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PRIMARY RESEARCH

Optimizing student outcomes in digital learning: The combined effects of adaptive technologies, engagement, and digital literacy

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Abstract
The study explores the use of adaptive learning technologies to examine the moderation and mediation role of digital literacy and student engagement. Given the educational context, it's difficult to understand how adaptive learning technologies engage students in learning or coursework. This study will focus on 344 Iraqi graduate and undergraduate public and private university students. Drawing on social constructivist theory, the study investigates how adaptive learning technologies significantly enhance creative thinking and academic performance through students' engagement and improvement in digital literacy. The findings show that adaptive learning technologies have a direct impact on student engagement. However, student engagement mediates the relationship among adaptive learning technologies, creative thinking, and academic performance. Furthermore, digital literacy moderates the relationship between students' engagement, creative thinking, and academic performance. This research acknowledges that teachers should integrate these tools into their courses in a way that synergizes with students' digital skills. Students should be actively encouraged to develop their critical awareness by learning about vulnerability and seeing the world through the gaze of community partners.

INTRODUCTION

The increasing adoption of digital learning environments necessitates a careful examination of which components best facilitate learning success for students. As institutions of education continue to deploy more sophisticated technology, the role of passive content consumption is being replaced with more personalized and active learning experiences (Soelistianto et al., 2024). This technological change further points to an important gap in existing literature: that is, understanding the psychological and structural complexities that occur when educational technology is invested in and result in genuine learning outcomes. The education field can greatly benefit from predicting student performance early. A variety of studies have been completed in the field of education to look at how students engage with learning systems and predict student performance. By predicting early student performance, postsecondary institutions can determine whether the student will or will not be successful during their enrollment period (Pavlov et al., 2024).

Globalization, the quick advancement of knowledge and technology, and economic expansion. Students must be prepared by education to deal with societal realities, global concerns, and upcoming research. Students who

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receive a high-quality education are more likely to acquire critical thinking abilities (Widiastuti et al., 2023). Thinking exercises will develop a mindset during the learning process that serves as both the primary goal of learning and is helpful in the future (Putri et al., 2023). Critical and creative thinking skills are crucial for students to acquire in order to fulfil the demands of the twenty-first century (Gulzar et al., 2022). The ability to think critically and creatively is essential for general cognitive and intellectual advancement (Mursid et al., 2022). Students have to use critical and creative thinking abilities to make decisions and solve challenges that arise in their lives thoroughly (Almulla, 2023). Students with critical thinking abilities will be able to link and assess all facets of the issue, think logically, acquire analytical skills, and make decisions when faced with a variety of possibilities (Chen et al., 2022; Widiastuti et al., 2023).

Adaptive learning technologies have emerged as efficient tools, actively modifying curriculum materials and approaches based on an individual student's needs (Soelistianto et al., 2024). The project incorporates a focus on interactive AI tools and adaptive learning technology to remove barriers to educational success and create inclusive educational environments to support all types of students, including those from diverse backgrounds (Godwin Olaoye et al., 2024). Likewise, individualized feedback is vital to the learning process as it provides students with customized replies about their performance, which, in turn, supports students in developing their skills and understanding of concepts. Adaptive learning technologies leverage AI algorithms to process student data in real-time and create an individualized learning experience that considers different learning modalities, speeds, and levels of comprehension (Xiaoyu & Tobias, 2023). These technologies can adjust instructional strategies and content delivery based on a student's unique set of strengths and weaknesses, to ensure every learner obtains meaningful support to create success. In addition to increasing understanding and retention, this personalized approach significantly increases student engagement and creates an experience that is more active and motivating (Dutta et al., 2024).

Academic achievement is a major concern for students at HEIs (Agaoglu et al., 2025). Determining the elements that influence student success is therefore essential. It has long been known that a key factor influencing student achievement is student involvement. "The quality and quantity of students' psychological, cognitive, emotional, and behavioural reactions to in-class and out-of-class academic and social activities to achieve successful learning outcomes" is how Godwin Olaoye et al. (2024) defined student engagement. Students who are actively involved in their education are probably motivated to work hard, show up to class, and participate in other educational activities. They typically communicate their thoughts, take part in class discussions, use digital learning resources, and are eager to learn new things. Successful students are those who devote a great deal of effort to their education (Pavlov et al., 2024). Nevertheless, despite the benefits of student engagement being reported in the literature, its empirical relationship to academic success has not been sufficiently investigated (Lee, 2014). Thus, the purpose of this study is to evaluate how student engagement affects academic achievement (Assem et al., 2023; Wani & Ismail, 2024).

The effectiveness of engagement in the digital space is not consistent; it is dependent on the ability of the learner to navigate and use the tools presented. Digital Literacy, which encompasses the technical, cognitive, and social skills necessary to use, evaluate, and create information in digital contexts, provides the skills to a proficiency level for complete digital engagement. In past research, engagement and technology use have often been treated as universal variables, neglecting the moderating effect of preparation (Liu et al., 2024; Tekesbaeva et al., 2023). However, in order to fully utilize these technologies, students must have a balanced level of digital literacy, which will also determine how well these tools can foster engagement. Digital literacy encompasses not only what you do with technology but also what you know and can do with it, as well as how you can use it to improve learning. More sophisticated digital abilities put students in a better position to strategically use interactive AI tools, personalised feedback, and adaptive learn-

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ing technology, which increases their chances of succeeding academically.

This learning theory illustrates how people learn socially through social contact and in a social setting, building on social constructivism theory (Lombardo & Kantola, 2021). According to this view, learning is a collaborative, interactive process in which people build knowledge with the support of their social surroundings (Kim, 2001). Therefore, technology tools play a critical role in facilitating these venues where students can co-construct knowledge as these social interactions occur (Agius et al., 2013). For example, students participate in the process of knowledge co-creation during the learning process when they interact with AI-powered tools or receive personalised feedback (Mursid et al., 2022). However, even though these tools present faculty with incredible opportunities, their effectiveness in fostering student participation depends on the students' level of digital literacy (Liu et al., 2023). According to earlier studies, students with lower levels of digital literacy may find it difficult to use AI tools and adaptive technology to gain meaningful access to instructional content. Along the way, it will also help us better understand how digital literacy helps make these tools appropriate for a variety of students.

LITERATURE REVIEW

Social Constructivism Theory

Social constructivism argues that knowledge is not passively absorbed, but rather created by the learner through experiences with their surroundings and social context (Kim, 2001). A central idea of this theory is mediation, which implies that learning depends on "tools and signs", cultural artifacts such as languages, symbols, and technologies that help shift the transformations of mental functions from the social plane to an individual's plane (Agius et al., 2013). In an example of digital education, the adaptive learning system itself mediates the learning experience as a complex mediating artifact that actively organizes the learning environment to promote active construction of knowledge over oversimplified recall. Through continuous assessment and adaptive difficulty, AL systems model the constructivist design principle of scaffolding knowledge by always shifting the instructional "support" to maintain the learner (Lombardo & Kantola, 2021). The "tools and signs" in the digital context, including the AL platform, data visualizations, navigation features, and communication features, are also complex (Liu et al., 2024). Therefore, a student with developed digital literacy will naturally use these mediators more effectively and more fully realize their creative thinking and academic performance as a result. Conversely, a student who struggles with the digital interface will diminish their engagement efforts because of the cognitive demands of using tools in an area with which they already struggle. Therefore, it is hypothesised that an individual's digital competency either fundamentally strengthens or weakens their potential for successful knowledge construction (Dutta et al., 2024).

Additionally, a conceptual model based on the ideas of social constructivism theory is proposed in this work, with a focus on the social and collaborative components of learning. The social constructivist theory of scaffolding is used by adaptive learning technology (Agius et al., 2013; Kim, 2001). By tailoring content, pace, and difficulty to each learner's needs, these technologies help students close the gap between their present comprehension of the subject matter and the intended learning outcomes. Soelistianto et al. (2024) contend that adaptive systems will slowly provide students with opportunities to interact with the system until they move to the next tier. This aligns nicely with the social constructivist instructional model, which values both collaboration in real time and problem-solving. These resources allow students to engage with content in fluid, simulated social interactions. More importantly, the resources facilitate the types of metacognitive tasks essential for deep engagement and the building of knowledge, such as participation and reflection. Students paired with peers with higher levels of digital literacy will have the greatest benefit from these resources, and as student pairs interact and learn from each other, student engagement will increase in addition to the outcomes (Park et al., 2024). Conversely, students who only have lower levels of digital literacy may not fully use these educational strategies, which could inhibit their

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ability to engage and learn. The next aim of this research is to determine the impact that digital literacy levels have on student engagement and usage of digital tools.

Adaptive Learning Technologies and Student Engagement

The educational delivery is undergoing significant changes due to adaptive learning technologies (Essa et al., 2023). Adaptive learning technologies utilize data analytics and algorithms to customize the learning experience to individual student needs and performance. Based on real-time feedback from students' interactions with the adaptation systems, adaptive learning systems can adapt the quantity, pace, and mode of delivery, which is all determined within the context of the session they are in. The adaptive learning systems, therefore, enhance learning outcomes by providing students with a learning method that matches their needs and learning preferences to enhance the learning process (Tekesbaeva et al., 2023). Pavlov et al. (2024) identify that a myriad of adaptive learning style-based products promote an increase in student engagement, which attends to their individual needs and preferences. Similarly, Godwin Olaoye et al. (2024) discovered that adaptive learning technologies support teaching and allow teachers to adapt to the learning environment for their learners in order to provide appropriately challenging opportunities for students depending on their skill levels. Adaptive learning is also valuable within large educational contexts where traditional non-adaptive methods are proven to be ineffective. According to Xiaoyu and Tobias (2023), students retain the information longer when using adaptive learning systems because of the personalised and instantaneous feedback they receive. According to Wang et al. (2023), personalised, real-time feedback in adaptive learning systems is more effective in maintaining students' focus on the subject matter, with greater increases in information retention.

In addition to customizing the content, a vital aspect of how AL makes its mark on engagement is through the delivery of real-time, specific feedback and interactive mechanisms (Liu et al., 2023). Adaptive systems, typically powered by some form of AI, provide immediate diagnostic information about student response processes leading to timely self-correction opportunities, which is an ongoing cycle of mastery-action (Godwin Olaoye et al., 2024). This immediate, actionable feedback is a principal component of an effective learning environment, shown to stimulate student motivation and active engagement (Rahmawati et al., 2022; Xiaoyu & Tobias, 2023). In addition, the interactivity of these alternative learning systems requires learners to make decisions and solve problems on a routine basis, and this prompts deeper levels of behavioral engagement and involvement (Yaseen et al., 2025). Hanaysha et al. (2023) state that the positive effect is sometimes assessed based on student perception, as opposed to being objective and strictly grade-based. Gulzar et al. (2022), the overwhelming majority of studies affirm the premise that the proactive, responsive nature of AL systems is a robust motivating influence on student motivation and sustained engagement throughout the learning phase.

H1: Adaptive learning technologies have a direct impact on student engagement.

Student Engagement as Mediating

The degree of student engagement largely determines a student's learning outcomes, including academic performance (Gulzar et al., 2022). The point at which pupils are emotionally, behaviourally, and cognitively engaged in the learning process is its broadest definition (Xiaoyu & Tobias, 2023). Engagement in schoolwork has three dimensions: behavioural engagement is the student's actual participation in classroom activities; cognitive engagement is the student's level of effort applied in learning difficult material; and emotional engagement is the student's feelings concerning interest and a sense of belonging in the educational context (Godwin Olaoye et al., 2024). It has also been shown that students who are more engaged in their education perform better in school, retain information longer, and are more satisfied with their educational experience (Almulla, 2023). Adaptive learning systems, such as interactive AI tools and various ways of providing feedback to students in person-

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alized ways, can also enhance the students' interest in the educational process (Putri et al., 2023). Such technologies also provide students with greater autonomy over their education and a greater emphasis on student-centered education. Educators using these strategies can create environments wherein the functionality of a student's learning is catered to meet their particular needs and preferences, contributing to the student's ability to engage in the educational experience as a whole (Dutta et al., 2024). Adaptive learning technologies help engage students by customizing the educational experience to an individual student's curricular needs and learning preferences. These systems allow students to progress at their own speed, which may promote competence and autonomy (Lo et al., 2024). Soelistianto et al. (2024) showed that adaptive learning systems significantly increased student engagement by tailoring the learning to each student's unique preferences and speed.

Creative thinking is typically described as the cognitive process of producing ideas or solutions that are original and relevant (Gulzar et al., 2022), therefore demanding a degree of cognitive effort, rather than just recall. Many studies have demonstrated that high levels of student engagement, and in particular cognitive engagement (e.g., exerting effort, employing deep strategies, persisting), are associated with the development of creativity and higher-order thinking(Agaoglu et al., 2025). Nonetheless, the effectiveness of technology to enhance creativity is not guaranteed; effectiveness is related to students' level of participation and their level of motivation (Putri et al., 2023). For example, a technology-enhanced adaptive system may require students to engage with an existing topic, requiring open-ended problem-solving in cohort groups, but creativity will only be enhanced if students are behaviorally and cognitively engaged in the problem-solving task (Widiastuti et al., 2023). The technology serves as the AL, but engagement is the agency that mediates the interaction between the learners and the complex learning task that produces a CT outcome (Mursid et al., 2022).

Students can now participate in immersive and flexible learning environments thanks to interactive AI tools (Hanaysha et al., 2023; Jam et al., 2018). These tools provide students with real-time, context-specific feedback while adjusting task complexity based on their educational levels. This promotes cognitive engagement and improves students' comprehension of the material. Azhar et al. (2022) and Liu et al. (2023) demonstrated how AI-powered interventions improve group performance, teamwork, and knowledge acquisition in the classroom. Although they are linked, engagement and interaction are not the same thing. While engagement refers to a learner's more comprehensive and all-encompassing emotional, behavioural, and cognitive interest in the learning activity, interaction refers to direct exchanges between students and their classmates, teachers, and technological instruments (Xiaoyu & Tobias, 2023). For example, even though using an AI tool can give feedback right away, students cannot effectively internalize and act upon it if there is insufficient contact.

Hanaysha et al. (2023) have consistently asserted that the time, effort, and emotion (engagement) a student dedicates to his or her education are the most powerful proximal predictors of student success and achievement. Thus, when ALT increases a student's motivation and participation, engagement results in better comprehension of content, improved performance on assessments, and ultimately improved student grades. In this sense, ALT is a distal variable and its positive impact must flow through the proximal behavioral (and psychological) pathways of engagement to produce the desired performance outcomes (Dutta et al., 2024; Godwin Olaoye et al., 2024). Adaptive learning technologies, like AI-based adaptive learning platforms, revealed that while platform characteristics impacted educational quality directly, they also impacted educational quality indirectly, in a stepwise sequence, through self-regulated learning and, importantly, through learning engagement (Xiaoyu & Tobias, 2023). This systematic evidence supports our hypothesis that the interactive and personalized nature of AL technologies (literally, such as immediate feedback or personalized content) primarily works through improved active engagement in deeper forms of learning, which ultimately produces a measurable impact on academic per-

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formance and outcomes (Pavlov et al., 2024; Soelistianto et al., 2024).

H2: Student engagement has a mediating relationship between adaptive learning technologies and creative thinking.

H3: Student engagement has a mediating relationship between adaptive learning technologies and academic performance.

Digital Literacy as Moderating

Researcher defines digital literacy as the capacity to behave intentionally, appropriately, successfully, and with critical awareness while interacting with information and communication technology. For students to fully benefit from tools like AI-driven feedback mechanisms and adaptive learning systems, digital literacy is becoming more and more crucial as technology is used in education. Lo et al. (2024) showed that students with high levels of digital literacy are prepared to use technology in the classroom more successfully, leading to improved learning, engagement, and academic performance. More digitally competent students are expected to benefit more from AI technologies and the associated personalised feedback, which will increase learning outcomes and student engagement. Other ”low-tech” forms were found to be deficient, but students with low digital literacy might not use these technologies effectively, restricting participation (Lo et al., 2024). However, students with lower levels of digital literacy struggle to use these tools, which makes it harder for them to interact with them and results in a less useful platform. Because of its ability to either increase or decrease the influence of these tools on student engagement, digital literacy plays a moderating role. This is in line with other research showing that any connection with other cutting-edge learning systems requires digital literacy (Wani & Ismail, 2024).

However, in modern education contexts, particularly for blended or fully remote learning, the rationale suggests digital literacy is significant in this relationship (Hanaysha et al., 2023). The rationale suggests that engaged effort will only lead to high performance when a student has the ability to engage and utilize digital fluency in the digital-learning context (Dutta et al., 2024). Rahmawati et al. (2022) found that while engagement was consistent between groups, students with a high level of digital literacy were able to maintain a significantly more productive performance growth rate by unlocking their engaged effort by applying engagement strategies that directed limited time and used effective and efficient skills to focus on purpose. This engagement ability in digital literacies leads to a student’s limited time being spent learning content instead of struggling with the medium (Liu et al., 2023). In addition, high levels of digital literacy provide students with the aptitude to customize their learning experience by utilizing digital resources, finding their own supplementary materials, and using analytical tools to reflect and monitor their own progress; skills that contribute to both cognitive engagement and being highly effective and productive (Simon et al., 2022).

When a student is engaged, high digital literacy is an enabling factor because it allows the student to go beyond traditional forms of creative output (e.g., paper reports) and utilize advanced digital tools (e.g., 3D modeling, coding, interactive presentations) to demonstrate divergent thinking (Mursid et al., 2022). Absent this moderating skill, the highly engaged, creative student is likely to find his or her creative output structurally limited because the student is unable to utilize the latest and most powerful forms of creative expression, which diminishes the predictive power of cognitive engagement on observable or measurable creative output. Widiastuti et al. (2023) found that, while engaged students did demonstrate basic, underlying creative tendencies, only those with higher digital literacy were able to effectively manage ambiguity with high-level digital tools to rapidly iterate on their ideas, which are critical components of all high-level creative thinking. Agaoglu et al. (2025) show that the effectiveness of cognitive engagement on creativity is conditional on the learner’s ability to navigate the digital landscape that is the primary medium for both information gathering and creative production in most areas.

Previous research has thoroughly studied specific elements, such as interactive AI tools, personalised feed-

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back, and adaptive learning technologies, for enhancing student engagement independently of other aspects (Tekesbaeva et al., 2023). It has been demonstrated that adaptive learning technologies, including adaptive hypermedia, which base content on students' learning styles, scaffold students' cognitive and emotional engagement with course material. Research on tailored feedback also shows that it might encourage students and help them develop a growth mindset (Ryu et al., 2022; Wagbara, 2022). Nevertheless, unifying frameworks have not examined how these elements interact to affect student involvement. By examining how different technologies are combined to improve student engagement and comprehending the intricate relationships between these technologies outside of individual settings, our study seeks to close this gap. Additionally, this study suggests digital literacy as a mediator that has received little attention in the literature. While prior research acknowledges the importance of digital literacy in using technological tools, it does not thoroughly examine how these technologies affect student engagement and how digital literacy may either increase or decrease the impact of these tools (Liu et al., 2023).

H4: Digital literacy has a moderating relationship with student engagement and creative thinking.

H5: Digital literacy has a moderating relationship with student engagement and academic performance.

Conceptual Framework

In this study, Consistent with social constructivism, the conceptual model (Figure 1) was used to evaluate the impact of independent variables, such as adaptive learning technologies, on creative thinking and academic performance, with one moderator variable of digital literacy and one mediator variable of student engagement. The model was produced based on a theory that was developed before, and serves to facilitate an analysis of how each variable might affect student engagement with creative thinking and academic performance.

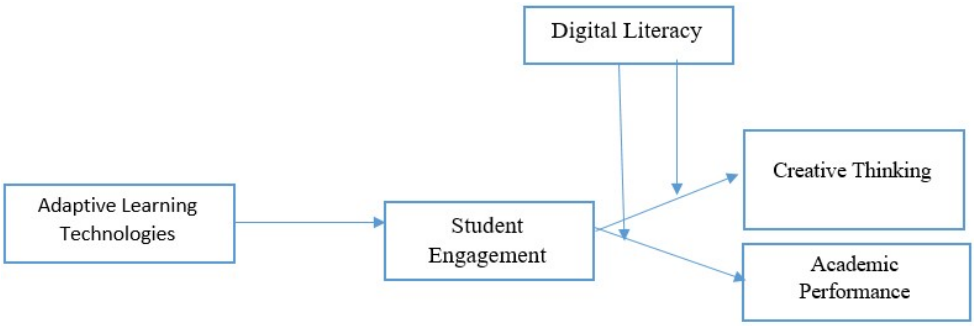

FIGURE 1. Conceptual model

RESEARCH METHODOLOGY

Research Design

A quantitative, cross-sectional survey design was used in this study to assess the conceptual model (Figure 1) that was hypothesized. As per the principles of social constructivism, the model assesses the relationships between the independent variable (adaptive learning technologies) and the dependent variables (creative thinking and academic performance) as mediated by student engagement and was moderated by digital literacy. Data was obtained using a cross-sectional approach, where data was obtained at a single point in time, to examine the relationships and conditional effects of the constructs simultaneously in a single study. All measurement instruments used in the study survey were adopted and adapted from previous studies and validated studies to confirm the reliability and construct validity of the instrumentation in a learning context.

Data Collection and Measurements

Data were gathered using a structured online questionnaire distributed via the university mailing lists, online learning environments, and social media channels associated with the participating higher education institutions.

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All responses were measured on a 5-point Likert-type scale, with responses ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). Adaptive learning technologies have measured 5 items, which were developed. Student engagement was assessed using 5 items, measured. Digital literacy was gauged with 5 items developed. Creative thinking has been measured by 5 items, which were developed by Agaoglu et al. (2025). Lastly, academic performance was assessed using 4 items, measured by Caratiquit and Caratiquit (2023).

Participants

The sample included 344 students who were either undergraduate or graduate students. All the participants were included in the study from both public and private universities in Iraq. This sampling strategy was intended to ensure variety and consistency. Participants were selected to include the breadth of educational experiences, such as those from larger universities. Participation for selection occurred based on two main eligibility requirements: Participants must have had experience with at least one of the digital learning tools listed (within the last six months), such as Adaptive Learning Technologies, personalized feedback mechanisms, systems, or interactive AI tools. All students gave voluntary consent, and informed consent was obtained for every student selected.

The final sample was adjusted to make it better suited to represent diversity in gender and education levels to improve the generalizability of the findings for academic contexts. The demographic profile of the final sample is provided in Table 1.

TABLE 1. Demographic characteristics of participants (*N*=344)

Variable	Category	Frequency (*n*)	Percentage (%)
Gender	Male	165	47.97
	Female	179	52.03
Educational Level	Undergraduate	258	75.00
	Graduate	86	25.00
University Type	Public	200	58.14
	Private	144	41.86

RESULTS

Validity, Reliability, and AVE of Constructs

SmartPLS 3.0 was used to make this analysis easier. Using this software, the raw data was analysed to see how consistently elements inside latent factors related to the target concepts. To evaluate the validity and reliability of questionnaire variables, we employed statistical techniques suggested by partial least squares (Hair et al., 2024). Cronbach's alpha assesses the internal consistency of measurement items within a factor (Cronbach's alpha >0.70). Conversely, Composite Reliability (CR) accounts for factor loadings while calculating dependability. Lastly, the AVE of each generated value is more than the designated cutoff limit, or AVE>0.50 (Hair et al., 2024).

TABLE 2. Results of measurement model

Constructs	Cronbach's Alpha	Rho_A	Composite Reliability	Average Variance Extracted (AVE)
Adaptive Learning Technologies	0.826	0.830	0.878	0.591
Academic Performance	0.892	0.899	0.925	0.756
Creative Thinking	0.932	0.937	0.949	0.788
Digital Literacy	0.945	0.946	0.958	0.820
Student Engagement	0.862	0.876	0.903	0.654

The evaluation of the measurement model confirms that all constructs used in this study have reliability and convergent validity (Table 2). The scales were all deemed to have excellent internal consistency with Cronbach's Al-

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pha values ranging from 0.826 (adaptive learning technologies) to 0.945 (digital literacy), and composite reliability values ranging from 0.878 to 0.958. Additionally, the values of Rho_A were all around the same or greater than both measures. These estimates indicate that all the items for each construct were highly consistent, and the instruments reliably measure the construct of interest, since all estimates are substantially higher than the traditional estimate of 0.70. Moreover, the measures strongly established convergent validity since the average variance extracted was well above the recommended minimum threshold of 0.50 across the board. The AVE estimates ranged from 0.591 (adaptive learning technologies) to 0.820 (digital literacy), thus confirming that items converged on their respective constructs and that the measures are valid and warrant working with in testing the provided hypotheses.

Discriminant Validity

In order to determine the uniqueness of various characteristics, discriminant validity was also investigated. We looked at our proposed construction's discriminant validity in addition to its convergent validity. We examined the AVE for each of our constructs. Each construct's AVE performs better than the correlations between constructs. The AVE > inter-construct correlations showed no discriminant validity issues (Fornell & Larcker, 1981). Each construct's AVE (bold and diagonal) is higher than the variable correlation, according to the inter-construct correlation matrix (Table 3).

TABLE 3. Discriminant Validity

	1	2	3	4	5
Adaptive Learning Technologies	0.769				
Academic Performance	0.472	0.869			
Creative Thinking	0.464	0.753	0.888		
Digital Literacy	0.441	0.789	0.777	0.906	
Student Engagement	0.595	0.700	0.700	0.788	0.809

Cross-Loading

We concluded that there were no cross-loading issues because all values were higher than the permissible threshold for cross-loading between constructs (Hair et al., 2024). Each built component's cross-loading is displayed in Table 4. There are no notable cross-loading issues, which leads to a "high level of discriminant validity".

TABLE 4. Cross-Loading

	ALT	AP	CT	DL	SE
ALT1	0.814	0.405	0.398	0.370	0.463
ALT2	0.731	0.301	0.349	0.323	0.432
ALT3	0.748	0.301	0.272	0.212	0.395
ALT4	0.824	0.389	0.356	0.323	0.494
ALT5	0.723	0.403	0.394	0.443	0.490
AP1	0.332	0.885	0.652	0.654	0.544
AP2	0.489	0.799	0.610	0.568	0.675
AP3	0.430	0.894	0.686	0.755	0.590
AP4	0.399	0.895	0.666	0.748	0.631
CT1	0.425	0.637	0.839	0.578	0.623
CT2	0.437	0.733	0.912	0.727	0.576
CT3	0.430	0.722	0.928	0.733	0.657
CT4	0.433	0.663	0.908	0.729	0.667
CT5	0.333	0.581	0.848	0.667	0.581
DL1	0.387	0.719	0.709	0.909	0.650
DL2	0.371	0.717	0.665	0.902	0.737
DL3	0.372	0.646	0.685	0.908	0.709
DL4	0.444	0.709	0.748	0.911	0.760
DL5	0.417	0.776	0.707	0.898	0.713
SE1	0.401	0.388	0.477	0.505	0.897
SE2	0.531	0.608	0.568	0.648	0.851
SE3	0.497	0.559	0.569	0.670	0.823
SE4	0.470	0.583	0.597	0.677	0.866
SE5	0.499	0.656	0.609	0.673	0.874

Structural Model Evaluation

SmartPLS computed all necessary path values, correlations for every variable, and overall model fit statistics (Hair et al., 2024). The researchers evaluated the stability of the structural model using the PLS approach. In particular, *R*-square values of academic performance = 0.639, creative thinking = 0.623, and student engagement = 0.354 all satisfied acceptable standards for structural validity. Furthermore, the harmonious fit between the sample data and the model used in this framework was confirmed by the Standardised Root Mean Residual (SRMR)

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of 0.075. Resampling procedures were used to evaluate the resilience and reproducibility of the measurement model, and 5000 bootstrap replications were used to confirm the statistical significance of these loadings. Using the robust Partial Least Squares (PLS) methodology as our selected analytical framework, we carried out a thorough analysis of the possible moderating influence on the expected association (Hair et al., 2024).

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Based on the primary effects model, we obtained latent variable scores for the independent and moderating factors analysis.

TABLE 5. Hypothesis testing

Relationships	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	*t* Statistics (|O/STDEV|)	*p* Values
ALT -> SE	0.595	0.598	0.031	18.947	0.000
ALT -> SE -> CT	0.115	0.117	0.038	2.988	0.003
ALT -> SE -> AP	0.162	0.165	0.035	4.599	0.000
DL * SE -> CT	0.085	0.087	0.029	2.881	0.004
DL * SE -> AP	-0.155	-0.155	0.037	4.227	0.000

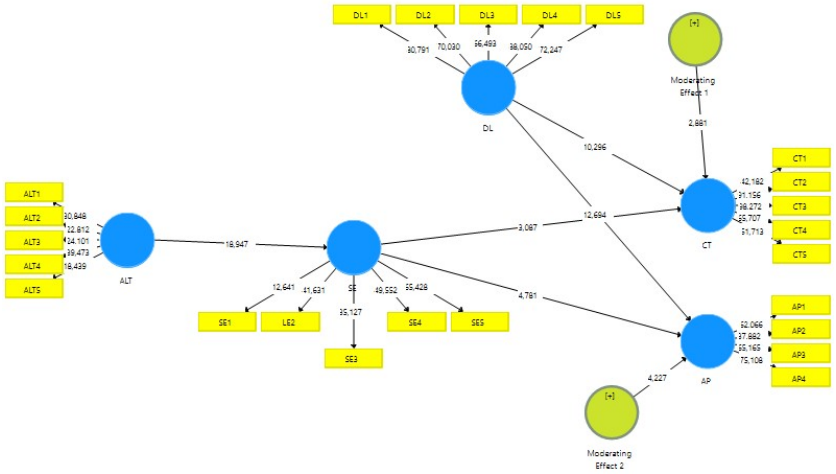

FIGURE 2. Structural model

DISCUSSION

Drawing on social constructivist theory, the study investigates how adaptive learning technologies significantly enhance creative thinking and academic performance through students' engagement and improvement in digital literacy. Although it emphasizes digital literacy as a means of alleviating barriers to access, this study contributes to the discussion of sustainable education and eliminates the necessity of separating students with different access, or no access, to technology from other students. When implemented correctly, adaptive learning systems can enrich and expand the learning experience for students from disadvantaged or underrepresented social backgrounds. Moreover, these tools help to activate the possibility of lifelong learning, which is a principle of sustainable education.

The significant direct impact found between adaptive learning technologies and student engagement affirms the basic invested interest principle of constructivism; that the potential for learning is maximized when students are actively involved in rich and meaningful interactions that reflect contextualized learning. The ongoing personalized interaction reduces frustration and increases intrinsic motivation, keeping the student's cognitive and behavioral effort constantly directed toward the task of knowledge construction, which is the essence of a high engagement state of being (Pavlov et al., 2024). The technologies personalize learning pathways so that students can learn at their own pace and receive the appropriate level of assistance. Likewise, it likely encourages a more engaging learning experience and strengthens the connection with the material. Supporting our findings were previous studies that showed the overall effectiveness of adaptive learning systems in engaging students.

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The research indicates that student engagement is the primary mechanism for ALT to stimulate creative thinking. Within the framework of social constructivism, CT is not a passive trait, but an active process of cognitive construction and reconstruction. ALT provides the scaffolding through structured resources and personalized challenges, but the engaged student is the one who actively uses this scaffolded learning experience to internalize, explore, and recombine concepts (Xiaoyu & Tobias, 2023). Moreover, high SE galvanizes the stamina and psychological safety needed for the students to interrogate their existing cognitive frameworks and develop new solutions, all of which is mediated by the accessible and supportive knowledge base developed through the adaptive system.

The discovery that SE mediates the relationship between ALT and academic performance reinforces the constructivist position that mastery (performance) is accomplished through work, as opposed to passive reception of information. ALT creates the ideal conditions by providing targeted content and prompt formative assessment to promote learning, yet AP will only take place when the student actively and consistently activates behavioral and cognitive engagement in learning and knowledge-building and synthesis (Ebele et al., 2023; Liu et al., 2023). This mediation confirms that the condition of the value of the adaptive construct was completely conditional upon the student accepting it as a consistent, effortful relationship in the process of learning; what they learned in the system was the quality of the scaffolding, translated into observable academic performance or success, consolidating their own understanding (Wang et al., 2023).

The moderation of digital literacy on the relationship between SE and CT. For an engaged student, high DL allows their efforts to be sufficiently transformed into higher-level, digitally-mediated creative products (e.g., using simulation software or creating multimedia presentations). In contrast, for a student exhibiting low DL, the learner's engagement is constrained by their lack of capacity to manipulate the tools of the culture, which limits the complexity and reach of the student's creative constructions and leads to a weaker connection between the learner's effort and innovative outputs. Students who possess a high level of digital literacy are better equipped to use the technology required to access digital learning environments. This is consistent with the literature now in publication, which emphasises the need for digital literacy in facilitating accessible learning in technologically advanced environments.

The moderating role of Digital Literacy (DL) in the Student Engagement (SE) and Academic Performance (AP) connection highlights the contextual necessity of technical aptitude in contemporary learning spaces. From a constructivist perspective, the digital environment is the social environment; therefore, the individual's ability to fluently navigate and manage the medium of instruction (DL) will be the primary factor affecting the efficiency of knowledge construction. High DL allows the engaged effort of the student to be optimally directed toward content, ensuring they can easily and efficiently access information, communicate, and hand in assignments, thus maximizing a return on their engagement in AP (Pavlov et al., 2024; Wani & Ismail, 2024). Low DL introduces cognitive load and friction, which dissipates the impact of the engaged effort and limits the successful integration of new knowledge.

This analysis suggests that digital literacy is important in enhancing students' use of digital learning resources. More digitally literate students were better able to make use of personalised feedback systems and adaptive learning technologies to increase engagement and performance. In contrast, although students with low digital literacy experienced obstacles in their use, students with high digital literacy were not inhibited, but rather enhanced their use of classroom tools in a conventional learning environment. Our findings suggest that if educational technologies are to benefit from, then targeted interventions such as accommodating digital literacy training programs will be needed to achieve equitable access. When educational institutions address these inequities, students can engage more, and the learning community may be more inclusive. Adaptive learning technologies, digital literacy, and personalised feedback matter for the engagement of students. As promising as AI tools may seem, their negative correlation with engagement is con-

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cerning and suggests we need to better engage in the designing and implementation of such supports.

CONCLUSION

This research with social constructivism theory investigates how adaptive learning technologies significantly enhance creative thinking and academic performance through students' engagement and improvement in digital literacy. The initial major finding demonstrates that adaptive learning technologies have an immediate impact on student engagement. Providing personalized just-in-time support at specific targets will aim to reduce cognitive frustration, maximizing a student's willingness to engage in the task, which focuses on cognitive effort, also referred to as deep engagement. We also confirmed that SE is the key mediator, where it captures the value of the technology into meaningful outcomes. Even ALT does not create outcomes passively, a rich environment developed through ALT first needs to elicit significant engagement, and once successful, the technology can offer opportunities for creativity and ultimately better academic performance.

Another critical piece of evidence identified the moderating role of digital literacy, showcasing a significant cultural tool that shapes knowledge construction productivity. In particular, our evidence showed that the positive relationship between student engagement and creative thinking- and academic performance, therefore, was significantly higher with DL included. If a student is significantly engaged, DL would mediate this engagement so that the student could proficiently (and, arguably, effectively) engage with digital artefacts to undertake a complex task. This might involve disclosing divergent thinking (using complex and/or advanced digital formats) and/or utilising the ordering of the learning platform and resources effectively to arrive at an academic performance grade, and so forth. A lack of DL, however, constructs an intercession point that reduces potential productive value from high engagement, or conversely, weakens learner potential to engage at the same level of effort into effective productivity, and relatedly, the academic outcome. Theoretically, this study supports the theorising of educational technology as an essential cognitive and social artefact framing and mediating the learning context. Practically, the findings pose a direct call to action to maintain educational development; both high-quality diverging artefacts and high DL represent an investable educational practice.

Limitations and Future Research

This study draws important implications, but some limitations deserve mention. First, since the study was conducted in a localized social context, namely with a particular group of students, the results may not be generalized to other educational contexts or student situations. Given the small sample size of the study, it is reasonable to assume that the findings will be diverse from a demographic perspective, and a more heterogeneous sample could provide future research with a different perspective about the impact of technology and adaptive learning across educational groups. A key limitation of the study is the homogeneity of the sample, which is made up mostly of Iraqi graduate and undergraduate students. This limits the transferability of the findings outside of the setting in Iraq. Future research would benefit from increasing the sample to include individuals from other countries or regions in order to improve the theoretical model's external validity. Furthermore, comparative analysis would need to consider even more complexities arising out of cross-cultural differences in both educational systems and in teaching practices. To gain a deeper understanding of students' experiences and perceptions of these digital tools, prospective research could implement hybrid approaches that capitalize on quantitative and qualitative data. We advocate for future researchers to examine different service learning and digital teaching practices in higher education, using an array of research methods. This type of research will help yield meaningful insights to improve critical digital literacy. We encourage academics and practitioners to expand their thinking about the interrelation between digital technology integration and training for early childhood educators. It is crucial for early childhood education to prioritize training in essential digital skills. Further, in examining essential

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digital skills and the extension or development of online social networks, we must avoid categorizing events in a binary or ambiguous manner.

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