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# Cognitive Styles and Learning Strategies on Smart Learning Environment Effectiveness in Secondary School Mathematics Achievement

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**ABSTRACT**

This study investigated the influence of cognitive styles and learning style preferences on the efficacy of a locally developed smart learning environment regarding students' academic achievement in mathematics within public secondary schools in Osun State, Nigeria. The research adopted a pretest-posttest control group quasi-experimental design. The study population encompassed all senior secondary school students in Osun State, from which 150 Senior Secondary II (SS II) students were selected using a multistage sampling procedure. Data collection instruments included the Mathematics Achievement Test (MAT), the Cognitive Style Inventory (CSI), and the Learning Style Inventory (LSI). Data analysis revealed no significant difference ($F(1, 107) = 0.06$; $p = 0.81$) in the influence of cognitive styles on the effectiveness of the smart learning environment. Conversely, the results demonstrated a significant difference regarding the influence of learning style preferences on the smart learning environment's impact on academic achievement in mathematics ($F(2, 143) = 4.933$; $p = 0.008$). The study concluded that a well-designed smart learning environment significantly enhances students' academic performance in mathematics. Crucially, the findings suggest that this technological intervention remains effective irrespective of students' individual cognitive styles, preferred learning strategies, or sex. These results advocate for the broader integration of smart learning technologies in mathematics education to bridge achievement gaps. By providing a versatile and interactive platform, such environments cater to a diverse range of learners, ensuring that instructional quality remains high and equitable across different psychological and demographic profiles in the secondary school system.



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## 1. INTRODUCTION

The limitations of orthodox methodologies in teaching mathematics call for a reorientation of instructional strategies in secondary schools, given the discipline's crucial role in everyday life. From basic arithmetic operations to complex concepts such as calculus and formal logic, they are vital tools in commerce, decision-making, industry, military operations, and programming (Pepin et al., 2021; Abdiraxmonov, 2024; Rakhmonov, 2025; Mamolo et al., 2022). This significance is reflected in Nigeria's education policy, which mandates passing mathematics as a prerequisite for university admission. Therefore, a shift from the traditional "talk and chalk" method to a student-centered approach is crucial to ensure in-depth understanding and practical relevance for learners (Oteyola et al., 2023).

In an effort to improve student academic achievement, various active learning strategies such as problem-solving techniques and drill and practice have proven effective at both secondary and tertiary levels (Omolafe et al., 2024; Agah et al., 2024; Lugosi et al., 2022). The integration of technology through blended learning models, particularly the flipped classroom, allows the focus of classroom learning to shift to higher-level aspects of Bloom's Taxonomy, such as analysis and synthesis (Obienyem et al., 2024; Omoniyi et al., 2025; Egara et al., 2024). Furthermore, the implementation of smart learning environments not only utilizes technology technically but also creates a pedagogical ecosystem that engages teachers and parents to facilitate continuous and real-time skill transfer (Kinshuk et al., 2016; Oteyola et al., 2023).

A smart learning environment (SLE) is a data-driven ecosystem that is adaptive and context-aware through the integration of formal and informal learning (García-Tudela et al., 2021; Kinshuk et al., 2016). According to Daniela (2021), technology-based learning is the foundation of SLE, transcending the limitations of traditional models. Cheung et al. (2021) identified that a major weakness of traditional environments is the inability of instructors to monitor each student's cognitive style, preferences, and learning outcomes in real time. In contrast, SLEs not only provide access without spatial and temporal constraints but also provide timely, relevant guidance and advice by leveraging artificial intelligence (AI) and the Internet of Things (IoT).

Cognitive style plays a crucial role in determining how individuals absorb and process information to solve problems (Hardiansyah et al., 2024; Hidajat et al., 2024; Muzaini et al., 2021). Cognitive style to perceived ease of use and usefulness of technology, which are key constructs in technology acceptance theory (Oteyola et al., 2022). Teachers' understanding of students' cognitive styles is crucial in problem-solving activities such as mathematics to maximize their potential (Hardiansyah et al., 2024). Therefore, it is important to evaluate whether the effectiveness of SLE on academic achievement is influenced by students' consistent ways of organizing information.

Generally, cognitive styles are categorized as field dependence (FD) and field independence (FI) (Aisyah et al., 2024; Muzaini et al., 2021). FD learners tend to perceive situations holistically, are more influenced by their surroundings, and rely on social sources of information such as teachers (Na et al., 2020; Zhou et al., 2023). In contrast, FI learners have a strong analytical orientation, are able to separate individual components from the whole, and prefer independent study. SLEs are designed to mitigate the limitations of scalability and customization in traditional learning by providing support tailored to the unique needs of both types of learners (García-Tudela et al., 2021).

Although the concept of learning styles has been widely debated, the VAK (Visual, Auditory, and Kinesthetic) model remains relevant as a strategy for diversifying teaching methods (Sayed et al., 2025). Visual learners learn better through diagrams and mind maps, while auditory learners are more effective through discussions and lectures (Halirat et al., 2025). Kinesthetic learners, on the other hand, require physical engagement and hands-on activities such as role-playing or model building. Integrating these modalities into a learning style learning system (SLE) allows for a more inclusive delivery of materials to accommodate students' diverse learning strategy preferences.

This study examines the influence of cognitive styles and learning preferences on the effectiveness of a locally developed Smart Learning Environment (SLE) to improve mathematics achievement for secondary school students in Nigeria. Following development principles in developing countries, the strategy employed included implementing a small-scale pilot program as proof of concept before broader expansion (Singh, 2022; Kant et al., 2025; Cheung et al., 2021). Furthermore, utilizing affordable devices such as smartphones, using open-source software, and providing offline access are crucial steps to address the challenges of unstable electricity and internet infrastructure (Selvakumar et al., 2025).

This experiment was conducted in three public secondary schools in Osun State, integrating iSpring software, Google Classroom, Google Docs, and WhatsApp to create a smart learning ecosystem that aligns with available local resources. The background to this research is the low academic performance of students in external examinations such as the WASSCE and NECO, where previous technology-based instructional strategies have not significantly impacted national examination results in the region. Through this approach, this study seeks to demonstrate whether locally designed SLEs can meet the standards of inclusive learning effectiveness regardless of differences in students' cognitive styles and learning preferences.

This study aims to investigate the influence of students' cognitive styles and learning strategy preferences on the effectiveness of a locally developed Smart Learning Environment (SLE) in improving mathematics academic achievement. Specifically, this study was designed to determine whether there are significant differences in the influence of cognitive styles (field-dependent and field-independent) and learning strategies (Visual, Auditory, and Kinesthetic) on student learning outcomes in secondary schools. Furthermore, this study evaluated the interaction effect of gender on the influence of students' cognitive styles and learning strategies in the context of implementing the smart learning environment.

In line with these objectives, this study formulated four null hypotheses to test the significance of the variables involved. The first and second hypotheses stated that neither cognitive styles nor learning strategies had a significant influence on the effectiveness of SLE in improving mathematics academic achievement in high school students. Meanwhile, the third and fourth hypotheses postulated that gender did not have a significant interaction effect on the influence of students' cognitive styles or learning strategies in the implementation of the locally developed smart learning environment. Through this testing, it is hoped that a comprehensive picture of the determinants of the success of learning technology at the secondary school level can be obtained.

## 2. METHOD

The research was an experimental design that adopted the pretest – posttest control group quasi experimental design. The population of the study comprised all students in public senior secondary school in Osun State, Nigeria. One hundred and fifty senior secondary II (SSII) students were selected using multistage sampling procedure. Four senior secondary schools with access to ICT technologies were purposively selected from two randomly selected local government areas (LGAs) of the randomly selected senatorial districts of the State. The schools were randomly assigned to experimental and control group in each of the LGAs. All the 150 SS II students in an intact class of one randomly selected arms in each of the schools were the sample for the study. Mathematics Achievement Test (MAT), Cognitive Style Inventory (CSI) and Learning Strategies Inventory (LSI) were used for data gathering. The MAT was a 40 items multiple choice questions that measured students' academic achievement in Mathematics. The items were selected from past West African Senior Secondary School Certificate Examination (WASSCE) questions. The CSI is a 40-item likert-type questionnaire.

This study used rigorously validated questionnaires and achievement tests to collect demographic data, cognitive styles, and student learning preferences. The Learning Style Inventory (LSI) questionnaire, adapted from Sim Nigeria Resources, consists of 21 items to identify visual, auditory, and kinesthetic learning preferences. Meanwhile, the Mathematics Achievement Test (MAT) instrument was developed based on a specification table covering all levels of Bloom's Taxonomy, from knowledge to evaluation. The quality of the MAT items was ensured through assessment by three expert teachers and Item Difficulty Index (IDI) analysis, with only items with a difficulty index above 0.3 being retained to ensure adequate instrument standards.

Content validity for the Cognitive Style Inventory (CSI) and LSI instruments was established through expert review from Obafemi Awolowo University to assess language clarity, appropriateness of purpose, and instrument organization. Based on the Lawshe test, a Content Validity Ratio (CVR) of alpha = 1 was obtained for both instruments. Furthermore, reliability testing was conducted on 20 students outside the study sample using the split-half method. Spearman Rank Order correlation analysis showed a reliability coefficient of $r = 0.79$ for the CSI and $r = 0.95$ for the LSI, which confirmed that all instruments had excellent internal consistency for use in research data collection.

The research procedure began with official permission from the principal and the appointment of a Mathematics teacher who had received special training as a research assistant. The study was conducted over six weeks, beginning with an initial visit to explain the research objectives and assign a personal identification number (PIN) to each student to ensure data consistency throughout the process. In the first week, all participants took a pretest to assess their initial abilities before entering the intervention phase. For the next four weeks, the experimental group received instruction through a locally developed Smart Learning Environment (SLE), while the control group used conventional methods (talk and chalk).

In the sixth week, all participants took a posttest and completed the Cognitive Style Inventory (CSI) and Learning Style Inventory (LSI). The collected data were then systematically scored and collated to ensure the accuracy of the results. Data analysis was conducted using Analysis of Variance (ANOVA) and 2-way ANOVA statistical techniques to test the influence of independent variables and interactions between variables on student academic achievement. This structured methodological approach ensured that the research results had strong internal validity in comparing the effectiveness of the two learning models tested.

## 3. RESULTS AND DISCUSSION

### Results

**$H_1$: Cognitive styles have no significant influence on the effect of smart learning environment on secondary school students' academic achievement in Mathematics**

This hypothesis was formulated to evaluate the extent to which cognitive style influences the effectiveness of a locally developed Smart Learning Environment (SLE) on high school students' mathematics achievement. The Cognitive Strategy Inventory (CSI) instrument, consisting of 40 items, was used to map students' cognitive strategies. Odd-numbered items measure field dependency and even-numbered items measure field independence. Given that cognitive style is a continuum, categorization was conducted strictly based on students' scores on the instrument to ensure valid differentiation between the two groups.

In the classification process, students were categorized as field-dependent or field-independent if there was a minimum score difference of 10 points between the two dimensions. Participants with a score difference below this threshold were classified as unidentified to maintain the purity of the comparative data. Next, a two-way ANOVA statistical technique was applied to analyze whether there was a significant effect of cognitive style on student learning outcomes within the SLE ecosystem. This analytical approach allowed researchers to examine the interaction between smart learning methods and students' innate cognitive characteristics in greater depth.

**Table 1.** Two-way ANOVA

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 142.744[a] | 4 | 35.686 | 9.122 | .000 |
| Intercept | 1297.316 | 1 | 1297.316 | 331.636 | .000 |
| Pretest | 62.560 | 1 | 62.560 | 15.992 | .000 |
| Group | 11.131 | 1 | 11.131 | 2.845 | .095 |

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Cognitive Style | 1.670 | 1 | 1.670 | .427 | .515 |
| Group * Cognitive Style | .222 | 1 | .222 | .057 | .812 |
| Error | 402.923 | 103 | 3.912 | | |
| Total | 16826.000 | 108 | | | |
| Corrected Total | 545.667 | 107 | | | |

Table 1 presents the results of a 2-Way ANOVA analysis of the influence of cognitive styles, categorized as field-dependent and field-independent, on the effectiveness of a locally developed Smart Learning Environment (SLE). The analysis showed no significant difference ($F(1,107) = 0.06$; $p = 0.81$) in the influence of cognitive styles on student learning outcomes in Mathematics. Given that the p-value is $> 0.05$, the null hypothesis stating that cognitive styles have no significant influence on the effectiveness of SLEs on high school students' academic achievement is not rejected.

This finding indicates that the implementation of smart learning environments has the potential to improve students' academic achievement in an inclusive manner without being limited by their inherent cognitive characteristics. In other words, the locally designed SLE proved effective in facilitating the learning process for both field-dependent and field-independent student groups. These results strengthen the argument that adaptive educational technology innovation can bridge the diversity of students' cognitive styles in achieving expected Mathematics competency standards.

**$H_2$: Learning strategies has no significant influence on the effect of the locally developed smart learning environment on senior secondary school students' academic achievement in Mathematics**

This hypothesis was formulated to achieve the second objective of the study, which was to evaluate the influence of student learning strategies based on the VAK (Visual, Auditory, and Kinesthetic) model on the effectiveness of a locally developed smart learning environment. Data on learning preferences were collected using the Learning Style Inventory (LSI) Part B instrument, which consists of items on a 4-point Likert scale (Strongly Agree to Strongly Disagree). The dominant learning style was determined by converting the raw scores for each category into percentages, with the highest percentage being designated as the student's primary preference. Strict data validation procedures were also implemented, with students with the same percentage score (tally) in more than one category being excluded from the classification to ensure the accuracy of the analysis.

To ensure methodological robustness, the Analysis of Variance (ANOVA) statistical technique was used at two crucial stages of the study. First, ANOVA was applied at the pretest to test the homogeneity of students' initial abilities across learning preference groups before the intervention. Second, the same technique was used at the posttest to test the research hypotheses at a significance level of $p = 0.05$. This analytical approach aims to determine whether there are significant differences in the academic achievement of Mathematics produced by the smart learning environment when viewed from the diversity of students' learning modalities.

**Table 2.** ANOVA of the influence of learning strategy's preference on the effect of Smart Learning Environment on students' pretest score in Mathematics

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | .448 | 2 | .224 | .128 | .880 |
| Within Groups | 247.045 | 141 | 1.752 | | |
| Total | 247.493 | 143 | | | |

**Table 3.** ANOVA of the influence of learning strategy's preference on the effect of Smart Learning Environment on students' posttest score in Mathematics

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | 50.311 | 2 | 25.156 | 4.933 | .008 |
| Within Groups | 718.994 | 141 | 5.099 | | |
| Total | 769.306 | 143 | | | |

Tables 2 and 3 present data on the influence of student learning strategy preferences on academic achievement in Mathematics. The results of the homogeneity test at the pretest stage ($F(2,143) = 0.128$; $p = 0.880$) indicated no significant differences in students' initial abilities across learning preference categories. However, at the posttest stage, a significant difference was found ($F(2,143) = 4.933$; $p = 0.008$), thus the null hypothesis stating that learning strategy preferences have no significant influence on the effectiveness of the locally developed Smart Learning Environment (SLE) was officially rejected.

Further (post-hoc) analysis using the Bonferroni test was conducted to identify the specific location of these differences. The results showed no significant differences in achievement between the auditory and visual groups ($p = 0.100$), nor between the kinesthetic and visual groups ($p = 0.449$). However, a significant difference in achievement was found between students with auditory and kinesthetic learning styles ($p = 0.017$), with an average difference of 1.600. This finding indicates that the locally developed SLE ecosystem provides a more optimal impact on improving achievement for students with auditory learning styles compared to students with kinesthetic learning styles.

**H3: Sex has no significant interaction effect on the influence of cognitive styles on the effect of the smart learning environment on the students' academic achievement in Mathematics**

This hypothesis was raised to test if the influence of cognitive styles on the effect of the locally developed smart learning environment is influenced by sex. 2-Way ANOVA was employed in testing the hypothesis at 95% level of significant.

**Table 4.** 2-Way ANOVA

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 192.873[a] | 8 | 24.109 | 6.765 | .000 |
| Intercept | 1266.217 | 1 | 1266.217 | 355.323 | .000 |
| Pretest | 55.480 | 1 | 55.480 | 15.569 | .000 |
| Group | 4.458 | 1 | 4.458 | 1.251 | .266 |
| Sex | 24.187 | 1 | 24.187 | 6.787 | .011 |
| Cognitive Style | .317 | 1 | .317 | .089 | .766 |
| Group * Sex | 2.159 | 1 | 2.159 | .606 | .438 |
| Group * Cognitive Style | 1.258 | 1 | 1.258 | .353 | .554 |
| Sex * Cognitive Style | 5.081 | 1 | 5.081 | 1.426 | .235 |
| Group * Sex * Cognitive Style | 8.424 | 1 | 8.424 | 2.364 | .127 |
| Error | 352.793 | 99 | 3.564 | | |
| Total | 16826.000 | 108 | | | |
| Corrected Total | 545.667 | 107 | | | |

Table 4 shows that sex has no interaction effect on the influence of cogntive styles on the effect of the locally developed smart learning environment on students' academic achievement. Students' academic achievement in Mathematics irrespective of their sex and cognitive style can be significantly enhanced by the smart learning environment. The locally developed smart learning can provide opportunities for students to learn at their own pace, sex and their cognitive styles.

**H4: Sex has no significant interaction effect on the influence of students' learning strategies on the effect of the smart learning environment on the students' academic achievement in Mathematics**

This hypothesis was formulated to determine the interaction effect of sex on the influence of learning style preference on the effect of the locally developed smart learning environment on students' academic achievement in Mathematics. 2-Way ANOVA was employed in testing the hypothesis at 95% level of significant.

**Table 5.** 2-Way ANOVA of the interaction effect of sex on the influence of learning strategies on the effect of the locally developed smart learning environment on students' academic achievement in Mathematics

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 264.428[a] | 12 | 22.036 | 5.718 | .000 |
| Intercept | 1968.475 | 1 | 1968.475 | 510.758 | .000 |
| Pretest | 43.764 | 1 | 43.764 | 11.355 | .001 |
| Group | 30.320 | 1 | 30.320 | 7.867 | .006 |
| Sex | 17.443 | 1 | 17.443 | 4.526 | .035 |
| Learning | 31.612 | 2 | 15.806 | 4.101 | .019 |
| Group * Sex | .027 | 1 | .027 | .007 | .933 |
| Group * Learning | 19.965 | 2 | 9.982 | 2.590 | .079 |
| Sex * Learning | 1.897 | 2 | .949 | .246 | .782 |
| Group * Sex * Learning | 4.425 | 2 | 2.212 | .574 | .565 |
| Error | 504.878 | 131 | 3.854 | | |
| Total | 21746.000 | 144 | | | |
| Corrected Total | 769.306 | 143 | | | |

Table 5 shows that sex has no interaction effect on the influence of learning strategies on the effect of the locally developed smart learning environment on students' academic achievement in Mathematics. The locally developed smart learning environment effect on students' academic achievement in Mathematics is not influenced by student learning style preference irrespective of their sex. The locally developed smart learning can provide learning opportunities for students in Mathematics irrespective of their cognitive style and their preferred learning style. The locally developed smart learning environment was able to help and guide to students according to their needs. Students with auditory learning style preference benefited more than those with kinesthetic learning style preference.

**Discussion**

**The Influence of Cognitive Style on the Effectiveness of SLE**

The results of this study indicate that cognitive styles, both field-dependent and field-independent, did not significantly influence the effectiveness of the Smart Learning Environment (SLE) in improving students' mathematics achievement ($p = 0.81$). This finding indicates that a locally designed smart learning ecosystem is inclusive and able to facilitate students' cognitive processes without being hampered by their inherent characteristics. This strengthens the argument that adaptive educational technology innovations can bridge the diversity of cognitive styles to achieve expected competency standards (Nwachukwu et al., 2025), in line with the view that smart learning environments can provide appropriate guidance and assistance tailored to individual needs (Dhouib et al., 2025; Peng et al., 2019).

These findings also add a new dimension to previous literature on the interaction between technology and cognitive styles in education. Drawing on development principles in developing countries that prioritize accessibility through affordable devices and local content, this study demonstrates that traditional barriers related to the limitations of the "talk and chalk" methodology can be overcome through a student-centered instructional model. The success of the SLE in minimizing the achievement gap between field-dependent and field-independent learners suggests that integrating appropriate pedagogy into smart technology can create a more equitable learning ecosystem.

### The Influence of Learning Strategies (VAK) and Learning Optimization

In contrast to cognitive styles, learning strategy preferences encompassing visual, auditory, and kinesthetic modalities were found to have a significant influence on final learning outcomes in the SLE ecosystem ($p = 0.008$). Although at the initial stage (pretest) student abilities were evenly distributed across preference categories, posttest results indicated that this smart learning environment had a more optimal impact on students with auditory learning styles compared to kinesthetic students ($p = 0.017$). This finding confirms that despite the system's adaptive nature, the effectiveness of information absorption is still influenced by how the material is presented and processed through students' dominant sensory areas.

These results reinforce previous studies on the importance of diversifying teaching methods to meet the needs of different learning modalities (Goyibova et al., 2025). Despite differences in performance across specific groups, this study concluded that overall, the Smart Learning Environment was still able to provide guidance and assistance tailored to individual student needs (Kinshuk et al., 2016). The SLE's ability to facilitate various learning strategies demonstrates its function as a flexible tool that overcomes the limitations of traditional learning environments, which often fail to accommodate the diversity of student learning styles in the classroom.

### The Role of Gender in the Smart Learning Ecosystem

Analysis of the interaction between gender and cognitive strategies showed that these variables did not have a significant effect on the effectiveness of Smart Learning Environments (SLEs). This finding indicates that both male and female students can significantly improve their academic achievement through the SLE ecosystem, regardless of inherent cognitive characteristics such as field-dependent or field-independent. Therefore, the implementation of this technology has been proven to produce consistent learning outcomes for all students, transcending traditional barriers often arising from differences in gender and cognitive styles.

These results reinforce previous studies emphasizing that well-designed smart learning environments must be able to accommodate individual needs in an inclusive manner (Debasu & Yitayew, 2024). The SLE's ability to provide equal learning opportunities without being influenced by the interaction of gender and cognitive styles demonstrates that this pedagogical innovation is effective in providing guidance tailored to each student's unique needs. This demonstrates that an adaptive technology approach can be a solution to address the academic achievement gap in secondary schools, regardless of the diversity of students' personal characteristics (Dolenc & Aberšek, 2015; Hakkal & Lahcen, 2025).

Similarly, the study results confirmed that there was no interaction effect between gender and learning strategy preferences on student achievement. This indicates that the benefits of the SLE in providing opportunities for learning in mathematics are universal and inclusive for all learners (Dhouib et al., 2025; Pan et al., 2022). The effectiveness of this smart learning environment in improving academic performance is not limited by the combination of student gender and specific learning modalities, whether visual, auditory, or kinesthetic.

Overall, the locally developed Smart Learning Environment has proven to be an effective, flexible learning tool, capable of providing guidance tailored to individual student needs. This technology allows students to learn at their own pace while transcending traditional barriers often associated with gender, cognitive style, and learning strategy preferences. Although students with auditory preferences have been shown to benefit more than their kinesthetic counterparts, SLE still serves as a platform that provides equitable learning opportunities for all.

## 4. CONCLUSION

This study concludes that the implementation of a locally developed Smart Learning Environment (SLE) is an effective pedagogical innovation for improving students' Mathematics achievement in public secondary schools. Key findings indicate that students' cognitive styles did not significantly influence the effectiveness of the SLE ($F(1,107) = 0.06$; $p = 0.81$), indicating that the system is capable of inclusively accommodating both field-dependent and field-independent cognitive characteristics. Although there was a significant effect of learning strategy preferences on learning outcomes within the SLE ecosystem ($F(2,143) = 4.933$; $p = 0.008$), with the system design varying depending on students' learning modalities, overall, a well-designed SLE has been shown to improve academic achievement inclusively, regardless of differences in cognitive styles, learning strategy preferences, or gender.

As a recommendation, schools and education policymakers in Osun State are advised to integrate Smart Learning Environments (SLEs) into the Mathematics curriculum to provide equitable learning opportunities for students with diverse cognitive backgrounds. Learning media developers need to optimize modality-based designs by integrating visual, auditory, and kinesthetic elements in a balanced manner to ensure optimal stimulation for all learner types. Furthermore, future educational technology development must remain grounded in local wisdom, taking into account the availability of facilities in public schools to ensure program sustainability, and supported by further research exploring specific factors in learning strategies to enhance the adaptive features of the smart learning ecosystem.

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