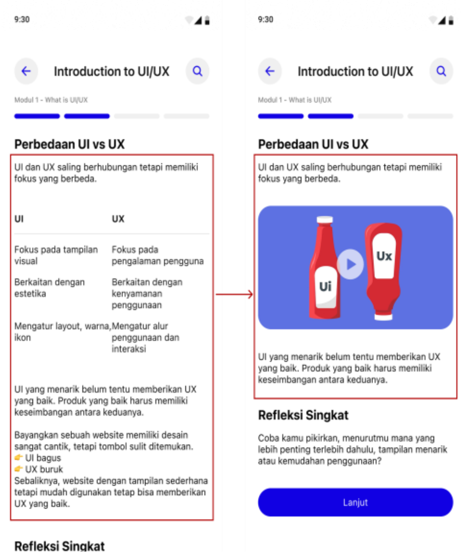

Figure 24. Reduced Text and Media Density on the Learning Material Page

The benefit of these research findings extends far beyond the Pixelio application. This study provides an empirical, user-driven framework illustrating how the integration of UID and SRL can solve broader usability challenges in mobile learning environments. Developers and instructional designers can adopt these cognitive-load-reducing strategies, such as content chunking, intuitive signaling, and predictable navigation models to other digital learning platforms facing similar screen-size constraints. Ultimately, this reinforces the importance of aligning interface design with cognitive and pedagogical principles to ensure more effective and sustainable mobile learning experiences.

4. Conclusion

This study concludes that the developed mobile learning application interface successfully integrates SRL theory with User Interface Design principles. Specifically, the interface is designed to facilitate the three phases of users' independent learning, forethought, performance, and self-reflection through systematic visual applications. These design outcomes were concretely realized through strategies such as micro-learning chunking, standardized typography, high-contrast visual cues for CTA buttons, and centralized navigation models to minimize screen complexity. Regarding the evaluation results, the findings indicate that the learners' ECL resulting from the interface usage generally fell into the low category. This demonstrates that the applied design framework is fundamentally effective in mitigating cognitive barriers. However, despite the low overall ECL, the qualitative evaluation confirmed that overlooking even minor interface frictions, such as overly dense text or ambiguous navigation, still poses a risk of depleting learners' working memory. This study asserts that optimizing the visual interface is not merely an aesthetic enhancement but a crucial pedagogical necessity. For Future works, the developed design framework should be adapted and implemented across broader educational platforms facing similar mobile learning screen constraints. Additionally, longitudinal empirical studies are recommended to investigate how this low-cognitive-load mobile learning environment ultimately affects learners' actual academic performance and long-term self-regulation skills.

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