Enhancing Cognitive Load in Smartphone Micro-Interactions Through Human-Centered Design

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August 28, 2023

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***Abstract*— The ubiquity of smartphone usage in our daily lives necessitates the exploration of effective design strategies for enhancing user experience and reducing cognitive load. Micro-interactions, which are detailed, and functional interactions designed to accomplish specific tasks, play a crucial role in the overall usability of smartphones. However, micro-interactions can also become barriers when there is a delay between user interaction and system response. This paper aims to develop a smartphone micro-interaction design that facilitates human cognition without adding excessive cognitive load. To achieve a comprehensive impact, the focus of development will be on fundamental features of smartphones. The design development process will be guided by human-centered design methodology, involving modifications to object structures and enhancements to sensory stimuli within the micro-interaction between users and smartphones. Through design development and cognitive load analysis based on cognitive theories, the study intends to provide cognitive assessment evidence demonstrating the influence of micro-interactions on human cognitive processes and quantify the changes in cognitive load resulting from increased utilization of micro-interactions. The ultimate outcome of this research is a comparison of the speed between smartphone usage with the current micro-interaction design and the improved micro-interaction design. Findings indicate that the utilization of enhanced micro-interaction designs facilitates faster learning interaction design.**

Keywords— micro-interaction, smartphone, cognitive load, human-centered design

I. INTRODUCTION

Smartphone usage has become essential for people in Indonesia, with approximately 67% of internet users accessing the internet through smartphones. However, the limited screen size of smartphones restricts interactions, especially in micro-interactions. Micro-interactions are detailed and functional interactions designed to facilitate specific tasks. They play a crucial role in smartphone usability but can also pose challenges, particularly when there are delays between user input and system response, impacting cognitive load and user-device fit.

Suboptimal micro-interaction design can indirectly affect cognitive load, related to human cognitive architecture. Cognitive load theory explains the resources used in working memory for activities and can influence social cognitive performance. Human-centered design methodology can address these issues by modifying micro-interaction designs in core smartphone functions, aiming to reduce cognitive load and enhance user experience.

The objectives of this research are to explore the impact of micro-interactions on cognitive load during smartphone usage and to investigate the effects of updated micro-interactions on cognitive load. By developing a new micro-interaction design prototype and conducting evaluations, this study aims to improve cognitive processes and reduce fatigue associated with delays during tasks.

Overall, this research aims to address the problem of cognitive load during smartphone interactions, specifically focusing on core smartphone functions, by enhancing micro-interaction design.

II. MICRO-INTERACTIONS AND COGNITIVE LOAD

In this section, I will discuss every important aspect of the research to understand more about the idea. Related work will discuss about previous work contribution on the idea of this research. Micro-interaction will discuss about what is micro-interaction on a mobile device mean. Cognitive load theory will also be explained.

A. Related Work

Related works are an inspiration for the research. There are several related to this research as shown in table I.

TABLE I. Related Literatures

Num.	Reference	Title	Methodology
1.	Ruksana Banu. A; Wedad Salim Ali Al Siyabi; Yusra Al Minje	A Conceptual Review on Integration of Cognitive Load Theory and Human-Computer Interaction	Cognitive Load Theory, User Interaction
2.	Michael D. Byrne	Cognitive Architectures in HCI: Present Work and Future Directions	Cognitive Architecture, Human-centered solution

B. Micro-interactions

Micro-interactions can be defined as detailed and functional interactions designed to perform specific tasks. They aim to simplify the completion of tasks without requiring users to be consciously aware of the actions being taken. While micro-interactions don't necessarily have to be small in size, they should make users feel at ease, quick, and without experiencing additional difficulties during the interaction.

Micro-interactions enhance the usability of a platform through their clear and consistent structure. A well-designed micro-interaction consists of four components that occur in a continuous sequence. These components include a trigger that initiates the micro-interaction, followed by rules that define how the micro-interaction functions, accompanied by feedback that illustrates the operation of the rules, and concluded by loops and modes that influence the final outcome of the micro-interaction.

Within the context of smartphones, basic micro-interactions play a fundamental role in facilitating user interactions. However, issues can arise in these core micro-interactions. These issues can be related to inappropriate object placement, a lack of intuitive design, or inadequate sensory stimuli. When these issues occur, they can indirectly affect the cognitive load associated with human cognitive architecture.

To address the potential impact of micro-interactions on cognitive load, it is crucial to explore their effects and identify ways to optimize their design. By employing a human-centered design approach, the structure of micro-interactions can be modified to reduce cognitive load and improve the overall user experience. This research aims to examine the influence of micro-interactions on cognitive load during smartphone usage, specifically focusing on core smartphone functions, and to propose updated micro-interaction designs that alleviate cognitive load.

C. *Cognitive Load Theory*

Cognitive load theory is discussed to define cognitive load and explore the assessment metrics used to measure the difference between the current state and the desired state. The theory takes into account the limited storage capacity of the human brain and the cognitive architecture involving working memory and long-term memory processes. While cognitive architecture provides a foundation, it alone cannot fully explain an individual's brain performance without specific task interactions. To assess cognitive performance, comprehensive knowledge of specific tasks is necessary, including a target model of predefined activities.

In the context of human-computer interactions, cognitive processes play a significant role. The development of human-computer interaction design can contribute to supporting and optimizing cognitive processes. By applying a human-centered design approach that minimizes cognitive load, designers can enhance usability and evaluate the cognitive outcomes using timestamps as assessment metrics. These timestamps capture both overt (explicitly performed) and covert (implicitly performed) actions, allowing for a quantitative evaluation of cognitive load.

With an understanding of cognitive load theory and the application of human-centered design principles, the research aims to investigate the influence of micro-interactions on cognitive load and improve the design of micro-interactions to reduce cognitive load. This research seeks to enhance the overall user experience by promoting efficient cognitive processes and optimizing the design of micro-interactions on smartphones. To measure cognitive load with an approach that offers increased simplicity, task-time measurement and learning rates can be used.

1) *Task-time measurement*

The process of task time calculation involves measuring time-on-task, which refers to the total amount of time actively spent on a learning process to acquire skills, knowledge, grades, and attitudes. Engaged time, a component of the total time spent directly engaged in learning, is the specific duration that will be measured. The measurement form example can be seen on figure 1.

Form A: Observation Form

TYPE OF ACTIVITY: P / I / G / O (P= plenary work, I = individual work, G= Group work, O = other) Lesson phase: Introduction / Development / Conclusion				
	20 sec.	20 sec.	20 sec.	20 sec.
Off task				
On task:				
Reading				
Writing				
Drawing				
talking / discussing				
active listening to teacher				
Observing*				
asking questions to teacher				
responding to teacher				
other activity** (Name them):				

* Learning activity whereby the senses are used.
** Another activity that enhances the learning-process

Title for this section of the lesson; for example " introduction " or " practicing English speech "

....

Fig. 1. Task-time measurement form

2) *Learning rates*

Learning rates refer to the speed at which tasks are completed within a specific time frame. To calculate the learning rate, the formula derived from the learning curve theory can be used. The learning rate formula helps measure the rate at which learning and task completion occur. The learning rate measurement can be seen on formula below.

$$K_n = K_m \left(\frac{n}{m}\right)^b \quad (1)$$

The formula is composed by 5 variables such as *m* which represents some number of units produced, *n* represents some larger number of total units produced ($n>m$), K_m represents "cost" of producing unit *m* (dollars, hours, etc.), K_n represents "cost" of producing unit *n*, and *b* represents another formula which will be explained with the formula (2) below with *R* representing learning rate.

$$b = \frac{\log R}{\log 2} \quad (2)$$

III. Solution Design

In this section, the problem with micro-interaction will be discussed. The problem at hand is the variation in cognitive load experienced by smartphone users when using different micro-interaction designs. Smartphone users rely on micro-interactions in their daily interactions with specific applications or systems, highlighting the importance of developing effective micro-interaction designs.

A. Analysis

The impact of poor micro-interaction design on reducing users' cognitive load while learning to use smartphones is acknowledged by researchers. To address this issue, a research study is conducted to develop micro-interaction designs using the human-centered design methodology, which prioritizes user needs in the design development process. Evaluation is performed using human cognitive load assessment metrics to compare the existing design with the proposed design. Gap analysis is employed to identify the differences between the testing results of the proposed design and the baseline design. To understand the idea more clearly, please look at figure 2.

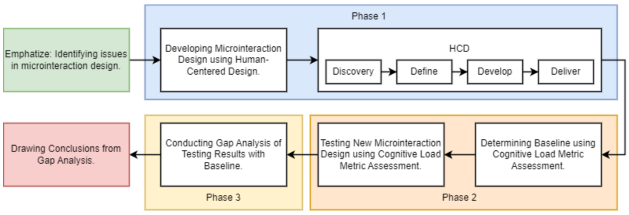

Fig. 2. Solution Design

B. Development Plan

Based on figure 2, there are essential phases of the research which are divided into three phases. The first phase is developing micro-interaction design using human-centered design. The second phase is testing the micro-interaction designs using cognitive load metric assessment. The third phase is conducting gap analysis of testing results with baseline. Every phase will be further explained in the following paragraphs.

The first phase of this large task series aims to build two similar-looking designs but with different micro-interactions. The first design created is the existing prototype design, equipped with the micro-interactions found in the user interface, serving as a reference. The second design is a prototype with a similar appearance but with differing micro-interactions. Creating these two designs allows for a comparison of micro-interaction performance, requiring a baseline design and a modified design for comparison. To create a prototype that can represent micro-interaction performance on smartphones, the researchers decided to adopt the human-centered design method. Within the chosen human-centered design approach, the double diamond approach is utilized, consisting of four processes: discover, define, develop, and deliver. In the first phase, each stage of design development plays a crucial role. Every development process in the first phase holds an important role. The process can be explained as:

1) Discovery: In the discovery phase, a deeper review will be conducted on each problem background to ensure that the problem being addressed is a real issue. To validate the existence of the problem, the researcher will reconfirm the findings obtained from the background and begin working from the collected data. The results of these findings will influence the data to be sought from the sample during the define process.

2) Define: In the define phase, the problem discovery process has already been carried out during the preparation of the final project. To further explain the problem and ensure clarity on the problem to be solved, the researcher will design a questionnaire aimed at determining someone's knowledge of micro-interactions and the essential functions that should be present in a smartphone. Guidelines for the questionnaire's questions can be seen in table II. A survey will be conducted by filling out the questionnaire with 100 individuals to seek representation for the entire population, with a 10% error margin, with the goal of understanding the Indonesian public's understanding of micro-interactions and the necessary features in a smartphone.

TABLE II. Questionnaire Structure Guide

Questionnaire Part	Question Numbers
0: Introduction	1-5
I: Micro-interactions	6-11
II: Smartphone utilities	12-15

3) Develop: In the develop phase, prototype development will take place. The built prototype will be based on the micro-interactions found in MIUI 13.0 with similar functionality. The prototype will encompass 3 functions chosen by respondents as the highest preferences. All micro-interactions will involve 5 common types, such as scrollbar, slide-down notification, button, pull-to-refresh, and swipe animation.

4) Deliver: In the deliver phase, the completed prototype will undergo several iterations to achieve alignment between the prototype design and real-world design models. Usability testing, typically conducted in general scenarios, will not be carried out as the development focuses on assessing cognitive load, so the ultimate goal is not usability value but rather time measurement for subsequent calculations.

The second phase in figure 2 illustrates the design testing process with cognitive load assessment, which aims to test the time taken by individuals when performing tasks on the new design. The task sequence will be determined based on the smartphone utilities sequence with the most popular choices identified through a survey. According to Faulkner, to discover issues in at least 90% of the respondents, 15 participants are required for the second testing. It can be observed that the average detection of issues among 15 respondents is 97%, which sufficiently represents the general conditions. The time was recorded twice: when users first used the prototype and after getting familiar with it for 2-3 minutes.

The final phase of the completion of the final project, as depicted in figure 2, is the gap analysis used to examine the performance differences among testing respondents regarding the two distinct designs. The differences can be measured through the subjects' learning rates for both designs. Through this analysis, answers can be derived that align with the previously formulated problem. The solutions will demonstrate the impact of users' cognitive load while using smartphones and the significance of reducing cognitive load through improved design. Thus, this research can contribute to the development of better and user-friendly micro-interaction designs.

IV. Design Implementation and Evaluation

A. User Interface Development

The questionnaire created based on the plan in Table II was used to test two aspects: respondents' knowledge of micro-interactions, assessed through questions six to eleven, and questions about smartphone utility, addressed in questions twelve to fifteen. The evaluation of micro-interactions revealed that 75.7% of people were unfamiliar with the term "micro-interactions." However, 88.54% of respondents recognized commonly used types of micro-interactions, with over 77% of respondents being aware of all the frequently used types.

Specifically, 85.4% of respondents were familiar with the pull-to-refresh interaction, while approximately 77.7% were aware of swipe animation or slide bars. Furthermore, 92.2% of respondents knew about button interactions, 94.2% recognized slide-down notifications, and 93.2% were aware of scrollbars. From this information, it can be concluded that respondents interacted with common micro-interactions without necessarily being aware of them.

The evaluation of smartphone utility revealed the most used functions. The top three essential features were making and receiving phone calls, selected by 88.3% of respondents, followed by internet browsing, chosen by 74.8% of respondents. Additionally, 55.3% of respondents valued the utility of capturing, viewing, and storing pictures.

Based on the results of the questionnaire, we can conclude that the three essential utilities that should be present on a smartphone are the utility for making and receiving phone calls and messages, the utility for capturing, viewing, and storing images and/or videos, and the utility for browsing the internet. The prototype will be made with those features but equipped with different micro-interactions. Figure 3 and figure 4 are the example of the difference between baseline and modified designs.

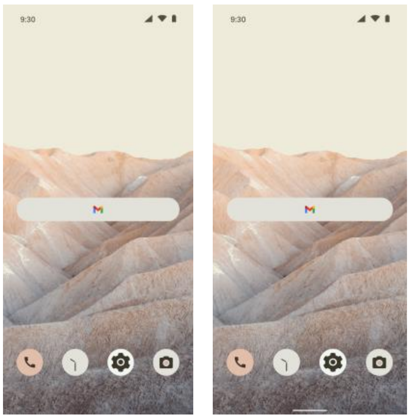

Fig. 3. Home Page Comparison

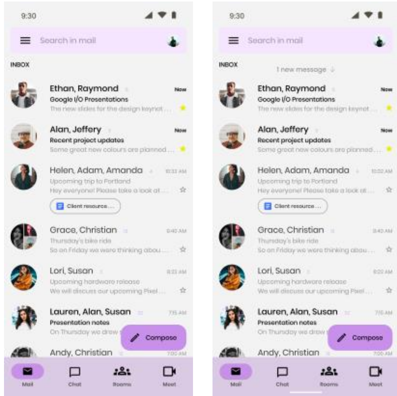

Fig. 4. Email Page Comparison

Although their looks are similar, their interactions between pages are not. The interactions on how they move are the focus of micro-interaction. There are four different tasks that should be finished during testing.

B. Testing Results

The test was done to baseline design and modified design. The prototype testing for each design was conducted with 15 individuals to observe the duration of all activities performed related to the 3 main features. The age of the respondent subjects varied between 19-22 years. The testing result for both designs can be seen in table III below. The data will be used to calculate the average learning rate.

TABLE III. Test Result

Design	First Time (s)	Second Time (s)
Baseline	70.54	28.89
Modified	41.5	28.89

C. Learning Rates

Through calculations, it was found that the learning rate when using the baseline design was 56.94%, while the learning rate when using the modified design was 73.51%. A comparison was then made between the learning speed and the improvement between the testing of the two designs. It was found that the updated design had a higher learning speed by 16.57% or an overall increase in speed by 29.91% from the initial speed. This increase in speed indicates that improved micro-interactions can reduce cognitive workload in the brain.

V. Conclusion

The following are the conclusions that address the problem statement. Firstly, it was found that micro-interactions have an impact on cognitive load, as evidenced by a higher learning rate in the redesigned interaction design, which increased from 56.94% to 73.51%. This indicates a speed difference of 16.57%, suggesting that individuals learn tasks more quickly. Secondly, the study revealed that increased utilization of micro-interactions leads to an increased cognitive load for users, as supported by the higher learning rate observed. The experiment showed a significant increase in speed of 29.91%, highlighting the significant role of increased micro-interactions.

References

[1] Banu, R., al Siyabi, W. S. A., & al Minje, Y., 2021, A Conceptual Review on Integration of Cognitive Load Theory and Human-Computer Interaction. Proceedings - 2021 International Conference on Software Engineering and Computer Systems and 4th International Conference on Computational Science and Information Management, ICSECS-ICOCSIM 2021, 667–672.

[2] Byrne, M. D. ,21, Cognitive Architectures in HCI: Present Work and Future Directions. https://doi.org/10.1109/ICSECS52883.2021.00127

[3] Kirschner, Sweller, Kirschner, Zambrano, 2018, From Cognitive Load Theory to Collaborative Cognitive Load Theory, Crossmark, https://doi.org/10.1007/s11412-018-9277-y

[4] Oviatt, S. (2006). Human-centered design meets cognitive load theory: Designing interfaces that help people think. Proceedings of the 14th Annual ACM International Conference on Multimedia, MM 2006, 871–880. https://doi.org/10.1145/1180639.1180831

[5] Rashid, A., Zeb, M. A., Rashid, A., Anwar, S., Joaquim, F., & Halim, Z. (2020). Conceptualization of smartphone usage and feature preferences among various demographics. Cluster Computing, 23(3), 1855–1873. https://doi.org/10.1007/s10586-020-03061-x

[6] Saffer, 2014, Microinteractions: Designing with Details, O'Reilly

[7] Norman, Spencer, 2019, The Four Fundamental Principles of Human-Centered Design and Application. (n.d.). Retrieved November 1, 2022, from https://jnd.org/the-four-fundamental-principles-ofhuman-centered-design/