A Co-Design-Based Development Model for an Adaptive Learning System: A Case Study on Enhancing Digital Science Literacy for Junior High School Students

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Abstract - This paper details the development and empirical evaluation of an adaptive learning system aimed at enhancing digital science literacy among junior high school students in Indonesia. The primary challenge addressed is the limitation of one-size-fits-all educational models. Our research proposes a user-centric solution, the Sistem Rekomendasi Cerdas (SRC), developed through a co-design methodology. The system's core is a User-based Collaborative Filtering (UBCF) algorithm. Its effectiveness was evaluated through a pre-test/post-test experimental study involving 60 students, divided into an experimental and a control group. Quantitative results show that the experimental group achieved a significantly higher increase in science literacy scores ($p < 0.001$) compared to the control group. Qualitative findings from interviews with the experimental group reveal that the platform enhanced learning motivation, content relevance, and helped overcome learning barriers. This study concludes that the SRC, developed via a co-design model, is a highly effective tool for improving digital science literacy, demonstrating that a user-centered approach is fundamental to creating impactful educational technology.

Keywords - Adaptive Learning, Co-Design, Recommender System, Digital Literacy, Usability.

1. INTRODUCTION

The advancement of digital technology has fundamentally reshaped the educational landscape, demanding a parallel evolution in student competencies, particularly in digital science literacy. However, in many educational contexts, particularly in cities outside major metropolitan hubs like Palangka Raya, Indonesia, the adoption of personalized learning technologies remains nascent. A significant research gap exists concerning the application of machine learning algorithms to personalize science education for secondary school students in such specific local settings [1]. Conventional pedagogical approaches often employ a one-size-fits-all model, which fails to accommodate the diverse learning styles, paces, and interests of individual students [2]. This can lead to decreased engagement and suboptimal learning outcomes.

Research within the last five years has consistently affirmed the potential of Adaptive Learning Systems (ALS) to address these challenges [3] - [11]. Recent studies indicate that AI-driven ALS can not only improve learning outcomes but also significantly enhance student engagement [12] - [16]. In the specific context of a provincial capital like Palangka Raya, the digital literacy challenge reflects broader national issues but presents unique local dynamics. While national policies like "Merdeka Belajar" (Freedom to Learn) encourage digital innovation, their implementation and impact at the local school level, such as in Palangka Raya, still face numerous constraints related to infrastructure and digital readiness [17], [18]. This localized gap underscores the need for tailored technological solutions.

Technically, recommender systems based on Collaborative Filtering (CF) continue to be an active area of research [19], [20], [21]. The latest research focuses on improving accuracy and

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addressing problems like the "cold start" issue by developing hybrid models [22], [23], [24]. Furthermore, the concept of "serendipity" (recommending relevant yet unexpected items) has gained particular attention in educational contexts for its ability to broaden horizons and foster student curiosity. In parallel with these technical advancements, the participatory co-design approach is increasingly recognized as a fundamental best practice. Current literature emphasizes that directly involving students in the design process not only ensures better usability but also fosters a sense of ownership and relevance [25], [26], which is critical for successful adoption in a specific community like a school in Palangka Raya.

This research distinguishes itself from prior work through its focused context, methodology, and evaluation. The novelty of this research can be articulated in three key points. First, it specifically focuses on enhancing digital science literacy at the junior high school level in Palangka Raya, Indonesia. This provides a focused case study within a non-metropolitan Indonesian city, a context that is significantly underrepresented in educational technology literature. Second, the core innovation lies not merely in the technology (the application of a User-based Collaborative Filtering algorithm), but in the developmental methodology. We adopted a participatory co-design framework, actively engaging junior high school students from Palangka Raya throughout the design lifecycle. This ensures the solution is culturally and contextually appropriate. Third, this study provides a rigorous empirical evaluation of the system's effectiveness within this specific cohort, combining quantitative data with qualitative insights from local students.

To address these gaps, this research details the development and evaluation of an adaptive learning system, Sistem Rekomendasi Cerdas (SRC), designed for and with students in Palangka Raya. The system leverages a User-based Collaborative Filtering (UBCF) algorithm to provide serendipitous recommendations [27], [28]. This paper presents the systematic process of this co-design-based model and provides an empirical evaluation of its effectiveness in enhancing learning outcomes for its target students.

2. RESEARCH METHOD

This research methodology followed a chronologically structured, multi-phase approach, beginning with system development and culminating in an empirical evaluation. The entire research workflow and its stages are visually illustrated in the timeline in Figure 1.

Figure 1. System Development and Evaluation Timeline

As the timeline indicates, the research was divided into two primary phases: a System Development and Validation Phase, encompassing the first four stages, and an Experimental Evaluation Phase, comprising the subsequent five stages.

2.1. Phase 1: System Development and Validation

The initial stage involved a qualitative analysis of user needs through a participatory co-design session with 15 junior high school students. These authentic insights revealed preferences

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for visual content, simple gamification, and an uncluttered interface, forming the foundational blueprint for the system's design. The system's intelligence is driven by a User-based Collaborative Filtering algorithm. It recommends items to a user based on the preferences of other similar users. Similarity is calculated using the Pearson Correlation Coefficient, which measures the linear relationship between the ratings of two users [29], [30], [31]. To validate the algorithm's logic, manual calculations were performed on a hypothetical dataset, as illustrated below in Table 1.

Table 1. Calculation Example

Student	Material A: Solar System	Material B: Photosynthesis	Material C: Food Chain	Material D: Volcano	Material E: Electric Current
Budi	5	4	?	2	4
Citra	4	5	5	1	?
Dian	2	?	2	5	2
Eka	5	4	4	2	4

To generate a recommendation for Budi, the system computes his similarity to other students. The similarity between Budi and Eka is exceptionally high (a correlation coefficient of +1.0), as their rating patterns are identical for the commonly rated items. The system subsequently identifies that Eka rated Material C highly (a score of 4), which Budi has not yet accessed. Consequently, Material C is recommended to Budi. Upon completing the functional prototype, a controlled pilot study was conducted with 3 students to validate its usability. The quantitative instrument used was the System Usability Scale (SUS) [32]. The results, summarized in Table 2, confirmed the platform's high usability and functional reliability, indicating its readiness for the main experiment.

2.2. Phase 2: Experimental Evaluation

With the SRC platform successfully developed and its usability validated in Phase 1, the research progressed to its second and principal phase: the empirical evaluation. This phase was designed to rigorously measure the effectiveness of the personalized learning system in enhancing students' digital science literacy. To achieve this, a quasi-experimental study employing a pre-test/post-test control group design was implemented [32], [33], [34]. The specific methodology for this phase is detailed below:

a. Participants: A total of 60 junior high school students from SMP NU Palangka Raya were recruited and randomly assigned to two groups: an experimental group (N=30) and a control group (N=30).
b. Instruments: A validated digital science literacy test was used for the pre-test and post-test. A semi-structured interview protocol was used to gather qualitative data from a sample of students in the experimental group.
c. Procedure: Both groups took the pre-test. Over a six-week intervention period, the experimental group used the full SRC platform with personalized recommendations enabled. The control group used an identical platform, but with the recommendation feature disabled (presenting materials in a standard, non-personalized list). After the intervention, both groups took the post-test. Subsequently, interviews were conducted with students from the experimental group.
d. Data Analysis: Quantitative data were analyzed using descriptive statistics and an independent samples t-test on the gain scores (post-test minus pre-test) to compare the two groups. Qualitative data from interview transcripts were analyzed using thematic analysis.

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Table 2. Usability Measurement Results from Pilot Study

Testing Metric	Indicator	Result (Preliminary Data)	Professional Interpretation
Usability	System Usability Scale (SUS) Score	79.5 / 100	This score is significantly above the industry average (68) and falls into the "Good" category (Grade B). This indicates that students can interact with the platform effectively and efficiently with a very gentle learning curve.
Functional Reliability	Core Task Completion Rate	95%	Participants successfully completed 19 out of 20 core task scenarios (e.g., registration, login, giving a rating) without assistance, confirming the system's functional reliability.

3. RESULTS AND DISCUSSION

This section presents the core findings from the experimental evaluation phase, providing strong evidence of the SRC platform's impact on student learning. The results are organized into two complementary sub-sections. First, the quantitative data from the pre-test/post-test experiment is analyzed to statistically measure the platform's effectiveness. Following this, the qualitative findings from student interviews are presented to offer a deeper, contextual understanding of the user experience and the mechanisms behind the quantitative outcomes.

3.1. Quantitative Results

The quantitative analysis confirms the effectiveness of the SRC platform. The descriptive statistics (Table 3) show that while both groups started at a similar baseline, the experimental group demonstrated a substantially larger increase in scores after the intervention.

Table 3. Descriptive Statistics of Pre-Test and Post-Test Scores

Group	Test Time	N	Mean	Standard Deviation
Experimental	Pre-Test	30	58.5	6.21
Experimental	Post-Test	30	81.7	5.88
Control	Pre-Test	30	58.2	6.45
Control	Post-Test	30	65.4	6.02

To verify if this observed difference in improvement was statistically significant, an independent samples t-test was performed on the gain scores (Post-Test score minus Pre-Test score) for each student. The results of this analysis are summarized in Table 4.

Table 4. Independent Samples T-Test Results on Gain Scores

Group	N	Mean Gain Score
Experimental	30	23.2
Control	30	7.2

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The result of the t-test was highly significant, $t(58) = 8.95$, $p < 0.001$. This statistical outcome provides strong evidence that the SRC platform was significantly more effective in improving students' digital science literacy scores. A deeper look into these figures reveals the magnitude of this effect. The t-statistic of $t(58) = 8.95$ indicates a very large difference between the mean gain scores of the two groups relative to their internal variability. The degrees of freedom ($df = 58$) are derived from the total number of participants minus the two groups. The p-value of $p < 0.001$ is the most critical finding. This value represents the probability that a difference as large as the one observed (a 16-point gap in mean improvement) could have occurred by random chance alone, assuming the SRC had no real effect. Since this probability (less than 0.1%) is substantially lower than the conventional significance threshold ($\alpha = 0.05$), we can confidently reject the null hypothesis, which states that there is no difference between the groups. Therefore, this statistical outcome confirms that the improvement seen in the experimental group is not a random fluctuation but a direct and significant effect of the personalized learning intervention provided by the SRC platform.

3.2. Qualitative Findings

Thematic analysis of the interviews with the experimental group revealed three major themes that provide context for and help explain the quantitative success:

a. Theme 1: Enhanced Engagement and Content Relevance: Students felt the personalized recommendations made learning more engaging and directly relevant to their interests. This fostered a sense of curiosity and a desire to explore further. As one student noted, "...seru, karena video-video yang muncul itu pas banget sama yang saya lagi penasaran."
b. Theme 2: A Personalized and Directed Learning Experience: Students perceived the system as being "smart" and tailored to them, which made the learning process feel more efficient and focused. One student expressed, "Paling suka karena materinya terasa dibuat untuk saya. Kalau saya kasih rating tinggi di topik biologi, besoknya lebih banyak muncul materi biologi yang lain."
c. Theme 3: Overcoming Learning Barriers: The SRC helped students engage with topics they previously found difficult or uninteresting by presenting them in accessible formats (e.g., short videos). As a student explained, "Ada beberapa materi fisika yang saya kurang suka, tapi karena direkomendasikan video yang penjelasannya bagus dan singkat, saya jadi ngerti."

3.3. Platform Visualization

As concrete evidence of the development outcomes, the following figures visualize the main user interface of the fully functional SRC platform. Figure 2 illustrates the main dashboard that greets the student upon login. The design is clean and modern, featuring a personalized welcome message and the core recommendation carousel, which is a direct implementation of the co-design findings to present content in an engaging, non-intrusive manner. Furthermore, Figure 3 displays the interface for a specific learning material. This view integrates multimedia content (an embedded video player) with the primary interaction mechanism for the recommendation algorithm: a five-star rating system. This design directly addresses the students' expressed preference for video-based content and provides a simple, intuitive way for them to provide the data needed to fuel the personalization engine [35].

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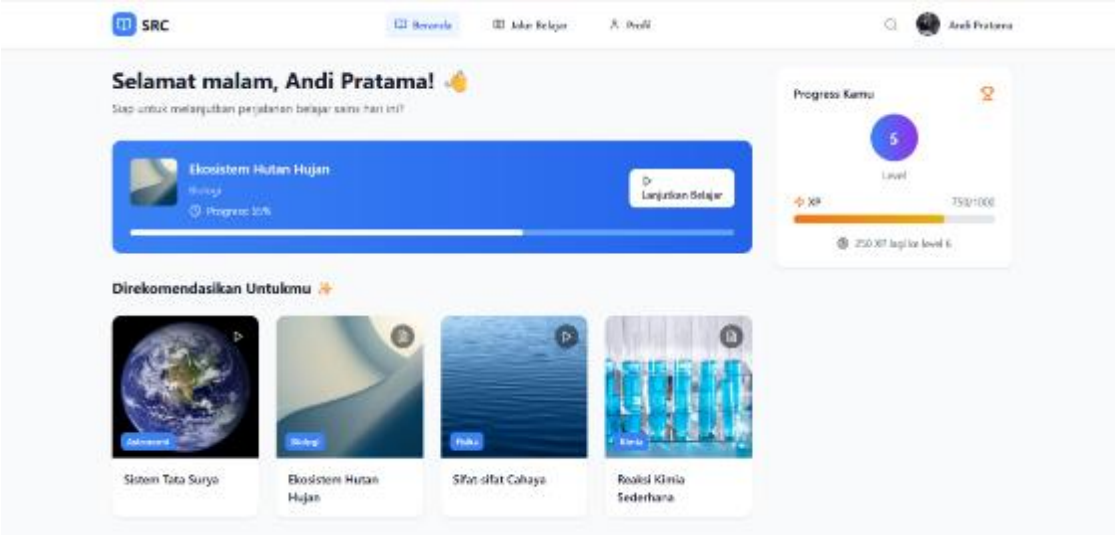

Figure 2. The Main Dashboard Interface of the SRC Platform.

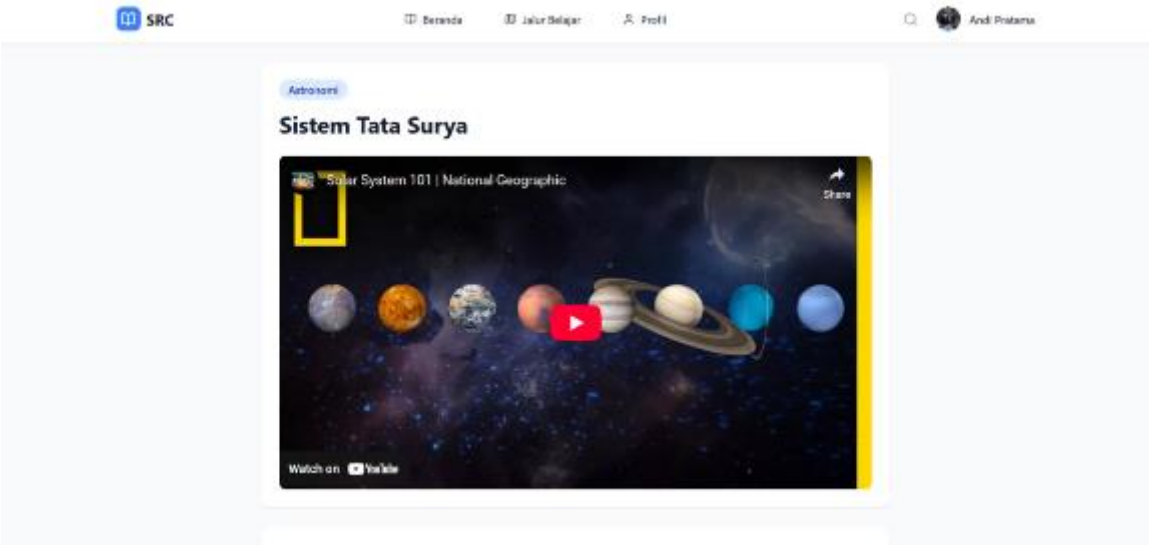

Figure 3. The Learning Material Page with Interaction Feature

The validated platform, as visualized above, now serves as a robust instrument for the next phase of research: a full-scale empirical study to measure its impact on learning outcomes.

3.4. Discussion

The results of this study strongly support the hypothesis that a personalized adaptive learning system, developed through a user-centric co-design process, can significantly enhance student learning outcomes. The quantitative data shows what occurred: a significant improvement in test scores. In parallel, the qualitative data explains why this happened, revealing that the improvement was driven by increased motivation, a sense of personal relevance, and the platform's ability to scaffold learning for difficult topics. The success of the SRC, as visualized in Figure 2 and 3, is not merely a technical achievement but a direct outcome of the development model. By grounding the design in the authentic needs and preferences of students, we built a tool that they not only could use but also wanted to use. This research demonstrates the critical importance of integrating pedagogical principles with user-centered design to create effective educational technologies. While limitations such as sample size and duration exist, the findings provide a robust foundation for future research and broader implementation.

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4. CONCLUSION

This paper has detailed the systematic development and, crucially, the empirical evaluation of an adaptive learning system aimed at enhancing digital science literacy. The research process resulted in a fully functional, web-based prototype of the Sistem Rekomendasi Cerdas (SRC), which was developed using a participatory co-design methodology. The effectiveness of this platform was then rigorously tested in a quasi-experimental study involving 60 junior high school students. The primary findings of this research are both statistically significant and contextually rich. Quantitatively, the experimental group using the personalized SRC platform demonstrated a significantly greater improvement in digital science literacy scores compared to the control group ($p < 0.001$). This provides strong empirical evidence for the system's effectiveness. Qualitatively, the findings from student interviews explained this success, revealing that the platform significantly enhanced learning motivation, the perceived relevance of content, and helped students overcome barriers to learning difficult topics.

The central conclusion of this study is that the integration of a participatory co-design process is fundamental to creating educational technology that not only is highly usable but also produces tangible and significant learning gains. The SRC is no longer just a validated prototype; it has been empirically verified as an effective tool for enhancing student learning outcomes in this context. These findings have significant practical implications for educators, curriculum designers, and technology developers, underscoring the critical importance of a user-centered approach in the EdTech field. The successfully validated platform now stands as a proven instrument, with strong potential for broader implementation and further research into its long-term effects on student engagement and academic achievement.

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