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A WEB-BASED ADAPTIVE LEARNING SYSTEM FOR PERSONALIZED DEVELOPMENT OF HIGHER-ORDER THINKING SKILLS USING DIFFERENTIATED INSTRUCTION TO SUPPORT SUSTAINABLE DEVELOPMENT GOALS (SDGS)

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Abstract

The development of higher-order thinking skills (HOTS) requires adaptive digital learning systems capable of addressing learners' diverse characteristics and learning needs. This study presents the design, development, and evaluation of PiVERS, a web-based adaptive learning system developed to support the personalized development of HOTS through differentiated instruction, contributing to the sustainable development goals (SDGs), particularly SDG 4 (quality education). PiVERS dynamically adapts learning content, activities, and assessment mechanisms based on learners' cognitive abilities, preferences, and learning profiles, enabling personalized learning pathways that emphasize analysis, evaluation, and creation. A design-based research (DBR) approach was employed, involving needs analysis, system architecture design, expert validation, limited field implementation, and iterative refinement. The system was implemented with eleventh-grade high school students, and empirical data were collected using HOTS assessment instruments, classroom observations, and user perception questionnaires. Experimental results indicate a statistically significant improvement in students' HOTS, with the experimental group achieving higher learning gains than the control group. Usability evaluation further confirms high user engagement and positive perceptions of system effectiveness. PiVERS provides an effective and scalable adaptive learning system for implementing differentiated instruction within web-based environments to enhance HOTS development in secondary education.

Keywords: Adaptive learning, HOTS, Differentiated instruction, PiVERS web-based digital learning.

1. Introduction

The development of higher-order thinking skills (HOTS) has become a critical objective in contemporary education, as these skills enable learners to analyse information, evaluate alternatives, and create solutions for complex real-world problems. However, conventional instructional approaches often fail to accommodate learners' diverse cognitive abilities, learning preferences, and prior knowledge, resulting in uneven learning outcomes and limited cognitive engagement. Recent studies have shown that digital learning environments can enhance HOTS development, particularly when instructional strategies are designed to support advanced cognitive processes through interactive and adaptive mechanisms [1, 2].

Advances in web-based technologies and adaptive learning systems have enabled the design of learning environments that dynamically adjust content, learning pathways, and assessment strategies based on learner characteristics. Adaptive systems collect and analyse learner data to personalize instruction, thereby improving engagement, motivation, and learning effectiveness [3, 4]. In parallel, differentiated instruction has emerged as an effective pedagogical framework for addressing learner diversity by modifying learning content, processes, and outcomes according to individual needs [5, 6]. When implemented through digital platforms, differentiated instruction can be operationalized as a system-level adaptation mechanism rather than a purely instructional strategy.

Despite the growing body of research on adaptive and personalized learning, many existing digital learning systems remain limited in their ability to systematically integrate HOTS-oriented learning objectives with differentiated instruction within a scalable web-based architecture. Previous studies have explored web-based adaptive presentation techniques, AI-enabled learning platforms, and interactive digital media to support higher-order thinking [7-11]. However, these systems often emphasize content delivery or usability, with limited focus on how adaptive mechanisms explicitly support higher-order cognitive processes such as analysis, evaluation, and creation across diverse learner profiles.

From a broader perspective, the development of adaptive learning technologies is closely aligned with the Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education), which emphasizes inclusive, equitable, and high-quality education supported by effective learning technologies. Web-based adaptive learning systems offer scalable solutions that can extend access to personalized learning experiences while maintaining instructional quality, making them particularly relevant for secondary education contexts with heterogeneous learner populations.

In response to these challenges, this study presents Personalized Virtual Education Resource System (PiVERS), a web-based adaptive learning system designed to support the personalized development of HOTS through differentiated instruction. PiVERS integrates HOTS-oriented learning modules with multi-level adaptive mechanisms that dynamically adjust learning content, activities, and assessments based on learners' cognitive profiles, preferences, and performance data. The objectives of this study are to design and evaluate the effectiveness of PiVERS in enhancing students' HOTS and to examine its usability and adaptive performance in authentic classroom settings. The novelty of this research lies in (i) the integration of HOTS development within a differentiated instructional

framework operationalized at the system level, (ii) the implementation of multi-level learner profiling to enable personalized learning pathways, and (iii) the positioning of PiVERS as a scalable web-based adaptive learning system aligned with SDG-oriented educational innovation.

2. Literature Review

Web-based learning systems have been widely recognized for their potential to support HOTS by enabling interactive, flexible, and cognitively demanding learning activities. Previous studies report that web-based and online learning environments can enhance students' analytical, evaluative, and creative thinking when learning tasks are designed to promote active engagement and problem-solving [1, 2, 12]. Compared to conventional instruction, web-based platforms allow learners to interact with complex content and higher-level cognitive tasks in a more dynamic and accessible manner [3].

The effectiveness of web-based learning is further enhanced through adaptive learning mechanisms that personalize content, learning pathways, and feedback based on learners' characteristics and performance data. Research on adaptive presentation techniques and learner profiling demonstrates that adaptive systems can improve engagement and learning outcomes by tailoring instruction to individual needs [4, 8]. Recent reviews of artificial intelligence–enabled adaptive learning platforms also highlight the role of data-driven adaptation in delivering scalable personalized learning experiences [9, 11]. However, many adaptive systems emphasize content efficiency rather than explicitly supporting HOTS development.

HOTS-oriented digital learning environments require deliberate instructional designs that integrate problem-based, scenario-based, and reflective activities to stimulate analysis, evaluation, and creation [13-15]. Differentiated instruction provides a pedagogical foundation for addressing learner diversity by adapting content, processes, and outcomes to learners' profiles [5, 6]. When implemented through adaptive web-based systems, differentiation becomes a system-level mechanism rather than a purely instructional strategy.

As illustrated in Fig. 1, web-based adaptive learning systems typically employ a client–server architecture to deliver personalized learning materials, interactive activities, and assessments based on learner profiles. Despite advances in adaptive web technologies, there remains a need for systems that systematically integrate HOTS-oriented design with differentiated instruction within scalable web-based architectures. This gap underlines the importance of developing adaptive learning systems that align personalization mechanisms with higher-order cognitive objectives.

3. Methodology

This study employed a Design-Based Research (DBR) approach to design and evaluate PiVERS, a web-based adaptive learning system for personalized Higher-Order Thinking Skills (HOTS) development through differentiated instruction. The DBR process involved analysis, design, development, and evaluation stages. PiVERS implements a multi-level adaptive mechanism that personalizes learning content, activities, and assessments based on learners' profiles, including

achievement levels, preferences, and performance data. The system was implemented with eleventh-grade students using experimental and control groups. Data were collected through HOTS assessments, classroom observations, and student perception questionnaires. Learning effectiveness was analysed using paired and independent t-tests to evaluate system performance. Detailed procedures are reported elsewhere [16].

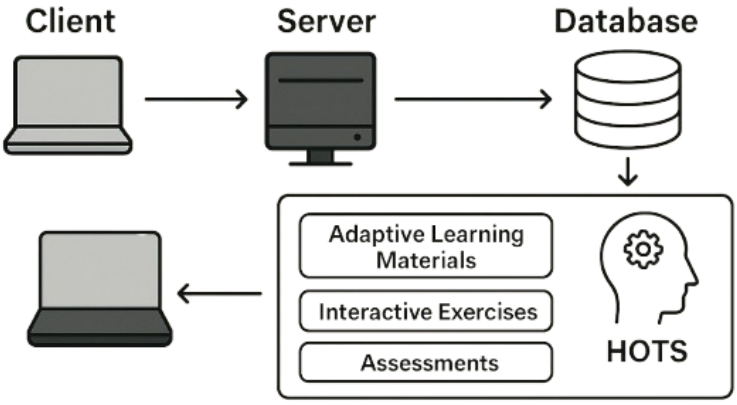


Fig. 1. A client-server system based on web-based adaptive digital learning.

4. Results and Discussion

The development and implementation of PiVERS, a web-based adaptive learning system, demonstrates its effectiveness in supporting personalized development of HOTS through differentiated instruction. As illustrated in Fig. 2, the system development workflow includes needs analysis, content design and validation, interface development, feature integration, and system testing. Each stage incorporates adaptive mechanisms that adjust learning content, activities, and assessments based on learners' profiles, enabling personalized learning pathways that emphasize analysis, evaluation, and creation.

Usability testing involving 120 eleventh-grade students indicates a high level of user acceptance and engagement. A total of 87% of students reported that PiVERS was easy to use, while 82% perceived the system as effective in supporting HOTS-oriented learning. Students highlighted adaptive pathways, personalized feedback, and varied learning activities as key features that enhanced motivation and facilitated understanding of complex analytical tasks.

The effectiveness of PiVERS was further evaluated through experimental and control group comparisons. In the experimental group, students' HOTS scores increased significantly from 62.4 to 87.1, whereas the control group showed a more modest improvement from 63.1 to 75.2. Statistical analysis using paired t-tests confirmed a significant improvement within the experimental group ($p = 0.000 < 0.05$), and independent t-tests revealed significant differences between the experimental and control groups ($t = 5.422$; $p = 0.000$). These results indicate that PiVERS outperforms conventional learning approaches in fostering higher-order cognitive skills.

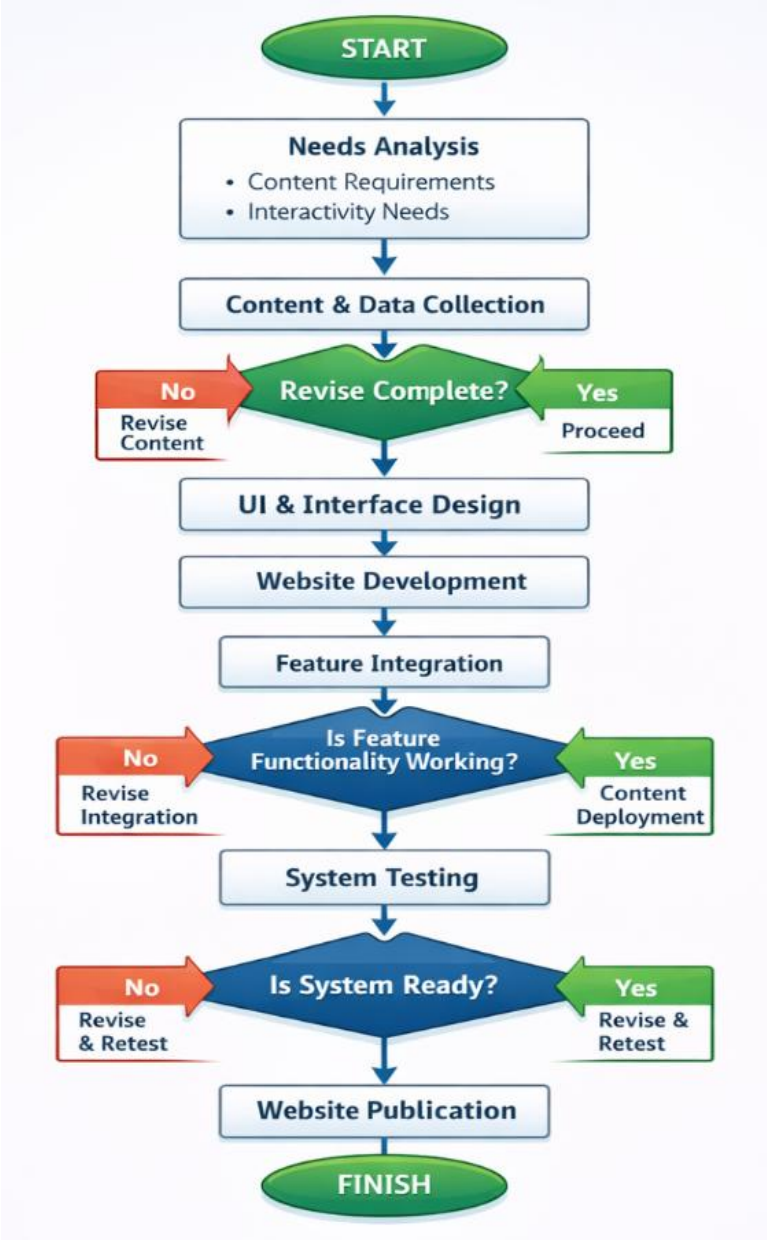
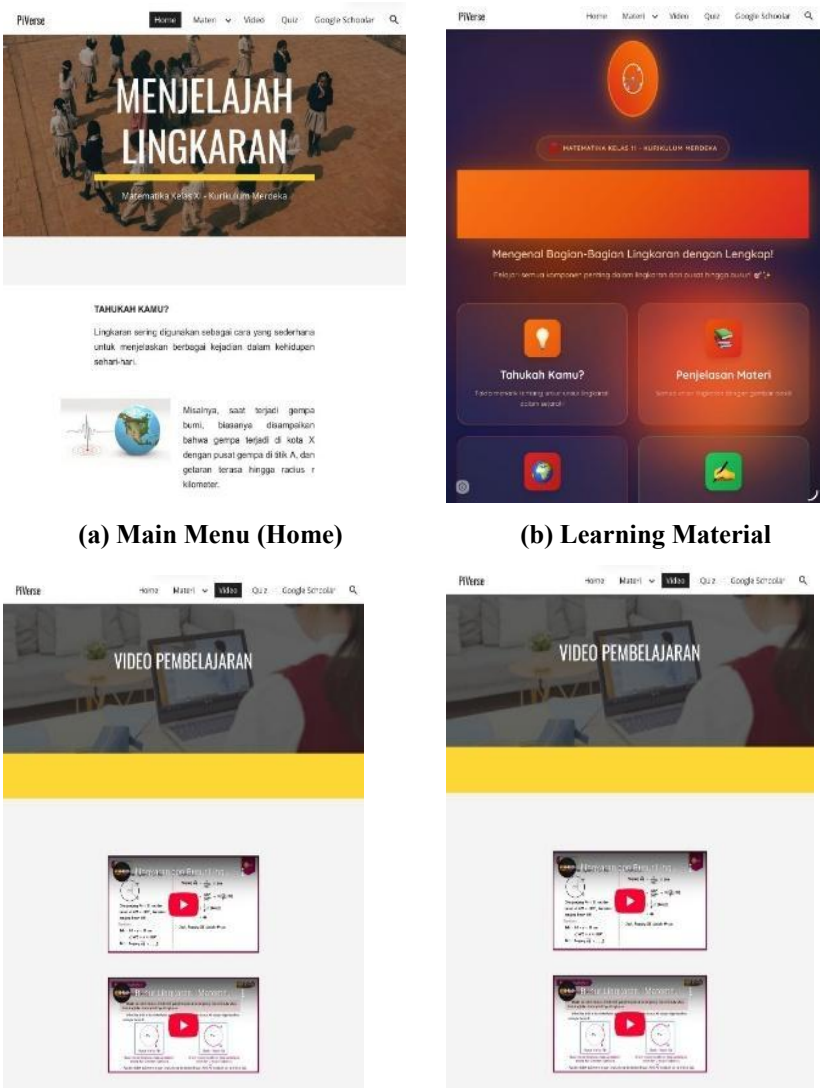


Fig. 2. Flowchart PiVERS applications.

Figure 3 presents the PiVERS application interface, highlighting core system components, including adaptive learning materials, videos, and quizzes. The system integrates features such as adaptive quizzes, scenario-based tasks, concept mapping, and real-time feedback to support active knowledge construction and differentiated learning experiences. These features align with previous findings that interactive and adaptive digital learning environments contribute significantly to HOTS development [17, 18].



(a) Main Menu (Home) **(b) Learning Material**

(c) Learning Videos **(d) Quiz**

Fig. 3. PiVERS application product with appearance of (a) main menu, (b) learning material, (c) learning video, and (d) quiz.

From a system-performance perspective, PiVERS effectively operationalizes differentiated instruction as a technology-driven adaptation mechanism, rather than a purely pedagogical strategy. By dynamically aligning instructional content with learners' abilities and preferences, PiVERS supports scalable and personalized HOTS development. Moreover, the system contributes to the SDGs, particularly SDG 4 (Quality Education), by enabling inclusive, technology-enhanced, and high-quality learning experiences through adaptive web-based platforms. This study adds new information regarding SDGs as reported elsewhere [19-22].

5. Conclusions

This study concludes that PiVERS is an effective HOTS-oriented, web-based adaptive digital learning media system developed based on the principles of differentiated instruction. The implementation of PiVERS resulted in a statistically significant improvement in students' Higher Order Thinking Skills compared to conventional learning approaches, supported by high levels of student engagement and positive user perceptions. By dynamically adapting learning content, activities, and assessment mechanisms to learners' cognitive abilities and learning profiles, PiVERS facilitates personalized learning pathways that promote higher-order cognitive processes, including analysis, evaluation, and creation. Overall, PiVERS provides a scalable and robust pedagogical technical framework for the implementation of differentiated instruction within adaptive web-based learning environments, particularly at the secondary education level.

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