

Digital Learning Transformation through AWBIT: A Case Study on the Department of Mathematics Education, State University of Medan


Elfitra^{1*}, Edi Syahputra², Badzlan Darari³, Suci Frisnoiry⁴, Nerli Khairani⁵

^a Universitas Negeri Medan, Jl. William Iskandar Ps. V, Kenangan Baru, Sumatera Utara 20221 Indonesia

¹ elfitra@unimed.ac.id*; ² edisyahputr01.es@gmail.com ; ³ badzlan@unimed.ac.id. ⁴ sucifrisnoiry@unimed.ac.id, ⁵ nerlinst@yahoo.com
* corresponding author

ARTICLE INFO	ABSTRACT
Article history Received May 22, 2023 Revised Dec 15, 2023 Accepted Dec 19, 2023	This study aims to examine the effectiveness of Adaptive Web-Based Interactive Tutoring (AWBIT) in transforming digital learning and improving students' digital literacy in the Calculus course at the Department of Mathematics Education, State University of Medan. The study used a quasi-experimental method with a Nonequivalent Control Group Design, involving two classes as experimental and control groups. The experimental group used AWBIT, while the control group used conventional learning. The instruments used include pretest and posttest tests, student response questionnaires, and validation of material and media experts. The validation results showed that AWBIT was very feasible to use with an average score of 3.38 from material experts and 3.43 from media experts. Students responded positively to AWBIT with an average questionnaire score of 3.35 and a practicality of use at 3.75 high. Statistical tests show that the data is distributed normally and homogeneously. The results of the t-test showed a significant difference between the learning outcomes of the experimental and control groups, with a gain score of 0.61 in the experimental group and 0.34 in the control group. These findings show that AWBIT is effective in improving students' learning outcomes and digital literacy. This system provides adaptive, interactive, and personalized learning, according to the individual needs of students. This research supports the integration of technology in learning and is in line with the implementation of the Independent Curriculum and the Outcome-Based Education (OBE) approach in higher education.
Keywords AWBIT, Digital Literacy Adaptive Learning Calculus Math Education	

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I. Introduction

In the era of the rapidly growing digital revolution, higher education faces the challenge of aligning its learning systems with the demands of the 21st century (Anshari et al., 2025; Hu et al., 2025; Misra & Srivastava, 2024; Pérez-Rivero et al., 2023). Digital transformation is no longer limited to technological adoption but requires a fundamental reorientation of pedagogical paradigms toward flexibility, personalization, and responsiveness. Universities are expected to prepare graduates who are not only knowledgeable but also capable of navigating complex digital environments (Muhajir & Rosadi, 2024; Pare & Sihotang, 2023; Peng et al., 2022; Zhu et al., 2024). This shift necessitates learning designs that integrate technology meaningfully rather than superficially. Consequently, instructional innovation has become a strategic priority in higher education reform agendas worldwide. Failure to adapt pedagogical models risks widening the gap between academic learning and real-world digital competencies (Khlaif et al., 2024; Sulianta & Saudi, 2021).

Digital literacy has emerged as a core competency underpinning effective participation in academic and professional contexts. It encompasses the ability to critically evaluate information, use digital tools strategically, and engage responsibly in digital environments. In higher education, digital literacy is increasingly viewed as an outcome rather than merely a prerequisite for learning. Students with insufficient digital literacy often struggle to benefit fully from technology-enhanced instruction. Thus, learning systems must be intentionally designed to cultivate digital literacy alongside disciplinary knowledge. This requirement places additional demands on instructional design, particularly in cognitively demanding disciplines.

In mathematics education, digital transformation poses even greater challenges due to the subject's abstract nature and its high cognitive demands. Calculus is considered one of the most difficult courses, as it requires logical reasoning, strong conceptual understanding, and problem-solving skills (Engelbrecht & Borba, 2024; Vorotnykova et al., 2023; Weigand et al., 2024). Many students still

struggle with fundamental concepts such as differentiation and integration, and these difficulties are compounded by unequal levels of digital literacy (Gusteti, 2024). This situation highlights the urgent need for innovative approaches that not only make abstract concepts more accessible but also foster digital competencies essential for academic and professional success (Gökoglu & Erdogdu, 2024; Ritter & Standl, 2025; Whitworth, 2020).

Previous studies on adaptive learning in calculus have reported improvements in learning outcomes and student engagement. However, these studies generally emphasize isolated adaptive mechanisms, such as automated feedback or personalized learning paths, without integrating interactive tutoring, multimodal digital resources, and explicit digital literacy support within a unified web-based learning environment. In addition, many adaptive learning systems lack the flexibility to simultaneously accommodate diverse learning styles and learning paces, particularly in supporting sustained interaction and self-regulated learning in calculus. Consequently, there remains a clear research gap in the development and empirical evaluation of adaptive web-based learning models that holistically address both conceptual mastery in calculus and the enhancement of students' digital literacy.

To address this research gap, Adaptive Web-Based Interactive Tutoring (AWBIT) was developed as an innovative solution. Adaptive Web-Based Interactive Tutoring (AWBIT) was developed to address these challenges. AWBIT is designed to provide adaptive, personalized, and interactive digital learning experiences tailored to students' learning styles, paces, and individual needs (Harizah et al., 2020; Patil et al., 2024; Razilu, 2025; Wang, 2025; Zhang et al., 2023). Beyond serving as a digital platform, AWBIT integrates instructional videos, interactive quizzes, digital modules, and online assignments. Through this integration, AWBIT aims to create a dynamic and flexible learning ecosystem that strengthens students' conceptual understanding while supporting 21st-century competencies, including critical thinking, creativity, collaboration, and communication (Aziz et al., 2024; Yanev, 2021).

At the institutional level, the adoption of adaptive digital learning is also aligned with the State University of Medan's 2020–2024 Strategic Plan, which emphasizes integrating technology into teaching and learning and implementing an Outcome-Based Education (OBE) curriculum. Such initiatives aim to reinforce four literacies, data, technology, human, and language, that are indispensable in the digital era (Huda et al., 2023).

Therefore, this study aims to examine the effectiveness of Adaptive Web-Based Interactive Tutoring (AWBIT) in enhancing students' learning outcomes and digital literacy in Calculus courses at the State University of Medan.

Based on these considerations, this study aims to examine the effectiveness of Adaptive Web-Based Interactive Tutoring (AWBIT) in improving students' learning outcomes and digital literacy in calculus courses. The study empirically evaluates whether AWBIT outperforms conventional instruction in supporting conceptual mastery. It also investigates students' responses and learning gains within an adaptive digital environment. By addressing both cognitive and digital dimensions, this research seeks to contribute empirical evidence to advancing adaptive learning in higher education. The findings are expected to inform future instructional design and digital learning policy.

II. Method

A. Research Design

This study used a quasi-experimental method with a non-equivalent control group design (England, 2022; Peña et al., 2021). This design was chosen because the study subjects could not be randomly assigned, but it still provided a measurable comparison between the experimental and control groups (Chahine & Aban, 2024; Voleti, 2024). The study examined the effectiveness of Adaptive Web-Based Interactive Tutoring (AWBIT) in improving students' digital literacy and learning outcomes in Integral Calculus courses.

The research design involved two groups that received different treatments. The experimental group used AWBIT in learning, while the control group continued to use conventional methods such as lectures and discussions. Both groups were given a pretest to measure their initial abilities and a posttest to assess the improvement in learning outcomes after the treatment. The independent variable of the study is the use of AWBIT, while the dependent variables are students' calculus learning outcomes and digital literacy. Control variables include course material, number of meetings, and the same instructor for both groups.

Table 1. Non-equivalent Control Group Research Design

Group	Pretest	Treatment	Posttest
Experimental	O ₁	Learning with AWBIT	O ₂
Control	O ₃	Conventional learning	O ₄

B. Research Setting and Participants

The study was conducted during the even semester of the 2022/2023 academic year (March–August 2023) at the Mathematics Education Program, FMIPA, University of Medan. The research population consisted of all second-semester students taking the Integral Calculus course. Purposive sampling was used to determine the sample, considering the equivalence of initial characteristics between classes. The sample consisted of two classes, each with approximately 30 students. In addition to sample size, the participants shared relatively homogeneous

characteristics, including similar academic backgrounds, an age range of 18–20 years, and prior exposure to basic calculus concepts. All participants were enrolled in the same study program and had comparable access to digital devices and internet connectivity, ensuring that differences in learning outcomes could be attributed primarily to the instructional intervention rather than external factors. This number met the minimum statistical power requirement for a two-group t-test (Hjoujj, 2023).

C. Variables of the Study

The research instruments consisted of three types: (1) a digital literacy and learning outcomes test in the form of multiple-choice and essay questions, validated by subject matter experts and tested for reliability using Cronbach's Alpha (≥ 0.70); (2) a student response questionnaire on a 1–5 Likert scale covering ease, attractiveness, interactivity, and motivation; and (3) observations and field notes to document the learning process, conducted non-participatively to minimize bias (Abumosa, 2024; Ariawan et al., 2025; Suryono, 2021). Data were collected through pre- and post-tests, questionnaires, and observations, with instrument validity assessed through expert review and reliability tested empirically (Ahmed & Ishtiaq, 2021).

Data analysis was conducted descriptively and inferentially. Normality was assessed using the Kolmogorov-Smirnov test, and homogeneity using the Bartlett test. (El Morr et al., 2022; Terán-García & Pérez-Fernández, 2024; Wu & Zhao, 2024). The selection of statistical tests was determined by the quasi-experimental design and the characteristics of the collected data. An independent samples t-test was selected because the study compared means between two independent groups, assuming normality and homogeneity. Prerequisite tests were therefore conducted to confirm the appropriateness of parametric analysis. The use of normalized gain (N-gain) was intended to measure relative learning improvement, while effect size (Cohen's d) was applied to determine the practical significance of the AWBIT intervention. Differences in learning outcomes and digital literacy between the experimental and control groups were analyzed using an independent samples t-test at a significance level of 5% ($\alpha = 0.05$).

D. Data Analysis Techniques

The implementation of AWBIT was conducted systematically over eight instructional meetings. The procedure consisted of four main stages: (1) orientation, during which students were introduced to the AWBIT platform and its features; (2) guided learning, where students engaged with instructional videos, interactive modules, and adaptive quizzes based on their learning progress; (3) independent practice, in which students completed online assignments and received immediate feedback through the system; and (4) evaluation and reflection, involving posttest administration and student feedback collection. This structured implementation

ensured consistent exposure to AWBIT features throughout the intervention period.

The level of improvement was calculated using normalized gain (g), while the magnitude of the effect was determined through effect size (Cohen's d) with criteria in the following table:

Table 2. Criteria for Normalized Gain and Effect Size

Analysis	High Criteria	Moderate Criteria	Low Criteria
N-Gain (g)	$g \geq 0.70$	$0.30 \leq g < 0.70$	$g < 0.30$
Effect Size (d)	$d \geq 0.80$	$0.50 \leq d < 0.80$	$0.20 \leq d < 0.50$

To enhance methodological transparency and systematic analysis, the overall research procedure is summarized.

III. Results and Discussion

This research aimed to develop and test the effectiveness of Adaptive Web-Based Interactive Tutoring (AWBIT) in improving students' learning outcomes and digital literacy through a quasi-experimental design with an experimental and control group. The results are presented in four parts: expert validation, student responses, statistical analysis (normality, homogeneity, and hypothesis testing), and a comparison of learning outcomes.

A. Expert Validation Results

Validation by subject-matter and media experts demonstrates that AWBIT is highly suitable for use in the learning process. Subject matter experts gave an average score of 3.38, while media experts gave a score of 3.43. These results show that AWBIT meets pedagogical and technical quality standards, ensuring the validity of its content and user-friendly interface design (Mansour et al., 2024). The image shows the results of the expert validation.

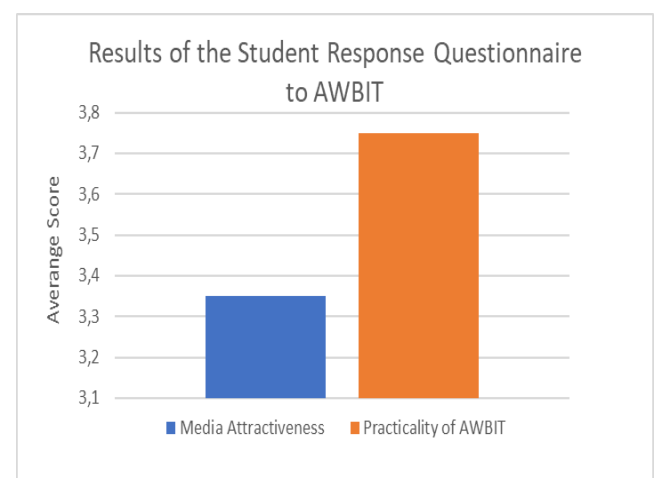


Fig. 1. AWBIT Product Validation Results

The expert validation results indicate that Adaptive Web-Based Interactive Tutoring (AWBIT) is highly valid and suitable for implementation in calculus instruction. Subject-matter experts assigned an average score of 3.38, indicating strong alignment among the instructional content, learning objectives, and the conceptual accuracy of the integral calculus materials. This score suggests that the content structure and learning activities are pedagogically sound, although minor refinements may further strengthen conceptual clarity and promote higher-order thinking skills.

Meanwhile, media experts gave an average score of 3.43, indicating that AWBIT excels in interface design, navigation, interactivity, and technical functionality. The higher media validation score confirms that the platform offers a user-friendly, accessible learning environment, which is essential for reducing cognitive load and supporting students' independent, adaptive learning processes.

B. Student Response to AWBIT

A total of 30 students filled out a questionnaire assessing ease of use, appeal, and motivation. The average response score was 3.35 (strongly agree), with practicality of use at 3.75 (high). This shows that AWBIT was well received and considered more appealing than conventional learning methods. The explanation above is shown in Figure 2.

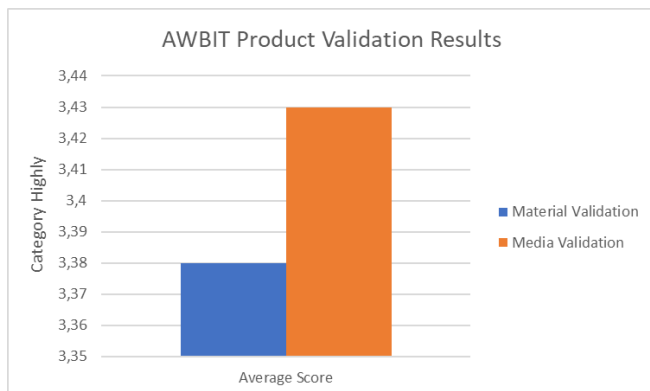


Fig. 2. Student Response to AWBIT Result

The results of the student response questionnaire indicate a positive perception of Adaptive Web-Based Interactive Tutoring (AWBIT). The average media attractiveness score was 3.35, suggesting that students perceived the visual design, layout, and interactive features of AWBIT as engaging and supportive of learning. An attractive interface is critical in web-based adaptive learning, as it enhances students' initial motivation and sustains their engagement during learning activities.

Furthermore, the practicality of AWBIT received a higher average score of 3.75, indicating that students found the platform easy to use, efficient, and well-integrated into their learning routines. This finding implies

that AWBIT effectively supports self-directed learning by allowing students to access materials, complete tasks, and receive feedback with minimal technical barriers. The higher practicality score also suggests that AWBIT's adaptive features facilitate personalized learning experiences, which are often lacking in conventional instructional methods (Hutain & Michinov, 2022; Junaid et al., 2025).

C. Statistical Assumptions

Prior to conducting inferential statistical analysis, it is essential to examine whether the research data meet the assumptions required for parametric testing. In quasi-experimental studies that compare means between groups, the assumptions of normality and homogeneity of variance must be met to ensure the validity and reliability of statistical conclusions. Therefore, a normality test was performed as a prerequisite to determine whether parametric statistical techniques were appropriate for this study.

D. Normality Test

The normality test was conducted as a prerequisite to ensure that the research data met the assumption of normality before applying parametric statistical tests. This assumption is essential because the study used an independent-samples t-test to compare learning outcomes between the experimental and control groups. In this study, normality was examined using the Lilliefors test and supported by a graphical analysis through a Normal Q-Q Plot. The data are considered normally distributed when the calculated Lilliefors value is less than the critical value, and the data points on the Q-Q plot closely follow the diagonal line. The results of the normality test are presented in Figure 3.

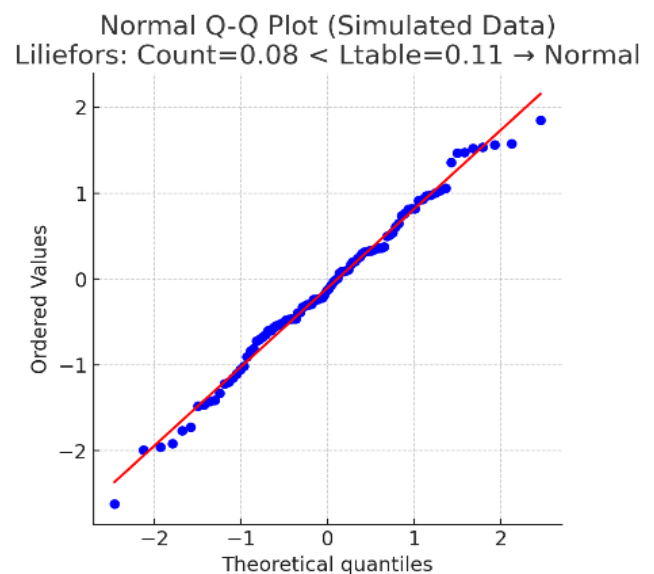


Fig. 3. Normality Test Result

Figure 3 presents the results of the normality test using the Lilliefors method. The analysis shows that the

calculated Lilliefors value ($L_{count} = 0.08$) is lower than the critical value ($L_{table} = 0.11$) at the significance level $\alpha = 0.05$. This result indicates that the data distribution does not deviate significantly from normality, thereby satisfying the normality assumption required for parametric analysis.

The Q-Q plot further supports this finding, as the observed data points closely follow the theoretical normal distribution line, with no substantial deviations at the tails. This pattern suggests that the data are symmetrically distributed and free from extreme skewness or kurtosis. Consequently, the fulfilment of the normality assumption strengthens the robustness of subsequent hypothesis testing and justifies the use of parametric statistical procedures, such as the independent samples t-test, in analyzing the effectiveness of the AWBIT intervention.

E. Homogeneity Test

After confirming that the data met the normality assumption, the next prerequisite analysis tested for homogeneity of variances between the experimental and control groups. Homogeneity of variance is a critical assumption in parametric comparative analysis, particularly when using an independent samples t-test, as it ensures that variability in scores across groups is comparable. To assess this assumption, Bartlett's test was employed because the data were normally distributed, making it an appropriate and sensitive method for evaluating equality of variance across groups.

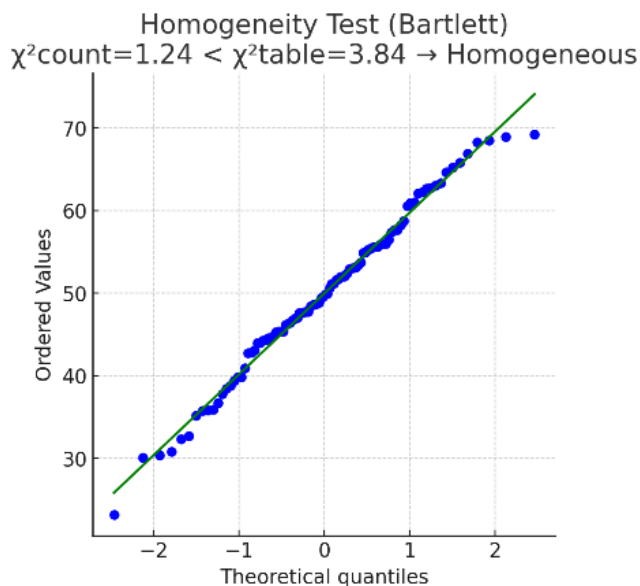


Fig. 4. Homogeneity Test Result

Figure 4 presents the results of the homogeneity test using the Bartlett method. The calculated value ($\chi^2_{count} = 1.24$) was lower than the critical value ($\chi^2_{table} = 3.84$, $\alpha = 0.05$), confirming that the variances of both groups were homogeneous.

This result indicates that the differences in learning outcomes between the experimental and control groups

cannot be attributed to unequal variances, but rather to the learning intervention itself. In other words, the statistical assumption of equal variance was met, strengthening the validity of subsequent hypothesis testing and ensuring that the observed differences more accurately reflect the impact of AWBIT.

F. Hypothesis Test

After the assumptions of normality and homogeneity were met, a hypothesis test was conducted to examine whether there was a statistically significant difference in learning outcomes between students who used Adaptive Web-Based Interactive Tutoring (AWBIT) and those who received conventional instruction. An independent samples t-test with a one-tailed significance level ($\alpha = 0.05$) was used, as the research hypothesis explicitly predicted that the experimental group's learning outcomes would be higher than those of the control group. This analysis aimed to determine the effectiveness of AWBIT in improving students' calculus achievement compared to traditional teaching methods.

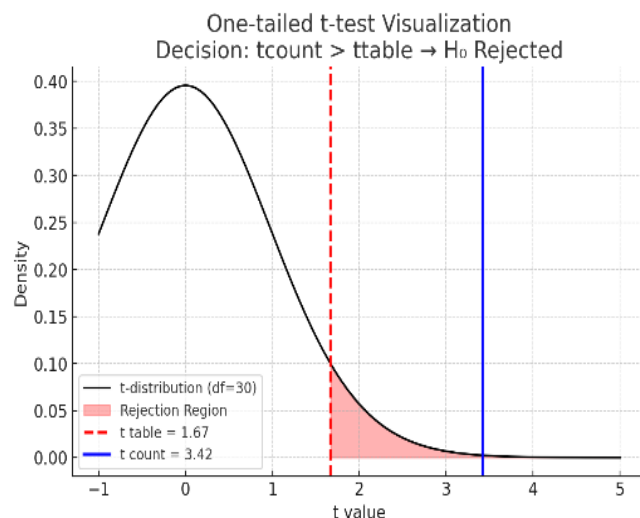


Fig. 5. Hypothesis Test Result

Figure 5 illustrates the distribution of the one-tailed t-test and the decision region used to evaluate the research hypothesis. The position of the calculated t-value ($t_{count} = 3.42$) well beyond the critical threshold ($t_{table} = 1.67$) places it clearly within the rejection region of the null hypothesis. This separation indicates not only statistical significance but also a substantial difference in learning outcomes between the experimental and control groups. The magnitude of this gap suggests that the observed effect is not marginal but reflects a meaningful instructional impact attributable to the AWBIT intervention.

From an educational perspective, these results imply that the adaptive and interactive mechanisms embedded in AWBIT effectively support students' conceptual engagement with calculus content. The system's ability to adjust learning pathways, provide immediate feedback, and offer varied representations of abstract concepts

appears to facilitate deeper cognitive processing (Fluck et al., 2020; Morris et al., 2024). This finding aligns with adaptive learning theory, which posits that personalized instructional responses enhance learning efficiency by reducing extraneous cognitive load and supporting self-regulated learning behaviors.

Furthermore, the rejection of the null hypothesis reinforces the robustness of the research design, given that prerequisite assumptions of normality and homogeneity were satisfied prior to hypothesis testing. This strengthens the internal validity of the findings and supports the appropriateness of using a parametric statistical approach. Consequently, the significant difference observed can be confidently attributed to the instructional treatment rather than random variation or measurement error (Ayob & Hamada, 2024). These findings confirm that an adaptive technology-based approach is not only feasible in design but also has a tangible impact on improving students' understanding of Calculus, particularly for those who face difficulties due to variations in learning styles and speeds.

Table 3. Average Learning Outcomes

Group	Average Pretest	Posttest Average	Gain Score
Experiment (AWBIT)	58,2	83,6	0,61
Control	57,8	72,3	0,34

Table 3 presents a comparative summary of students' learning outcomes in the experimental and control groups, based on their average pretest and posttest scores and normalized gain values. Both groups exhibited comparable initial abilities, as indicated by similar pretest averages (58.2 for the experimental group and 57.8 for the control group), suggesting that the two groups were relatively equivalent prior to the intervention. This equivalence strengthens the internal validity of the comparison, as post-intervention differences can be more confidently attributed to the instructional treatment.

Following the intervention, the experimental group that learned using Adaptive Web-Based Interactive Tutoring (AWBIT) demonstrated a substantial improvement, with the average post-test score increasing to 83.6 and a normalized gain score of 0.61, which falls within the medium improvement category. In contrast, the control group, which received conventional instruction, showed a more modest increase, with an average post-test score of 72.3 and a gain score of 0.34, categorized as low. The higher gain achieved by the experimental group indicates that AWBIT was more effective in facilitating meaningful learning progress compared to traditional teaching methods.

From a pedagogical perspective, the medium gain observed in the AWBIT group suggests that the system's adaptive mechanisms, such as personalized learning paths, immediate feedback, and interactive instructional content,

played a significant role in supporting students' understanding of abstract and cognitively demanding calculus concepts. These findings are aligned with adaptive learning theory, which posits that instruction tailored to learners' individual needs and learning pace can enhance conceptual mastery and reduce learning disparities. Practically, the results indicate that AWBIT is a viable and effective instructional model for improving student achievement in complex subject areas. Theoretically, the findings provide empirical support for the effectiveness of adaptive digital learning environments in higher education contexts.

The findings of this study provide strong support for adaptive learning theory (Saul et al., 2022; Zhilmagambetova & Kopeyev, 2023), which emphasizes that digital learning media should dynamically adjust instructional content and delivery to students' prior knowledge and learning needs. The significant improvement in the experimental group suggests that AWBIT's design, using interactive materials, quizzes, videos, and exercises, was successful in reducing the cognitive load of Calculus, thereby enabling students to grasp abstract and complex concepts more effectively (Oktaviyanthi & Agus, 2024; Ziatdinov & Valles, 2022).

The novel contribution of this study lies in positioning AWBIT not merely as an adaptive content delivery system but as an integrated web-based interactive tutoring model that simultaneously supports conceptual mastery and the development of digital literacy. Unlike most adaptive learning systems that emphasize personalized sequencing alone, AWBIT combines adaptivity, sustained interactivity, immediate feedback, and learner autonomy within a single platform. This integrated approach extends prior adaptive learning research by demonstrating that adaptive effectiveness in calculus learning is enhanced when personalization aligns with interactive and constructivist learning principles.

This aligns with, Purba & Saragih. (2023), who argue that technology-driven educational transformation enhances learning effectiveness through student engagement and meaningful experiences. AWBIT's flexibility in accessing materials, completing assignments, and receiving immediate feedback not only improves comprehension but also fosters learner autonomy. Avila et al., (2022) agree that the ability to provide timely feedback is particularly critical, as it prevents misconceptions from persisting and enhances the quality of self-regulated learning.

The positive student response ($M = 3.35$, strongly agree) further demonstrates that AWBIT is not only cognitively effective but also motivating. This confirms Mu√±oz et al. (2022), who show that adaptive platforms increase participation by granting students space for exploration and personalization. Motivation here functions as a mediating factor, transforming interaction with digital tools into meaningful learning gains, which explains why

the experimental group's outcomes improved significantly (Geng et al., 2020).

Validation from material and media experts (scores of 3.38 and 3.43, respectively) indicates that AWBIT meets both pedagogical and technical standards. This finding supports Hashmi et al. (2025) in their view that the success of web-based systems depends heavily on high-quality content and interactivity. Adhering to UX/UI principles suggests that AWBIT is not merely functional but also user-centered, ensuring long-term sustainability and scalability in higher education. Theoretically, these findings reinforce the integration of adaptive learning theory and constructivist frameworks by showing that adaptive systems can accommodate diverse learner profiles while maintaining uniform mastery objectives. Practically, AWBIT offers a replicable instructional model for courses with high cognitive demands, particularly in higher education contexts undergoing digital transformation.

In the context of mathematics learning, AWBIT addresses the persistent issue of conceptual abstraction. Embedding experiential tasks and interactive features, like the AR-based media tested by Cahyana et al. (2024) AWBIT, promotes active knowledge construction rather than passive reception. This experiential orientation aligns with constructivist principles, in which students engage in deeper cognitive processing, resulting in stronger mastery of abstract mathematical reasoning (Graafsma et al., 2023).

From an institutional perspective, AWBIT supports Outcome-Based Education (OBE), particularly its focus on the four literacies: data, technology, human, and language. This reinforces the point that adaptive LMS implementations can support flexible, student-centered learning. However, while this study shows that AWBIT contributes to digital literacy, future work should specify which dimensions, such as critical evaluation, online collaboration, or digital communication, are most directly improved (Song, 2020).

Despite these contributions, several limitations should be acknowledged. First, the quasi-experimental design and the relatively limited sample size restrict the generalizability of the findings. Second, the intervention was conducted within a single academic term, which may not fully capture the long-term effects of AWBIT on learning retention and sustained digital literacy development. Third, the study primarily relied on quantitative measures, limiting deeper insights into students' cognitive and metacognitive processes during adaptive learning.

Theoretically, the study strengthens both adaptive and constructivist frameworks by showing that adaptive systems can reconcile diverse learner profiles with uniform mastery goals in higher education. In practice, AWBIT offers a replicable model for high-cognitive-

demand courses while contributing to the broader agenda of digital transformation in universities. Its dual role as both a learning innovation and a digital literacy enhancer positions AWBIT as a strategic response to the demands of the digital era.

Overall, the results of this study demonstrate AWBIT's effectiveness in improving learning outcomes and digital literacy and highlight its broader significance for advancing higher education. By combining adaptivity, interactivity, and constructivist design, AWBIT represents a pedagogical innovation that prepares students to compete and contribute to increasingly digitized professional environments.

Future research is recommended to employ longitudinal and mixed method designs with larger, more diverse samples to examine the long-term impact of AWBIT across diverse learning contexts. Further studies should also investigate specific dimensions of digital literacy, such as critical evaluation, online collaboration, and digital communication, to clarify which competencies are most influenced by adaptive web-based tutoring systems. Additionally, examining AWBIT's effectiveness in other mathematical domains or disciplines would strengthen its scalability and transferability.”

IV. Conclusion

This study demonstrates that the implementation of Adaptive Web-Based Interactive Tutoring (AWBIT) represents an effective innovation in calculus learning within the Mathematics Education Department at the State University of Medan. The development and validation process confirms that AWBIT meets both pedagogical and technical standards, as evidenced by high evaluations from subject-matter and media experts. In addition, students' positive perceptions indicate that the platform is engaging, accessible, and supportive in facilitating the understanding of abstract calculus concepts, highlighting its practicality as a digital learning medium. Empirical findings further reveal that AWBIT significantly affects students' learning outcomes. The experimental group showed higher posttest scores and greater learning gains compared to the control group, with statistically significant differences between the two groups. These results indicate that adaptive web-based tutoring can effectively accommodate variations in students' learning pace and needs, thereby enhancing conceptual mastery more efficiently than conventional instructional approaches. The integration of interactive features and immediate feedback appears to play a crucial role in supporting students' active engagement and self-regulated learning. From a broader perspective, this research reinforces adaptive and constructivist learning theories by providing evidence that adaptive digital systems can support meaningful knowledge construction in higher education. The findings are also aligned with the principles of Outcome-Based Education and the Independent Learning, Independent Campus policy,

emphasizing the strategic role of technology in fostering essential 21st-century competencies. Overall, AWBIT not only improves academic achievement in calculus but also strengthens students' digital literacy, positioning it as a relevant and sustainable model for digitally enhanced learning in higher education.

References

- Abumosa, M. (2024). University Students' Perspectives on the Use of Interactive Presentation Technologies. *International Journal of Technology in Education and Science*, 8(4), 645–667. <https://doi.org/10.46328/ijtes.579>
- Ahmed, I., & Ishtiaq, S. (2021). Reliability and validity: Importance in Medical Research. *Journal of the Pakistan Medical Association*, 71(10), 2401–2406. <https://doi.org/10.47391/JPMA.06-861>
- Anshari, M., Almunawar, M. N., & de Pablos, P. O. (2025). Impacts of digital technologies across generations. In *Impacts of Digital Technologies Across Generations*. IGI Global. <https://doi.org/10.4018/979-8-3693-6366-9>
- Ariawan, I. P. W., Suyasa, P. W. A., Adiarta, A., Sukawijana, I. K. G., Santiyadnya, N., & Divayana, D. G. H. (2025). User Interface Design of Digital Test Based on Backward Chaining as a Measuring Tool for Students' Critical Thinking. *International Journal of Advanced Computer Science and Applications*, 16(1), 584–590. <https://doi.org/10.14569/IJACSA.2025.0160156>
- Avila, A.-G. N., Silva Feraud, I. F., Solano-Quinde, L. D., Zuniga-Prieto, M., Echeverria, V., & De Laet, T. (2022). Learning Analytics to Support the Provision of Feedback in Higher Education: a Systematic Literature Review. *2022 17th Latin American Conference on Learning Technologies, LACLO 2022*. <https://doi.org/10.1109/LACLO56648.2022.10013324>
- Ayob, H. H., & Hamada, T. I. (2024). Teaching mathematics in an EFL context at higher education; before, during and after the COVID-19 pandemic: a comparative study. *Journal of Applied Research in Higher Education*, 16(5), 2262–2272. <https://doi.org/10.1108/JARHE-05-2023-0186>
- Aziz, M. T., Hasan, L. M. U., & Rido'i, M. (2024). Analisis Kurikulum Bahasa Arab Berbasis 4C (Critical Thinking, Communication, Collaboration, Creativity) untuk Pengembangan Kompetensi Abad 21 pada Siswa. *DAARUS TSAQOFAH Jurnal Pendidikan Pascasarjana Universitas Qomaruddin*, 2(1), 216–222.
- Cahyana, U., Lestari, I., Irwanto, I., & Suroso, J. (2024). Development of a mobile learning network for science with augmented reality and its impact on students' literacy and numeracy. *International Journal of Innovative Research and Scientific Studies*, 7(2), 576–586.
- Chahine, R., & Aban, I. (2024). Likelihood-based inferences for trials incorporating participants' treatment choice. *Contemporary Clinical Trials Communications*, 39. <https://doi.org/10.1016/j.conctc.2024.101306>
- El Morr, C., Jammal, M., Ali-Hassan, H., & El-Hallak, W. (2022). Statistics. In *International Series in Operations Research and Management Science* (Vol. 334, pp. 45–60). Springer. https://doi.org/10.1007/978-3-031-16990-8_2
- Engelbrecht, J., & Borba, M. C. (2024). Recent developments in the use of digital technology in mathematics education. *ZDM - Mathematics Education*, 56(2), 281–292. <https://doi.org/10.1007/s11858-023-01530-2>
- England, A. (2022). Quantitative and qualitative research methods. In *Research for Medical Imaging and Radiation Sciences* (pp. 71–96). Springer International Publishing. https://doi.org/10.1007/978-3-030-79956-4_5
- Fluck, A. E., Ranmuthugala, D., Chin, C. K. H., Penesis, I., Chong, J., Yang, Y., & Ghous, A. (2020). Transforming learning with computers: Calculus for kids. *Education and Information Technologies*, 25(5), 3779–3796. <https://doi.org/10.1007/s10639-020-10136-0>
- Geng, X., Xu, Y., Chen, L., Ogata, H., Shimada, A., & Yamada, M. (2020). Learning analytics of the relationships among learning behaviors, learning performance, and motivation. In C. M., S. D.G., H. R., H. D., C. N.-S., K. K., & P. M. (Eds.), *Proceedings - IEEE 20th International Conference on Advanced Learning Technologies, ICALT 2020* (pp. 161–163). Institute of Electrical and Electronics Engineers Inc. <https://doi.org/10.1109/ICALT49669.2020.00054>
- Gökoglu, S., & Erdogdu, F. (2024). Virtual technology innovations in education. In *Virtual Technology Innovations in Education*. IGI Global. <https://doi.org/10.4018/979-8-3693-6030-9>
- Graafsma, I. L., Robidoux, S., Nickels, L., Roberts, M., Polito, V., Zhu, J. D., & Marinus, E. (2023). The cognition of programming: logical reasoning, algebra, and vocabulary skills predict programming performance following an introductory computing course. *Journal of Cognitive Psychology*, 35(3), 364–381. <https://doi.org/10.1080/20445911.2023.2166054>
- Gusteti, M. U. (2024). *Era Digital dalam Kelas Matematika: Menggabungkan Teknologi dengan Alat Peraga Tradisional*. Mega Press Nusantara.
- Harizah, Z., Kusairi, S., & Latifah, E. (2020). Students' critical thinking skills in interactive demonstration learning with web-based formative assessment. *Journal of Physics: Conference Series*, 1567(4). <https://doi.org/10.1088/1742-6596/1567/4/042038>
- Hashmi, N., Intaratat, K., Lomchavakarn, P., & Bansal, A. (2025). Enhancing Student Motivation and Engagement Through Human-Like Interactions and Natural Language Output. In B.-T. M., L. M. L., Z. V. M., M. L. S., T.-C. P., & D. B. (Eds.), *Communications in Computer and Information Science: Vol. 2457 CCIS* (pp. 67–87). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/978-3-031-89760-3_6
- Hjoujj, A. A. (2023). Social studies teachers' role in developing citizenship among secondary school students from teachers' point of view in Jordan. *Humanities and Social Sciences Letters*, 11(3), 322–337. <https://doi.org/10.18488/73.v11i3.3504>

- Hu, X., Xu, Y., Liao, H., & Ma, J. (2025). A Systematic Literature Review Study of Digital Transformation in Higher Education: Technologies, Challenges and Trends. *ICETM 2024 - Proceedings of the 2024 7th International Conference on Educational Technology Management*, 146–153. <https://doi.org/10.1145/37-11403.3711424>
- Huda, B., Paryono, T., & Fauzi, A. (2023). *UI/UX design: bagi para perancang dan pengembang produk atau layanan digital*. Asadel Liamsindo Teknologi.
- Hutain, J., & Michinov, N. (2022). Improving student engagement during in-person classes by using the functionalities of a digital learning environment. *Computers and Education*, 183. <https://doi.org/10.1016/j.compedu.2022.104496>
- Junaid, M., Zhong, W., Ghaffari, A. S., & Deng, X. (2025). Enhancing E-learning satisfaction in digital education: a comprehensive analysis of influential factors in Punjab's E-learning institutes. *Interactive Learning Environments*, 33(4), 2848–2860. <https://doi.org/10.1080/10494820.2024.2423176>
- Khlaif, Z. N., Ayyoub, A., Hamamra, B., Bensalem, E., Mitwally, M. A. A., Ayyoub, A., Hattab, M. K., & Shadid, F. (2024). University Teachers' Views on the Adoption and Integration of Generative AI Tools for Student Assessment in Higher Education. *Education Sciences*, 14(10). <https://doi.org/10.3390/educsci-14101090>
- Mansour, R. S., Desouky, O., & AbdelGawad, M. (2024). Exploring Artificial Intelligence Tools for Materials Science in Engineering: A Work-in-Progress in Undergraduate Classroom Integration. *ASEE Annual Conference and Exposition, Conference Proceedings*.
- Misra, P., & Srivastava, R. (2024). Digital Divide and Sustainable Development. In *World Sustainability Series: Vol. Part F3420* (pp. 451–472). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/978-3-031-68427-2_23
- Morris, D. D., Ma, H., & Dizaji, F. S. (2024). Exploring the Impact of Mastery Grading on Student Performance. *ASEE Annual Conference and Exposition, Conference Proceedings*.
- Morze, N., Varchenko-Trotsenko, L., Terletska, T., & Smyrnova-Trybulska, E. (2021). Implementation of adaptive learning at higher education institutions by means of Moodle LMS. *Journal of Physics: Conference Series*, 1840(1), 12062.
- Muhajir, M., & Rosadi, D. (2024). Integrating Decision Tree and BIRCH Clustering Algorithms of BERTopic for Analyzing Public Sentiment on Dirtyvote Movie. *Mathematical Modelling of Engineering Problems*, 11(12), 3391–3401. <https://doi.org/10.18280/mmep-111217>
- Muñoz, J. L. R., Ojeda, F. M., Jurado, D. L. A., Peña, P. F. P., Carranza, C. P. M., Berríos, H. Q., Molina, S. U., Farfan, A. R. M., Arias-González, J. L., & Vásquez-Pauca, M. J. (2022). Systematic review of adaptive learning technology for learning in higher education. *Eurasian Journal of Educational Research*, 98(98), 221–233.
- Oktaviyanthi, R., & Agus, R. N. (2024). Exploring the link between cognitive load and brain activity during calculus learning through electroencephalogram (EEG): Insights from visualization and cluster analysis. *Journal on Mathematics Education*, 15(4), 1383–1408. <https://doi.org/10.22342/jme.v15i4.pp1383-1408>
- Pare, A., & Sihotang, H. (2023). Pendidikan holistik untuk mengembangkan keterampilan abad 21 dalam menghadapi tantangan era digital. *Jurnal Pendidikan Tambusai*, 7(3), 27778.
- Patil, A. A., Joshi, H., Shinde, P., Jadhav, J., & Pise, G. (2024). Adaptive Tutoring Systems: Crafting Personalized Learning Experiences. *2024 2nd International Conference on Advances in Computation, Communication and Information Technology, ICAICCIT 2024*, 261–266. <https://doi.org/10.1109/ICAICCIT64383.2024.10912102>
- Peña, C. M. L., Huisacayna, M. V. P., Talavera-Mendoza, F., & Serrano-Rodríguez, R. (2021). Interactive and Ubiquitous Audiovisual Media in Solving Verbal Arithmetic Problems. In A. Garcia-Holgado, F. J. Garcia-Penalvo, S. C. S. Carina, A. Infante-Moro, & J. C. Infante-Moro (Eds.), *Proceedings - 11th International Conference on Virtual Campus, JICV 2021*. Institute of Electrical and Electronics Engineers Inc. <https://doi.org/10.1109/JICV53222.2021.9600421>
- Peng, L., Deng, Y., & Jin, S. (2022). The Evaluation of Active Learning Classrooms: Impact of Spatial Factors on Students' Learning Experience and Learning Engagement. *Sustainability (Switzerland)*, 14(8). <https://doi.org/10.3390/su14084839>
- Pérez-Rivero, C. A., de Obesso, M. D. L. M., & Núñez-Canal, M. (2023). Digital competence among university professors: analysis of the impact of the COVID crisis. *Economic Research-Ekonomska Istrazivanja*, 36(3). <https://doi.org/10.1080/1331677X.2022.2155859>
- Purba, A., & Saragih, A. (2023). Peran Teknologi dalam Transformasi Pendidikan Bahasa Indonesia di Era Digital. *All Fields of Science Journal Liaison Academia and Society*, 3(3), 43–52.
- Razilu, Z. (2025). *Inovasi Pembelajaran Integrasi Artificial Intelligence dalam Teknologi Pendidikan*. Penerbit Widina.
- Ritter, F., & Standl, B. (2025). Enhancing Algorithmic Thinking Through Semantic Waves: Integrating Necessity Learning Design in Computer Science Education. *IEEE Global Engineering Education Conference, EDUCON*. <https://doi.org/10.1109/EDUCON62633.2025.11016370>
- Saul, K., Howard, A. K. T., Webster, Z., & Spencer, D. (2022). An Adaptive Learning Engineering Mechanics Curricular Sequence. *ASEE Annual Conference and Exposition, Conference Proceedings*.
- Song, M. (2020). Integrated STEM teaching competencies and performances as perceived by secondary teachers in South Korea. *International Journal of Comparative Education and Development*, 22(2), 131–146. <https://doi.org/10.1108/IJCED-02-2019-0016>

- Sulianta, F., & Saudi, M. H. (2021). The Growth of Citizenship Geographical Education in Indonesia from the Social Studies Curriculum. *Review of International Geographical Education Online*, 11(3), 72–78. <https://doi.org/10.33403/rigeo.800470>
- Suryono, Y. (2021). Development of project-based historical knowledge assessment instruments. *Historical Encounters*, 8(1), 16–29. <https://doi.org/10.52289/hej8.102>
- Terán-García, E., & Pérez-Fernández, R. (2024). A robust alternative to the Lilliefors test of normality. *Journal of Statistical Computation and Simulation*, 94(7), 1494–1512. <https://doi.org/10.1080/00949655.2023.2291138>
- Voleti, S. S. (2024). Nonrandomized controlled study. In *Translational Orthopedics* (pp. 243–248). Elsevier. <https://doi.org/10.1016/B978-0-323-85663-8.00013-1>
- Vorotnykova, I. P., Morze, N. V., & Hrynevych, L. M. (2023). Digital transformation of secondary education of Ukraine and the quality of teaching natural and mathematical sciences in the conditions of war. In V. T.A., 103 Chudnivsyka Str. Zhytomyr State Polytechnic University Zhytomyr, O. V.V., 18/2 Bulvarno-Kudriavska Str. Borys Grinchenko Kyiv University Kyiv, P.O., & 9 M Berlynskoho Str. Institute for Digitalisation of Education of the NAES of Ukraine, Kyiv (Eds.), *CEUR Workshop Proceedings* (Vol. 3553, pp. 57–74). CEUR-WS.
- Wang, Q. (2025). An AI-driven, autonomous, interactive English learning language tutoring system. *Journal of Computational Methods in Sciences and Engineering*, 25(2), 1155–1166. <https://doi.org/10.1177/14727978-241296719>
- Weigand, H.-G., Trgalova, J., & Tabach, M. (2024). Mathematics teaching, learning, and assessment in the digital age. *ZDM - Mathematics Education*, 56(4), 525–541. <https://doi.org/10.1007/s11858-024-01612-9>
- Whitworth, A. (2020). Fostering digital skills and competencies through discursive mapping of information landscapes. In *European Higher Education Area: Challenges for a New Decade* (pp. 531–543). Springer International Publishing. https://doi.org/10.1007/978-3-030-56316-5_33
- Wu, L., & Zhao, C. (2024). Descriptive statistics of continuous variables. In *Textbook of Medical Statistics: For Medical Students* (pp. 45–61). Springer. https://doi.org/10.1007/978-981-99-7390-3_4
- Yanev, A. Y. (2021). Developing and integrating new modules for a web-based education platform. *2021 17th Conference on Electrical Machines, Drives and Power Systems, ELMA 2021 - Proceedings*. <https://doi.org/10.1109/ELMA52514.2021.9502995>
- Zhang, Y., Ahmed, A., Liang, H.-N., & Baghaei, N. (2023). Exploring the Transformative Potential of Virtual Reality in History Education: A Scoping Review. In H. Xie, L. C.-L., W. Chen, G. Xu, & E. Popescu (Eds.), *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics): Vol. 14409 LNCS* (pp. 107–121). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/978-981-99-8385-8_9
- Zhilmagambetova, R., & Kopeyev, Z. (2023). Personalized adaptive learning: analysis, comparison, conclusions. *«Вестник НАН РК»*, 403(3), 102–113.
- Zhu, Y., Jafari, A., Behzadan, A. H., & Issa, R. R. A. (2024). A Roadmap to the Next-Generation Technology-Enabled Learning-Centered Environments in AEC Education. *Journal of Civil Engineering Education*, 150(3). <https://doi.org/10.1061/JCEECD.EIENG-19-72>
- Ziatdinov, R., & Valles, J. R. (2022). Synthesis of Modeling, Visualization, and Programming in GeoGebra as an Effective Approach for Teaching and Learning STEM Topics. In *Mathematics* (Vol. 10, Issue 3). <https://doi.org/10.3390/math10030398>.