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Integrating Intelligent Feedback Models in E-Learning Platforms for Graduates' Digital Empowerment, Innovation, and Inclusion in the Digital Economy

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Abstract

This study examined the role of intelligent feedback models in empowering next-generation graduates and promoting participation in the digital economy through innovation and inclusion. The study was anchored on the Social Cognitive Theory (SCT) which emphasizes the influence of feedback and environmental factors on learners' behavior and self-efficacy. A descriptive survey research design was adopted. The population comprised learners on e-learning platforms, from which a sample of 420 respondents was selected using purposive sampling. Data were collected using Intelligent Feedback and Graduates' Digital Empowerment Questionnaire (IFGDEQ), *which yielded a Cronbach's Alpha reliability coefficient of 0.89. Data were analyzed using Pearson Product Moment Correlation and regression analysis. Findings revealed that intelligent feedback significantly enhanced learner engagement ($\beta = .62$, $p < .001$), digital competence ($\beta = .68$, $p < .001$), and innovation capability ($r = .59$, $p < .001$). Digital competence also significantly influenced digital economic participation ($\beta = .71$, $p < .001$). The study concluded that intelligent feedback models are effective mechanisms for promoting graduates' digital empowerment, innovation, and inclusion. It was recommended that e-learning providers should incorporate adaptive feedback mechanisms to promote inclusive and sustainable digital development.*

Keywords: *Intelligent feedback, e-learning platforms, digital competence, graduates' digital empowerment, innovation, inclusion, digital economy.*

1. 0 Introduction

The rapid advancement of Artificial Intelligence (AI), Machine Learning (ML), and Information and Communication Technology (ICT) has fundamentally transformed educational systems across the world. These technological innovations have reshaped teaching and learning processes by facilitating personalized instruction, intelligent tutoring, adaptive assessment, and data-driven decision-making. Consequently, e-learning has evolved from a supplementary mode of instruction into a strategic component of higher education and workforce development, providing learners with flexible, accessible, and learner-centred educational opportunities (UNESCO, 2023; OECD, 2023).

The widespread adoption of digital technologies has accelerated the growth of electronic learning (e-learning) as an effective alternative and complement to conventional face-to-face instruction. E-learning enables learners to access educational resources regardless of geographical location or time constraints, thereby promoting lifelong learning, flexibility, and educational equity (Al-Fraihat et al., 2020). The increasing availability of internet connectivity, mobile technologies, cloud computing, and artificial intelligence has further strengthened the effectiveness of e-learning environments, making them indispensable tools for developing twenty-first-century competencies required in the digital economy (World Economic Forum, 2023).

E-learning refers to all forms of teaching and learning facilitated through electronic technologies, including the Internet, computer networks, mobile devices, and digital communication platforms. It is commonly described as online learning, web-based learning, virtual learning, or digital learning because instructional activities are delivered through electronic media that enable interaction among learners, instructors, and learning resources irrespective of physical distance (Moore and Kearsley, 2019). Modern e-learning environments therefore support both synchronous and asynchronous learning experiences while encouraging collaboration, knowledge sharing, and self-directed learning (Uwah and Ododo, 2022).

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A major component of contemporary e-learning is the Learning Management System (LMS**)**, which provides an integrated platform for creating, delivering, managing, monitoring, and evaluating learning activities. Learning Management Systems enable institutions to administer courses, distribute learning materials, conduct assessments, monitor learner progress, and facilitate communication between instructors and learners (Ihama and Eguasa, 2021). Recent advances in AI have further enhanced LMS functionality through intelligent recommendation systems, automated assessment, predictive learning analytics, and adaptive feedback mechanisms that personalize learning according to individual learner characteristics (Holmes et al., 2022).

One of the most promising AI applications in digital education is intelligent feedback**.** Unlike traditional feedback, which is often delayed, generic, and instructor-dependent, intelligent feedback employs artificial intelligence, machine learning, and learning analytics to generate immediate, personalized, adaptive, and context-sensitive responses based on learners' performance, behaviours, and learning needs (Hattie and Timperley, 2007; Holmes et al., 2022). Such feedback supports self-regulated learning by helping learners identify misconceptions, monitor their progress, and receive individualized guidance that improves engagement, motivation, and academic achievement.

Beyond improving learning outcomes, intelligent feedback has considerable potential for promoting digital empowerment, particularly among the youth. Digital empowerment refers to the process of equipping individuals with the knowledge, digital competencies, confidence, and opportunities required to participate effectively in technology-driven societies and economies (UN Women, 2024, Pham, 2024).). As governments and international organizations increasingly promote digital transformation as a pathway to sustainable development, empowering graduates through technology-enhanced learning has become a global priority because of the impact of technlogy in today's digital economy (United Nations, 2023).

Despite substantial investments in digital education, significant disparities continue to exist among the young graduates in access to digital technologies, acquisition of digital skills, participation in innovation ecosystems, and engagement in the digital economy. Graduates, particularly in many developing countries including Nigeria, often encounter barriers such as inadequate ICT infrastructure, limited digital literacy, socio-cultural stereotypes, financial constraints, and unequal educational opportunities, all of which restrict their participation in technology-driven careers and entrepreneurship (World Bank, 2024; UN Women, 2024). These challenges reduce the effectiveness of existing digital learning initiatives and limit graduates' ability to benefit fully from emerging digital opportunities.

Although contemporary e-learning platforms have expanded educational access, many existing systems still rely on conventional feedback approaches that provide standardized responses irrespective of learners' backgrounds, abilities, or learning preferences. Such generic feedback mechanisms rarely consider differences in prior knowledge, digital competence, motivation, or learning styles, thereby limiting learner engagement, persistence, and skill development. Consequently, many learners experience low course completion rates, inadequate instructional support, and limited acquisition of innovation-related competencies essential for success in today's knowledge economy (Al-Fraihat et al., 2020).

Emerging evidence suggests that AI-powered intelligent feedback can significantly improve learner engagement, self-regulated learning, academic performance, and digital competence through adaptive and personalized instructional support (Holmes et al., 2022). However, relatively little empirical research has examined whether these intelligent feedback mechanisms can extend beyond academic achievement to promote graduates' digital empowerment, innovation capability, and meaningful participation in the digital economy. Existing studies have largely concentrated on learning performance, system usability, technology acceptance, or learner satisfaction, with limited attention given to broader socio-economic outcomes such as digital inclusion, entrepreneurship, innovation capacity, employability, and economic participation, particularly among graduates in developing countries.

Furthermore, few studies have investigated how intelligent feedback models can be integrated into e-learning platforms to simultaneously enhance digital competence, stimulate innovation, and foster inclusive participation in the digital economy. This represents a significant knowledge gap because educational technologies should not only improve learning outcomes but also contribute to social inclusion and sustainable economic development as advocated by the United Nations Sustainable Development Goals, particularly Goals 4 (Quality Education), 8 (Decent Work and Economic Growth), and 9 (Industry, Innovation and Infrastructure) (United Nations, 2023).

Against this background, there is a compelling need to investigate how intelligent feedback models integrated within e-learning platforms can promote graduates' digital empowerment, strengthen innovation capability, and enhance inclusion in the digital economy, particularly within the Nigerian higher education context. This study therefore seeks to empirically examine the influence of intelligent feedback mechanisms on graduates' digital competence, innovation capability, and readiness to participate effectively in the digital economy. The findings are expected to provide valuable insights for educators, policymakers, educational technology developers, and higher education institutions seeking to design inclusive, intelligent, and learner-responsive e-learning systems capable of supporting sustainable digital transformation.

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1.1 Objectives of the Study

The objectives include, to:

1. Examine the effect of intelligent feedback on learner engagement.
2. Determine the influence of intelligent feedback on digital competence.
3. Investigate the relationship between intelligent feedback and innovation capability.
4. Assess the effect of digital competence on digital economic participation.
5. Evaluate the mediating role of digital competence between intelligent feedback and digital economic participation.

1.2 Null Hypotheses

H1: Intelligent feedback significantly influences learner engagement.

H2: Intelligent feedback significantly influences digital competence.

H3: Intelligent feedback significantly influences innovation capability.

H4: Digital competence significantly influences digital economic participation.

H5: Digital competence mediates the relationship between intelligent feedback and digital economic participation.

2 Intelligent Feedback in E-Learning Platforms

The rapid advancement of Artificial Intelligence (AI), Machine Learning (ML), and learning analytics has revolutionized conventional Learning Management Systems (LMSs), transforming them into Intelligent Learning Management Systems (ILMSs) capable of delivering adaptive, personalized, and data-driven learning experiences (Uwah and Ododo, 2021; Holmes et al., 2022). Unlike traditional LMSs that primarily facilitate content delivery and course administration, ILMSs leverage artificial intelligence algorithms, predictive analytics, and learner data to provide intelligent instructional support tailored to individual learners' needs, preferences, and learning behaviours. This evolution has significantly improved the capacity of e-learning environments to provide dynamic, learner-centred instruction while enhancing educational quality and effectiveness.

At the core of Intelligent Learning Management Systems are intelligent feedback models, which utilize machine learning techniques, educational data mining, and learning analytics to continuously monitor learner interactions, assess academic progress, identify knowledge gaps, and generate personalized recommendations in real time (Hattie and Timperley, 2007; Siemens & Long, 2011; Holmes et al., 2022). These intelligent feedback mechanisms extend beyond the delayed and generic responses commonly associated with conventional e-learning systems by providing timely, adaptive, and context-sensitive feedback that supports learners throughout the learning process. Consequently, learners receive individualized guidance that promotes self-regulated learning, improves motivation, increases engagement, and enhances academic achievement.

The integration of intelligent feedback models further strengthens the effectiveness of e-learning platforms through the incorporation of complementary AI technologies, including adaptive learning systems, intelligent tutoring systems, automated assessment, predictive learning analytics, recommender systems, conversational agents, and virtual assistants (Luckin et al., 2016; Holmes et al., 2022). These technologies facilitate continuous monitoring of learner performance and enable instructional interventions that are responsive to individual learning needs. By delivering immediate feedback and personalized learning pathways, intelligent feedback systems improve learner satisfaction, knowledge retention, critical thinking, and overall learning outcomes while supporting inclusive and learner-centred educational practices.

Machine learning, one of the principal branches of Artificial Intelligence, serves as the analytical engine that powers intelligent feedback systems. Through supervised, unsupervised, and reinforcement learning techniques, machine learning algorithms process large volumes of learner-generated data to recognize behavioural patterns, predict academic performance, detect learners at risk of poor achievement, and recommend appropriate instructional interventions (Baker and Inventado, 2014; Sutton and Barto, 2018). As learners continuously interact with digital learning environments, these algorithms refine their predictive accuracy, enabling Intelligent Learning Management Systems to adapt instructional strategies and provide increasingly personalized educational experiences that accommodate diverse learner characteristics, abilities, and preferences.

Beyond enhancing academic performance, the integration of intelligent feedback models presents significant opportunities for advancing digital empowerment, innovation, and inclusive participation in the digital economy. Intelligent e-learning platforms can facilitate the development of critical twenty-first-century competencies, including digital literacy, problem-solving, creativity, collaboration, and innovation, which are essential for success in technology-driven societies and labour markets (World Economic Forum, 2023; UNESCO, 2023). Through personalized learning experiences and continuous performance feedback, learners are empowered to acquire relevant digital competencies, build confidence in using emerging technologies, and become active participants in digital transformation initiatives.

Furthermore, intelligent feedback systems can contribute to reducing educational inequalities by providing equitable access to individualized learning support regardless of learners' socio-economic background, geographical location, or prior digital experience. Such inclusive learning environments are particularly valuable for empowering women and other underrepresented groups, whose participation in digital innovation and technology-related careers remains comparatively low in many developing countries (UN Women, 2024; World Bank, 2024). By

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promoting equitable access to quality digital education, intelligent feedback models can strengthen women's digital competence, foster innovation and entrepreneurial capabilities, enhance employability, and increase meaningful participation in the digital economy.

Consequently, integrating intelligent feedback models into e-learning platforms represents more than a technological enhancement of conventional Learning Management Systems. Rather, it provides a strategic framework for developing intelligent, adaptive, and inclusive educational ecosystems capable of supporting lifelong learning, strengthening digital competencies, promoting innovation, and preparing graduates with the knowledge, skills, and confidence required to thrive in an increasingly digital and knowledge-driven global economy.

2.1 Impact of Intelligent Feedback Models on Graduates' Digital Empowerment

The integration of Intelligent Feedback Models (IFMs**)** into e-learning platforms has emerged as a transformative strategy for enhancing graduates' digital empowerment and preparing them for meaningful participation in the knowledge-driven and digitally connected global economy. Advances in Artificial Intelligence (AI)**,** Machine Learning (ML)**,** learning analytics, and educational data mining have enabled e-learning systems to evolve from conventional content delivery platforms into intelligent learning environments capable ofHolmes et al., 2022; UNESCO, 2023 providing personalized, adaptive, and real-time instructional support (). Unlike traditional feedback approaches that are often delayed, generalized, and instructor-dependent, intelligent feedback systems continuously analyse learners' interactions, monitor learning progress, identify knowledge gaps, and generate individualized recommendations that align with learners' abilities, preferences, and learning objectives (Hattie and Timperley, 2007; Azevedo and Bernard, 2023). Consequently, these systems improve learning effectiveness, promote self-regulated learning, and increase learners' readiness to exploit emerging opportunities in the digital economy.

A major contribution of Intelligent Feedback Models is their ability to strengthen graduates' digital competence through personalized learning experiences. By providing immediate, data-driven, and context-sensitive feedback, intelligent systems enable learners to recognize their strengths and weaknesses, correct misconceptions promptly, and progress according to their individual learning pace. Such adaptive support facilitates the development of essential twenty-first-century competencies, including digital literacy, information management, communication, collaboration, computational thinking, critical thinking, and problem-solving skills, all of which are increasingly required in technology-driven workplaces (UNESCO, 2023; World Economic Forum, 2023). Furthermore, personalized feedback enables learners to assume greater responsibility for their own learning, thereby improving autonomy, confidence, and lifelong learning capabilities.

Beyond developing technical competencies, intelligent feedback systems play a significant role in enhancing learner engagement, motivation, and self-efficacy. According to Social Cognitive Theory**,** learning is influenced by the dynamic interaction between personal factors, behaviour, and environmental conditions, with feedback serving as a critical source of self-efficacy beliefs that influence learners' persistence and performance (Bandura, 1986). Similarly, Hattie and Timperley (2007) argued that effective feedback is among the most powerful influences on learning because it helps learners understand where they are, where they need to go, and how to improve. Through continuous monitoring and adaptive instructional support, Intelligent Feedback Models encourage sustained engagement, reduce learning frustration, and promote higher levels of academic achievement and learner satisfaction.

Intelligent Feedback Models also contribute significantly to the development of innovation and entrepreneurial capabilities by fostering creativity, critical thinking, reflective learning, and independent problem-solving. AI-powered adaptive learning environments encourage graduates to experiment with alternative solutions, evaluate multiple perspectives, and refine innovative ideas through continuous feedback and iterative improvement. These experiences cultivate higher-order cognitive skills and innovation competencies that are essential for leadership, entrepreneurship, and active participation in the Fourth Industrial Revolution (Schwab, 2017). Empirical evidence further indicates that the acquisition of advanced digital skills enhances innovation capacity, employability, entrepreneurial intentions, and workforce competitiveness among graduates, thereby increasing their contribution to economic development and digital transformation (Lestari et al., 2024; World Economic Forum, 2023).

Another important contribution of Intelligent Feedback Models lies in promoting educational inclusion and equitable access to quality learning opportunities. By adapting instructional content and feedback to learners' diverse abilities, learning preferences, prior knowledge, and competency levels, intelligent systems provide individualized learning experiences that accommodate heterogeneous learner populations. Such personalization helps reduce educational inequalities associated with socio-economic background, geographical location, gender, disability, and varying levels of digital literacy (Holmes et al., 2022; UNESCO, 2023). These inclusive learning environments are particularly important for learners from underserved communities, enabling them to acquire relevant digital competencies and participate more effectively in knowledge-based societies.

Moreover, digital inclusion has become a critical determinant of graduates' economic empowerment and labour market participation. As digital technologies continue to reshape employment patterns and entrepreneurial opportunities, graduates equipped with strong digital competencies are more likely to access quality employment, create innovative enterprises, and contribute to sustainable economic growth (World Bank, 2024). Intelligent feedback systems therefore

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extend beyond improving academic performance by serving as strategic tools for developing digitally empowered, innovative, and globally competitive graduates. Consequently, integrating Intelligent Feedback Models into e-learning platforms provides a robust foundation for strengthening digital competence, promoting innovation and entrepreneurship, enhancing employability, and fostering inclusive participation in the digital economy.

2.2 AI-Driven Adaptive Learning and Graduates' Digital Empowerment

The emergence of Artificial Intelligence (AI) has fundamentally transformed the design, delivery, and management of digital education by enabling e-learning systems to become more intelligent, adaptive, and learner-centred. AI-driven adaptive learning integrates machine learning, learning analytics, educational data mining, and intelligent feedback mechanisms to create personalized learning environments that continuously respond to learners' characteristics, performance, preferences, and evolving educational needs (Holmes et al., 2022; UNESCO, 2023). Unlike conventional e-learning systems that provide uniform instructional experiences, AI-powered adaptive learning environments dynamically modify instructional content, learning pathways, assessment strategies, and support mechanisms according to individual learner profiles. This personalized approach not only enhances academic achievement but also contributes significantly to graduates' digital empowerment by strengthening digital competence, fostering innovation, and promoting equitable participation in the digital economy.

A defining characteristic of AI-driven adaptive learning is the integration of intelligent feedback systems, which provide immediate, personalized, and data-driven instructional support throughout the learning process. These systems continuously analyse learner interactions, monitor academic progress, identify misconceptions, predict potential learning difficulties, and recommend targeted learning resources and intervention strategies using artificial intelligence and predictive analytics (Holmes et al., 2022). Unlike traditional instructor-centred feedback, which is often delayed and generalized, intelligent feedback enables learners to receive timely and context-sensitive guidance that supports continuous improvement and self-regulated learning. According to Hattie and Timperley **(**2007)**,** effective feedback enables learners to understand their current level of performance, identify desired learning outcomes, and determine appropriate strategies for improvement. Recent empirical studies further indicate that AI-powered feedback enhances learner engagement, motivation, persistence, and academic performance by providing adaptive instructional support tailored to individual learning needs (Samina et al., 2025).

Closely associated with intelligent feedback are adaptive learning environments, which automatically adjust instructional content, learning pace, assessment difficulty, and pedagogical strategies based on learners' prior knowledge, cognitive abilities, learning preferences, and behavioural patterns. Through continuous analysis of learner-generated data, adaptive learning systems provide individualized learning experiences that accommodate diverse educational backgrounds and competency levels, thereby improving learning efficiency, satisfaction, and knowledge retention (Holmes et al., 2022). These adaptive environments also promote learner autonomy by allowing individuals to progress at their own pace and revisit learning materials whenever necessary. Such flexibility is particularly valuable for graduates who often balance academic activities with employment, entrepreneurship, or family responsibilities. Furthermore, UNESCO (2023) emphasized that AI-enabled adaptive learning expands access to quality education, supports lifelong learning, and promotes educational inclusion, especially for learners from disadvantaged and underserved communities.

AI-driven adaptive learning also plays a significant role in strengthening digital literacy, which represents a fundamental component of graduates' digital empowerment. Digital literacy encompasses the knowledge, skills, and confidence required to access, evaluate, create, communicate, and apply information effectively using digital technologies (UNESCO, 2023). Within AI-enabled learning environments, graduates acquire practical competencies in digital communication, information management, critical thinking, problem-solving, collaboration, and the responsible use of emerging technologies. These competencies are increasingly recognized as essential requirements for employability, innovation, entrepreneurship, and active participation in knowledge-based economies (World Economic Forum, 2023). Despite substantial progress in digital transformation, disparities in access to digital technologies, digital skills, and innovation opportunities continue to affect many graduates, particularly women and other underrepresented groups (World Bank, 2024). Consequently, strengthening graduates' digital literacy through AI-supported learning contributes to reducing digital inequalities while enhancing their economic opportunities, technological confidence, and capacity for lifelong learning.

The effectiveness of AI-driven adaptive learning systems is also influenced by learners' willingness to adopt and utilize emerging technologies. The Technology Acceptance Model (TAM) proposed by Davis (1989) suggests that individuals' intention to use technology is largely determined by their perceptions of its usefulness and ease of use. This perspective is further extended by the Unified Theory of Acceptance and Use of Technology (UTAUT**)**, which explains technology adoption through factors such as performance expectancy, effort expectancy, social influence, and facilitating conditions. AI-powered adaptive learning environments enhance these perceptions by simplifying complex learning processes, providing personalized instructional support, and improving educational outcomes. As learners experience the benefits of intelligent feedback and adaptive instruction, their confidence in digital technologies increases, leading to greater acceptance, sustained engagement, and continued utilization of AI-enabled educational platforms.

Beyond improving academic performance, AI-driven adaptive learning contributes substantially to graduates' digital

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empowerment by fostering innovation, creativity, critical thinking, and entrepreneurial competence. Personalized learning environments encourage learners to explore new ideas, experiment with innovative solutions, and develop higher-order cognitive skills required for leadership and participation in digitally transformed workplaces. These competencies are increasingly important within the Fourth Industrial Revolution, where artificial intelligence, automation, and digital technologies continue to reshape labour markets and economic systems. Through continuous interaction with intelligent learning technologies, graduates become better equipped to leverage digital tools for employment, entrepreneurship, innovation, and sustainable economic development.

Overall, AI-driven adaptive learning represents a transformative approach to digital education by combining intelligent feedback, adaptive instruction, learning analytics, and personalized support to improve learning experiences and educational outcomes. More importantly, it provides a strategic framework for graduates' digital empowerment by enhancing digital literacy, strengthening technology acceptance, promoting educational inclusion, reducing digital inequalities, and developing the innovation competencies required for meaningful participation in the digital economy. Consequently, AI-enabled adaptive learning serves not only as an instructional innovation but also as a catalyst for inclusive human capital development and sustainable socio-economic transformation.

3 Methodology

3.1 Model design

3.1.1 Framework of an Intelligent E-learning Feedback Model using MDP.

In a Markov Decision Process (MDP), a policy is a mapping from states to actions, that defines the behavior of an agent in the environment. It's a strategy that the agent follows to achieve its goals. The agent in the research work is the Reinforcement Learning algorithm , precisely the Policy Gradient (PG) algorithm. Reinforcement learning a a type of Artificial learning.

The framework as sown in Fig. 1, the Markov Decision Process (MDP) environment is the E-learning platform, the states are the various attributes or characteristics that describes the learner's interactions with the Leaning Management System. These attributes include knowledge levels, learning activities, learning goals/objectives, time spent, learning styles, completion status, assessment results, learner's engagement status (clicks, time spent, interactions) and other teaching and learning activities. The current state of the user S_1 is the initial activity of the user, it could be login or registration, taking a course, reading, uploading course contents, lecturing, watching videos, quizzes, assessing learners, running system updates etc, this initial state is transited to next state S_{t+1} at a particular time when the agent has performed an Action. An action include suggestion for another course, recommendation for course materials or resources, learning or teaching style, hints, etc, the responses to these actions (feedback strategies) by the users are called feedback . The Agent is the program algorithm (in this context, the Reinforcement Learning Algorithm), that decides what type of feedback strategies to display based on the user's current state, the feedback given by the users are the rewards to the Agent. The agent thereafter personalized the feedback and used it as rewards to upgrade or optimize the policy that formed the Learning Management System. The approach tackles the optimal needs of discovering the means of providing real time feedback support to Learning Management System (LMS) users in order to improve their effectiveness navigating through teaching and learning activities. There is a significant correlation between learners success and the qualities of their learning path throughout their course of study.

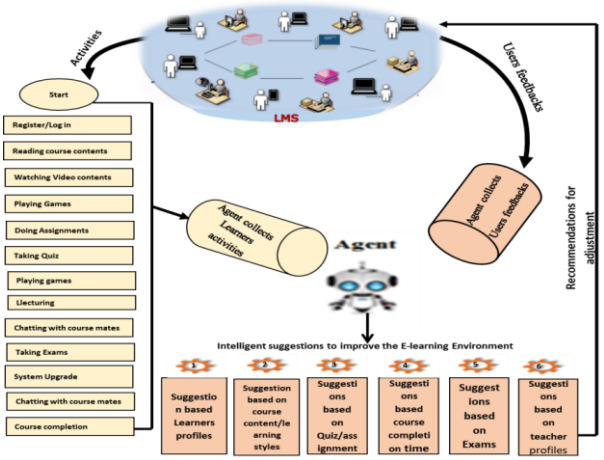

Fig. 1: Framework of an Intelligent E-learning Feedback Model using MDP

3.2 Research Design

A quantitative cross-sectional survey design was adopted. The population consisted of learners in online education programs, digital skill academies, and university e-learning platforms. Using Cochran's formula, a sample of 420 respondents was selected through purposive sampling to ensure representation across institutions. Data were collected using the Intelligent Feedback and Graduates' Digital Empowerment Questionnaire (IFGDEQ) with a total of 20 items, with five sections measuring learner engagement (item 1-5), digital competence(items 6-10), innovation capability(item 11-15), and digital economic participation (items 16–20). This questionnaire was generated in a google form and sent to students platforms in University of Uyo (150), University of Calabar (150), Akwa Ibom State University (60), and University of Cross River State (60) responses were received within one month. All the items were measured using a five-point Likert scale with points distributed as Strongly Agree (5), Agree (4), Undecided (3), Disagree (2) and Strongly Disagree (1). The instrument's reliability was 0.89 (Cronbach's alpha) and validated by 3 experts from the field of Educational Technology and 2 from Test and Measurement who studied the questions and made necessary adjustment. Ethical principles were strictly observed throughout the conduct of this study. Respondents

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were assured that the information provided would be treated with utmost confidentiality and used solely for academic

4 Data Presentation and Analysis

The statistical tool used in the analysis of the hypotheses include Pearson Moment Correlation and regression.

4.1 Demographic Data (n = 420)

variable	Category	Frequency	Percentage(%)
Age	20-25	110	26.2
	26-30	180	42.9
	31-35	90	21.4
	36+	40	9.5
Gender	Male	280	66.7
	Female	140	33.3
School Ownership	Federal	260	61.9
	State	160	38.1

Regression Analysis for Hypothesis Testing

H01: Intelligent Feedback → Learner Engagement

R	R^2	Beta	T	Sig.
0.62	0.38	0.62	8.74	0.000

Since **p < 0.05**, the null hypothesis was rejected. Intelligent feedback significantly influences learner engagement. However, the coefficient of determination (R^2 = 0.38) indicates that approximately 62% of the variation in learner engagement is explained by factors other than intelligent feedback, suggesting that additional variables may contribute to engagement.

H02: Intelligent Feedback and Digital Competence

R	R^2	Beta	T	Sig.
0.68	0.46	0.68	10.12	0.000

The null hypothesis was rejected. Intelligent feedback significantly influences digital competence. Nevertheless, with R^2 = 0.46, more than half of the variation in digital competence may be attributed to other factors such as prior ICT experience, access to technology, and motivation.

H03: Intelligent Feedback and Innovation Capability

R	Sig.
0.59	0.000

A significant positive relationship exists between intelligent feedback and innovation capability. However, the moderate correlation coefficient suggests that innovation capability is influenced by other factors beyond intelligent feedback, including creativity, learning environment, and access to digital resources.

H04: Digital Competence and Digital Economic Participation

R	R^2	Beta	T	Sig.
0.71	0.50	0.71	12.45	0.000

Digital competence significantly predicts digital economic participation. However, since only 50% of the variance is explained, other variables such as entrepreneurial orientation, internet accessibility, and economic opportunities may also play substantial roles.

H05: Multiple Regression for Mediation

Predictor	Beta	T	Sig.
Intelligent Feedback	0.23	4.36	0.000
Digital Competence	0.49	7.81	0.000

The results indicate that both intelligent feedback and digital competence significantly contribute to digital economic participation. However, digital competence exhibited a stronger predictive effect (β = 0.49) than intelligent feedback (β = 0.23), suggesting partial mediation. This implies that intelligent feedback influences digital economic participation primarily through the enhancement of learners' digital competence rather than through a direct pathway. Nevertheless, the relatively smaller beta value for intelligent feedback suggests that other mediating variables may also exist.

4.3. Discussion of Findings

The findings of the study revealed that intelligent feedback significantly enhanced learner engagement among graduates on e-learning platforms. This finding supports the assertion of Hattie and Timperley (2007**)** that effective feedback promotes learners' motivation, participation, and academic improvement. Similarly, the result agrees with Holmes et al. (2022)**,** who reported that AI-driven feedback systems improve learners' engagement and learning experiences.

The study also found that intelligent feedback significantly influenced digital competence, indicating that personalized learning environments contribute to the acquisition of digital skills. This finding is consistent with UNESCO (2023), which emphasized that technology-enhanced learning promotes digital literacy and lifelong learning. Furthermore, the positive relationship between intelligent feedback and innovation capability corroborates the findings of OECD (2021) and Durlach and Lesgold (2012), who noted that adaptive learning environments foster creativity and problem-solving skills.

The study further established that digital competence significantly influenced digital economic participation. This finding supports the reports of UN Women (2023) and the World Bank (2024), which highlighted digital skills as essential drivers of graduates' economic empowerment, inclusion, and participation in the digital economy.

5 Recommendations

1. **Higher education institutions** should integrate Artificial Intelligence (AI)-powered intelligent feedback models into Learning Systems (LMSs) to

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provide personalized, adaptive, and real-time feedback that enhances graduates' digital competence, engagement, and learning outcomes.

2. **University administrators** should invest in intelligent e-learning infrastructure, including AI-enabled Learning Management Systems, learning analytics tools, and reliable digital connectivity, to support effective implementation of adaptive learning environments.
3. **Governments and educational policymakers** should develop national policies that promote the adoption of AI-driven educational technologies while ensuring equitable access to digital infrastructure, particularly for institutions in underserved areas.
4. **Curriculum developers** should incorporate digital literacy, artificial intelligence, innovation, entrepreneurship, and emerging digital technologies into higher education curricula to prepare graduates for employment and entrepreneurship in the digital economy.
5. **Lecturers and instructional designers** should utilize intelligent feedback systems to provide continuous formative assessment, personalized learning support, and timely interventions that improve learner engagement, self-regulation, and academic performance.
6. **Educational institutions** should organize regular training programmes for lecturers and students on the effective use of AI-powered learning technologies, learning analytics, and intelligent feedback systems to maximize their educational benefits.
7. **E-learning platform developers** should design intelligent feedback systems that accommodate diverse learning styles, prior knowledge, digital competencies, and accessibility needs to ensure inclusive and learner-centred educational experiences.

6. Conclusion

This study provides evidence that Intelligent Feedback Models significantly enhance learner engagement, digital competence, innovation capability, and digital economic participation among graduates. The findings suggest that AI-driven feedback systems can become strategic tools for reducing gender disparities in digital education and promoting inclusive economic growth. Integrating intelligent feedback into e-learning platforms can empower next-generation graduates to become innovators, entrepreneurs, and leaders in the digital economy.

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