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GENERATIVE AI USE AND STUDENT ENGAGEMENT IN HIGHER EDUCATION: A PLS-SEM STUDY OF THE EFFICIENCY-COGNITION PARADOX

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ABSTRACT

Technological developments and Generative Artificial Intelligence (GenAI) in higher education is being adopted quickly and has made it more efficient in academic learning, but is also raising concerns about the impact on deep learning and interaction with students. The paper will deal with the efficiency-cognition paradox which is Pakistani institutions of higher education and known as the Cognitive Cost of Efficiency. The study is based on the conceptual framework of Unified Theory of Acceptance and Use of Technology (UTAUT), Constructivism and Cognitive Engagement in which Information literacy and Cognitive Engagement act as a mediating factor between the use of GenAI and skill development. A cross sectional quantitative research design was used, and data collection was done on 668 participants from the public and private higher education system in Pakistan. Partial Least Squares Structural Equation Modeling (PLS-SEM) was used to analyze the data. The results show that the use of GenAI has a positive effect on the development of skills, but the correlation is enhanced by the serial mediation of Information Literacy and Cognitive Engagement. Moreover, Digital Isolation had an adverse influence on Cognitive Engagement. The findings show that improving AI literacy and active learning methods is crucial to ensure the continued cognitive and professional development of students in an AI-driven learning environment.

Key words: *Generative Artificial Intelligence (GenAI), Information Literacy, Cognitive Engagement; Skill Development, Digital Isolation, Higher Education, PLS-SEM.*

1. INTRODUCTION

1.1 Generative Frontier of Building Academic Ecosystems.

The rapid development of Generative Artificial Intelligence (GenAI) has brought about a radical reorganization of the academic environment across the world with the shift of educational technology as the passive repository of information, to one of active thought. Although the adoption of Large Language Models (LLMs) has been widely reported in the context of the Western pedagogical system, its implementation in the context of the developing academic ecosystem (especially in Pakistan) is a distinctive socio-technical phenomenon. As the Pakistani higher education system has a demographic profile in which more than 60 percent of its population consists of individuals younger than 30 years old, the concept of GenAI is progressively being perceived by the higher

education sector as not only a supplementary tool, but a key means of technological leapfrogging (Majeed et al., 2024). National efforts, including the Pakistan National AI Policy (2024), which aims to entrench autonomous systems in the fabric of digital governance and scholarship, contribute to this change.

Nevertheless, the implementation of the tools to resource constrained settings comes with a unique set of complexities, which are not aligned with the existing world standards. GenAI plays a vital role in the Pakistani case as a tool that helps students with systemic challenges, such as inaccessibility to high-quality tutoring and the inability to use two languages (Shoukat, 2024). This results in a situation where the Generative Frontier becomes defined by a high-stakes, fast adoption cycle that in many cases outstrips the creation of ethical and cognitive protective measures. With universities all over the Global South scrambling to meet the standards of Digital Transformation as an international institution, the dependence on the agency of algorithms is a hallmark of the student experience. As a result, to become immersed in GenAI-enabled learning is no longer an option, but an organizational requirement that requires a stern exploration of how this unparalleled access to automated intelligence is transforming the intellectual culture of an expanding scholarly generation.

1.2 The Dilemma of Automated Efficiency.

The inherent contradiction of the present era of generative is the separation between academic output and mental work. Historically, the quality of a scholarly product, a technical report, a written coded algorithm, or a synthesized literature review, was a good proxy of the complexity of the student-level of engagement and intellectual mastery. Nonetheless, with the introduction of Generative AI (GenAI), a path of least resistance emerged, enabling the creation of high-quality artifacts without much psychological investment in the process, in minutes (Wang et al., 2025). This results in a false educational atmosphere where the rate of turn-in and seeming sophistication of the work covers a possible deterioration in real learning. The tool in this Efficiency-Engagement Nexus, does not simply support the student; it tends to take on the main cognitive load of synthesis and critical analysis, resulting in a situation where procedural efficiency thrives on the cost of intellectual rigor (Zeib & Tariq, 2024).

This fact is more relevant in tough academic settings such as in Pakistan where students are under extreme pressure to work in bulk in a short amount of time. The temptation of algorithmic shortcutting turns into a strategic need and not an additional resource, and students might seem to become more productive and able to cope with complex tasks, but their cognitive involvement, the mental heavy lifting to achieve long-term storage, is avoided (Guo et al., 2025). The efficiency benefits associated with GenAI, therefore, can be hidden by a cognitive cost, in which the user gets the desired result (the what) without necessarily experiencing the process of cognition (the how) of knowing how it works. This change requires a radical reconsideration of education assessment paradigms, with the old standards of efficiency becoming more and more conflicting with the essential objectives of cognitive development and mastering skills.

1.3 Theoretical Integration: Adoption to Cognitive Scaffolding.

In order to examine the implications of GenAI in the academic community, the paper will integrate the Unified Theory of Acceptance and Use of Technology (UTAUT) with the ideas of the learning theories of Connectivism and Constructivist. Although UTAUT is a very strong framework that helps to understand the structural determinants of technology adoption (performance expectancy and facilitating conditions), it is more focused on the stage of acceptance of the technological lifecycle (Venkatesh et al., 2003). But when the inquiry comes at the PhD level, adoption is only the first step towards a more intricate cognitive integration. By refocusing the theoretical perspective to the idea of Connections, this study regards learning to be a binding process between the specialized nodes of information, with GenAI serving as a powerful and independent node in

the personal learning network of the student (Siemens, 2004). It can be explored whether this technology is a scaffold that can improve the abilities of the student or a replacement that circumvents the beneficial process of knowledge construction.

According to Constructivist view, the usefulness of an educational tool is gauged by the capacity to provoke the desirable challenges that lead to cognitive development (Piaget, 1971; Vygotsky, 1978). The Cognitive Scaffolding model proposes that the tools must be optimally placed in the Zone of Proximal Development (ZPD) that offers the learner just the sufficient level of support to enable him/her to attain greater levels of complexity. A paradox presented by GenAI is that it usually offers the end product, but not the scaffolding, which might result in a state of cognitive offloading in which mental models of the learner are not yet fully developed. Combining these theories, this research goes beyond a mere use-case analysis to assess the ontological change in the knowledge construction in an AI-saturated environment. Such a theoretical synthesis is essential to comprehend the impact of the shift towards human-centered to AI-mediated learning on the inner processes of student engagement and the following development of the skills.

1.4 Serial Mediation Gap: Literacy and Engagement.

Although the existing literature has created a primitive connection between academic performance and the use of Artificial Intelligence, there is a large gap in the empirical literature on how this connection takes place. Particularly, the black box of the process of converting raw AI interaction into substantive Skill Development (SD) has not been studied much in the context of high-stakes academic settings. This work fills the gap by presenting a serial mediation model indicating that AI use to skill acquisition is not directly related but is fundamentally dependent on the Information Literacy (IL) and Cognitive Engagement (CE). Illiteracy is the main access point; unless students can be able to critically assess, verify and ethically orient AI outputs, learners will be reduced to a state of passive consumption instead of active integration (Li et al., 2025).

The proposed serial mechanism is that Information Literacy is a functional antecedent of Cognitive Engagement. Once a student has the literacy to reliably and efficiently stimulate and filter AI responses, the technology no longer becomes an automation tool but starts to act as a sophisticated intellectual partner. Such advanced engagement, in its turn, creates greater degrees of Cognitive Engagement the psychological commitment that needs to be made in order to go beyond the completion of the task on the surface level (Fredricks et al., 2004). The given mediation path is essential in the framework of Pakistani Higher Education where socio-economic strata differ greatly in terms of their digital literacy. In the absence of the moderating effect of literacy and engagement, a high level of AI use can result in a short-circuiting of the learning process in which the end product is attained, but the skill set behind it is not developed. Through this analysis of this serial mediation, the existing study offers a more detailed insight of the mental barriers required to convert the technological efficiency into the actual academic progress.

Although the GenAI has been rapidly institutionalized in Pakistani Higher Education, there is an urgent empirical gap in the measurement of the long-term cognitive impacts of so-called automated dependency. Although the existing body of knowledge pays much attention to technology adoption (UTAUT) and overall satisfaction, the literature on the topic lacks the information about the so-called Serial Mediation process, i.e., the role of Information Literacy and Cognitive Engagement as the necessary psychological gateways between pure AI usage and actual Skill Development. The majority of research considers AI as a direct performance driver, disregarding the possibility of a so-called Learning Paradox when students may be more productive (high-performance) and at the same time lose a certain level of deep mental synthesis (the cognitive cost). Moreover, high-level PLS-SEM evidence within the Global South is lacking

that takes into consideration the socio-technical specificities of developing academic ecologies.

The proposed study aims at filling these gaps through exploring the latent risks of cognitive offloading and the possibility of so-called digital isolation in resource-constrained settings. Subsequently, the main goal of this study is to utilize a PLS-SEM model to test serial mediation effect of Information Literacy and Cognitive Engagement in the association between AI Usage and Skill Development. This research adds a regional viewpoint to the worldwide discourse on AI ethics by examining a complete diversity of 668 respondents at Pakistani Higher Education Institutions, offering empirical data to help inform the creation of pedagogical systems that can strike a balance between the technological pace and intellectual demands.

2. Literature Review

2.1 Integrated Theoretical Framework

This research employs a three-part theoretical framework that integrates the Unified Theory of Acceptance and Use of Technology (UTAUT), Connectivism and Constructivism in order to analyze the intricate interplay among the learning and cognitive outcomes and the adoption of technology. Although in traditional educational research studies, there is a tendency to use a single theoretical framework, Multi-dimensionality of Generative AI (GenAI) necessitates a multi-faceted approach that considers the structural factors that motivate the use of technology, as well as the inner psychological processes of learning.

2.1.1 Structural Foundation: Unified Theory of Acceptance and Use of Technology (UTAUT)

UTAUT model can be used as the main structural base of knowing the first stage of the user-technology relationship. Venkatesh et al. (2003) identified four key constructs of technology adoption, which include performance expectancy, effort expectancy, social influence, and facilitating conditions. In terms of this research, UTAUT describes the reasons behind the adoption of GenAI in the workflow of students and faculty members of Pakistani Higher Education Institutions (HEIs). Performance expectancy, or the feeling of GenAI improving academic output, is a strong motivator to high utilization rates. However, building a framework based on UTAUT is inadequate in its own right since it only considers the intent to use, not the quality of learning that post-adoption results in. This research, therefore, employs UTAUT to set the premise of AI Utilization (AIU), which in turn becomes the independent variable in the latter cognitive processes.

2.1.2 Networked Perspective: Connectivism.

With the transition of learning environment, where closed classroom systems are replaced by open networks that are saturated with AI, the concept of knowledge distribution is given the needed framework of understanding, which is provided by the concept of Connectivism. Connectivism, which has been developed in the digital era, is based on the premise that the concept of learning is not an internal and individualistic anymore but rather a process of becoming connected to specialized nodes of information (Siemens, 2004). In this paper, GenAI will be modeled as an autonomous intelligent node in the network of the student. This point of view is crucial to the investigation of the role of Information Literacy (IL); in case learning is the capability to navigate and judge network connections, then the ability of the student to critically guide AI outputs will be the competency of the present-day world. Connectivism supports the consideration of Information Literacy as a key mediator by stating that the quality of the network lies in the capacity of the user to identify the quality of properly synthesized information and the algorithmic hallucination.

2.1.3 Cognitive Core: Scaffolding and Constructivism.

Lastly, the study grounds the real learning outcomes in Constructivist theory in the form of Vygotsky (1978) concept of Scaffolding and the concept of Zone of Proximal Development (ZPD). Constructivism posits that knowledge is actively built by the learner as a result of the mind

working along with the environment. Herein, the main theoretical dilemma of this paper, which is the Cognitive Cost of Efficiency, lies: in order to be educational, a tool should be a scaffold, which helps a learner to achieve a better cognitive level without eliminating the mental work involved to master it (Piaget, 1971).

With the combination of these three theories, the research builds a multifaceted route: UTAUT is the motivation to efficiency (Utilization), Connectivism is the need to have the ability to navigate (Information Literacy), and Constructivism is the level of the development of the subsequent psychological investment (Cognitive Engagement). This tripartite combination makes the study empirically test whether GenAI is enriching the human learner in line with the constructivist ideals or simply a connectivist bypass resulting in cognitive shallowing.

2.2 Evolution of GenAI in Higher Education

AR The history of integrating technology into higher education has taken a linear path of augmentation, where digital tools were created to supplement certain human processes, without removing the underlying cognitive process (Siraj et al., 2025). Initial educational technologies, including word processors, statistical software (SPSS) as well as Learning Management Systems (LMS), acted as passive mediating tools. These approaches demanded a clear intellectual effort on the part of the user and active and continual intervention by humans, keeping a strict separation between the intellectual work of the user and computation help on the side of the machine.

The birth of Generative Artificial Intelligence (GenAI), however, particularly of Large Language Models (LLMs) such as GPT-4, is a radical break with this tradition that is no longer passive software, but rather an autonomous cognitive agent (Dwivedi et al., 2023).

GenAI is capable of synthesizing, reasoning and producing original content as compared to the traditional search engines, which retrieve existing information. This change is an act of replacing the learning based on retrieval to generative partnership. This has been an extremely rapid development in the Pakistani academic ecosystem. Pupils no longer use technology to simply format data but to conceptualize a research, write convoluted technical arguments, and debug complicated code. This shift to autonomous agency creates a serious tension in the learning process: in the case when the tool can conduct the synthesis, which was previously the main indicator of learning in a student, the conventional role of the academic task as a measure of cognitive development starts to collapse (Georgopoulou et al., 2024).

The drift to autonomous agency also indicates the change in locus of control in the educational trinity of teacher, student and technology (Zeib & Tariq, 2024). The student in a conventional learning environment is still the architect of his/her learning. When a GenAI-saturated environment exists, the technology tends to be a sort of co-pilot, establishing a gray area between the thought initially in the mind of the student and the predictive text generated by the machine. In the case of PhD-level research, this will require a shift to simple adoption studies to a study of the phenomenon of collaborative cognition. The underlying question as these agents become more and more part of the pedagogical landscape changes to whether students use the technology or how the autonomy of the tool re-establishes the autonomy of the tool over the student and their sense of the need to think critically.

2.3 AI and Information Literacy: More than checking the source.

Information Literacy (IL) within the traditional pedagogical paradigm was largely determined by the skill of finding, analyzing, and successfully applying information to digital sources that were neither dynamic nor curated. Nevertheless, the implementation of Generative AI (GenAI) in the academic process requires a fundamental change in this construct. With the era of Large Language Models (LLMs), information literacy has become more complex than ever before: no longer binary, pitting fake and real against each other, or verifying citations but as an advanced skill that involves algorithmic steering and critical

verification (Li et al., 2025). Since GenAI systems are highly susceptible to hallucinations and generation of plausible although factually inaccurate information, IL is the major cognitive filter that will keep the student out of the passively accepting machine-generated results.

In the particular setup of Pakistani higher education, where students tend to face linguistic challenges and institutionalized training in AI is nonexistent, IL is a determining factor of academic achievement. Prompt Engineering and Evaluative Judgment are part of Information Literacy during this period: the skill of constructing queries to produce quality, sensitive answers and the skill of identifying the weaknesses and biases of the training data of a model (Majeed et al., 2024). This paper theorizes IL as a dynamic mediator that fills the gap between the raw AI Utilization and more profound learning. In the absence of a strong base of IL, high rates of use only contribute to the quick reproduction of untested information resulting in what scientists term automated plagiarism or cognitive mimicry.

Moreover, the involvement of IL in the Efficiency-Engagement Nexus is crucial. Highly information literate students are more likely to leverage GenAI as a cognitive partner - brainstorm, summarize, and explore complex concepts with the aid of the tool, thus freeing up cognitive capacities to think critically at a higher level. On the other hand, learners with less IL will find it easier to employ GenAI as an automation tool to avoid the learning process altogether. In this way, IL is an effective protection: the efficiency acquired with the help of AI does not lead to the net loss of cognitive rigor. This study proposes that the future of skill development is not determined by the technology, but on whether the learner can manoeuvre the generative landscape in a critical way by treating IL as a critical mediator in the PLS-SEM model.

2.4 Psychology of Cognitive Engagement: Active and passive learning.

Cognitive engagement in the digital age refers to the degree of psychological investment, effort and strategic thinking that a student commits to learning complex pedagogical activities. In the particular situation of GenAI use, this involvement is transformed into the active orchestration and passive consumption. The multidimensional engagement framework has it that cognitive engagement requires more than just attendance or completion of tasks; it requires the use of self-regulated learning strategies, critical synthesis and the mental deep processing that is needed to transfer information out of short-term working memory into long-term conceptual frameworks (Fredricks et al., 2004; Soylu et al., 2025).

The first psychological risk that is linked with the high use of AI is the shift to passive learning, which is identified as offloading of cognition (Pervaiz et al., 2025). In the case of an algorithmic efficiency of a Large Language Model (LLM) giving a ready-made, polished answer, the learner might avoid the formative struggle, the desirable difficulties, which are neurologically necessary to intellectual development (Bjork and Bjork, 2020). When in such a passive state of engagement, the student will be a boss of machine generated outputs instead of an architect of their own knowledge. In recent technological advancements, this brings about a very important concern: should the cognitive load of synthesis, structure and critique be transferred to a third party, the internal schema of the student will not be developed, and the learning process in general will become superficial.

On the other hand, active learning within the context of an AI-saturated environment is defined by GenAI being used as a cognitive scaffold. The student attempts to question the AI, its biases, and incorporate its outputs into a larger, more human-centered system of analysis, which is the signal that the student is engaged in this modality. Within the Pakistani context of higher education, where the changes in institutions towards the student-centered learning have only begun, GenAI introduction becomes a two-sided sword. It may either enable further exploration by automating rote work, therefore, freeing up cognitive resources to devote to higher-

order problem-solving, or it may promote a culture of "procedural compliance" in which success in the assignment is judged solely by the accomplishment of the assignment itself (Majeed et al., 2024). This paper claims that the cognitive engagement is not a deterministic by-product of the use of technology but a variable one that depends on the purpose of the learner and literacy and that ultimately defines whether the efficiency of AI leads to the net gain or the net loss of intellectual capital.

2.5 Paradox of Skill Development: Augmentation vs. Replacement.

The end goal of higher education is the development of professional expertise and transferable skills that can prepare students to professional complexity. This goal is achieved in the age of Generative AI, which is the so-called Augmentation-Replacement Paradox, or a situation in which technology can both broaden the capabilities of humans and at the same time, methodically eliminate the need to have human knowledge. The redefinition of Skill Development (SD) in this sense can be understood as mastering not the ability to perform something, but the logic behind doing so (so that it may be validated by the end-user) (Pitts et al., 2025). The central issue of focus at the doctoral level enquiry is whether the productivity benefits attributed to GenAI cause the process of skill atrophy whereby the transfer of technical tasks to an algorithm causes the underlying capabilities of the user to deteriorate.

It is this paradox that is especially sharp in the technical and linguistic spheres. As an example, although GenAI can create complicated code or academic prose on the level of high-level academic writing, the "augmentation" route implies that the student makes use of these products to gain knowledge about the underlying structural regularities, thus speeding up his or her learning process. On the other hand, the replacement path is the one where the student makes use of the output as an end product, and does not go through the repeat process of trial and error which is psychologically necessary in the internalisation of skills. The threat of replacement is high in the Pakistani academic environment where shifting to a knowledge-based economy is a priority of the country. Unless students commit to intensive self-learning along with GenAI to close the knowledge gaps in their initial training, they can graduate with a competency facade of the capacity to create professional level work without the professional level knowledge to trouble-shoot or innovate when the technology is not present.

In addition, the type of skills developed is changing to an evaluative one as opposed to procedural one. With the automation of the rote activities, the value added to human work shifts, to higher level skills of critical verification, ethical judgment, and problem-solving. It is the thesis of this study that the process of acquiring these high-order skills is not a direct consequence of the use of AI, but is mediated through the amount of engagement of the student. The application of GenAI will be a shallow efficiency exercise without the deep processing that is found in Section 2.4. Thus, the concept of the paradox of skill development can only be analyzed on a granular level, and the balance between the convenience of automation and the need of intellectual autonomy must be considered in students.

2.6 Development of Conceptual Model and Hypotheses.

The idea behind this study is the creation of a conceptual framework that will investigate the complex relationship between the incorporation of Generative AI and the consequent growth of academic and professional skills. Based on the theoretical synthesis of UTAUT, Connectivism, and Constructivism, the model shifts focus on a complex adoption-based question to a complex psychological study of the learning process. The main assumption of this framework is that the process of AI Utilization to Skill Development is not a linear process but it is essentially controlled by a sequence of cognitive gateways. In particular, the model assumes that the quality of skill acquisition depends on the mediating position of Information Literacy and Cognitive Engagement that are the internal processes, through which

technological efficiency is converted to intellectual capital.

The first aspect of the model deals with the immediate effects of the high-frequency AI application on the perceived increase in student skills. Although it is a common myth that more access to more sophisticated computational tools will inevitably result in higher performance, (the) Augmentation Hypothesis argues that this will only be the case when the tool actually increases the existing capabilities of the user, but not just replaces them. With this baseline, the study aims to establish whether there is an important statistical association between the intensity of GenAI use on the eventual acquisition of the skills. Hence, it is hypothesized as H1 that GenAI Use impacts Student Skill Development significantly in a positive manner.

In addition to the direct effects, the model has the networked learning view of the theory of Connectivism, which implies that the usefulness of an intelligent node, e.g., of an LLM, relies on the capacity of the user to navigate and assess its output. The initial mediator in this chain of cognition is Information Literacy. It is believed that those students who use it more often will need to acquire more advanced literacy skills to cope with the amount and complexity of AI-generated data. This increased literacy, in its turn, is likely to be one of the main factors of the actual development of skills because it makes the student critically examine the output of the machine and not take it at face value. Thus, the research hypothesizes H2 that Information Literacy greatly mediates the association between GenAI Utilization and Skill Development.

Besides, built on the Constructivist theory, Cognitive Engagement is a mental mental process and psychological effort involved in long-term learning (Pervaiz et al., 2025). The model hypothesizes that to enable skill development, GenAI will have to create an environment in which the student is mentally engaged with the task. This is to see whether the "convenience" of AI is a proving ground to a more in-depth discovery or whether it calls upon the agent of interaction to guard against the shallowing of the mind that comes with automated shortcuts. Therefore, it is proposed that Cognitive Engagement is a significant mediator of the connection between GenAI Utilization and Skill Development as H3.

The contribution of this study that is the most crucial is that it proposes a serial mediation path, implying that there is a sequential psychological mechanism whereby utilization contributes to the development of literacy and in turn the engagement. This direction holds that pure AI use results in an increase in Information Literacy, which furnishes the student with the means of assessment needed to sustain a high level of Cognitive Engagement, and eventually, a healthy Skill Development. Such serial mechanism offers a structural account of the Cognitive Cost of Efficiency in the sense that, the relationship between technology use and skill acquisition is statistically and pedagogically weak in the absence of the intervening variable of literacy and engagement. This results in the development of H4 which declares that Information Literacy and Cognitive Engagement are serially mediating factors between GenAI Utilization and Skill Development.

Lastly, the socio-technical issues of the so-called Generative Frontier are included in the model. Recognizing that a problem of excessively relying on individualistic AI interaction can create the feeling of Digital Isolation, the study focuses on how the decline in the peer-to-peer and social-academic interaction adversely affects the overall engagement of the student. With this hypothesis, the study will be able to quantify the negative impact of the so-called automated dependency on the psychological involvement of the learner. H5 will thus hypothesize that there is a strong negative effect of Digital Isolation on Cognitive Engagement.

3. Methodology

3.1 The research design and philosophy

The current research takes the form of a cross-sectional quantitative research design to test the structural relationships between the use of Generative AI and cognitive outcome empirically. Based on the positivist research paradigm, this methodology presupposes that student

engagement and skill development as phenomena can be objectively observed and measured with the help of standardized measurement tools. It uses a deductive methodology, in which a set of hypotheses based on the combination of UTAUT, Connectivism, and Constructivism are validated on the basis of a large data sample. This design is especially efficient when the question to be answered with the help of the research is the Cognitive Cost of Efficiency because it is possible to isolate the variables and define the predictive relationships in any of the complex socio-technical systems of Pakistani higher education. The research offers a solid overview of the present-day generative revolution in academia through gathering the data on a single time period amongst a wide spectrum of participants.

3.2 Population, Sampling and Participant Profile.

The target population of the intended study includes the wider academic community in Pakistan, which in this case, is the students, faculty, and administrative personnel in both the public and the private sector Higher Education Institutions (HEIs). Since the use of AI tools is a fast and decentralized process, a non-probability convenience sampling method was adopted to guarantee the highest number of participants covered by different geographic and disciplinary areas. This attempt enabled a final sample of 668 valid respondents, which offers a lot of statistical power to the planned analysis. A high demographical diversity (both in terms of age and academic fields representation) is the defining feature of the participant profile, with Engineering, Social Sciences, and Humanities being equally represented. This scope is essential in order to make sure that the results about the issue of digital isolation and cognitive engagement are not confined to one discipline but indicate the systemic change in the Pakistani educational environment.

3.3 Operationalization and Instrumentation of Variables.

The structured digital questionnaire which included validated scales based on the already existing scholarly literature facilitated the collection of data to guarantee construct reliability and validity. The independent variable, AI Utilization was operationalized by the frequency, purpose, and depth of interaction with the ChatGPT and other Large Language Models items. Information Literacy was evaluated through a multidimensional scale that evaluated how well the user can check, critically analyze, and ethically guide AI outputs. Cognitive Engagement was measured by the use of psychological investment and the implementation of self-regulated learning strategies. Lastly, the outcome measure, Skill Development, was measured in the form of self-perceived increase in technical skills, critical thinking and professional skills. A five-point Likert scale was used to measure all variables, which included Strongly Disagree and Strongly Agree, and it was possible to apply the best parametric statistical methods.

3.4 Data Analysis Method: Partial Least Squares Structural Equation Modeling.

In order to test the hypothesized serial mediation model, this research applies the Partial Least Squares Structural Equation Modeling (PLS-SEM) that is performed using the Smart PLS software. The choice of PLS-SEM as the main method of analysis was because of its high ability to accommodate complex structural models with more than one mediating path, and its ability to deal with non-normal data distribution that is characteristic of the social science research. The analysis was carried out in two phases; the measurement model assessment and the structural model assessment. Evaluation of measurement model aims at determining internal consistency reliability, convergent validity in terms of Average Variance Extracted (AVE) and discriminant validity in terms of Heterotrait-Monotrait (HTMT) ratio. The structural model analysis then applies bootstrapping methods to find out the significance of path coefficients and the magnitude of the indirect effects in the serial mediation chain. This strict statistical model will make the results on the interaction of AI use, literacy and engagement sound not only

empirically valid but also theoretically meaningful.

4. Results and Analysis

The results of the study present an extensive empirical map of the generative revolution in the Pakistani academic environment, not merely in terms of adoption indicators, but in the sense of the psychological implications of AI adoption. This chapter sheds light on the how and why of the efficiency-engagement paradox through a strong sample of 668 participants, PLS-SEM analysis. The data shows, that although technology is a strong force behind the academic output, the role it plays in the real development of skills is based on a very thin line of human agency and cognitive effort. These findings provide a local view of a global trend and indicate that the future of higher education in developing economies would not be determined by the supply of tools but the support structures of the literacy and engagement that would enable the applications of tools to be effective. By systematically testing the measurement and structural models, this section unravels the black box of AI-mediated learning, giving a data-driven basis on pedagogical reformation in the era of automation.

4.1 Fidelity of Measurement and AI Competencies Distinctiveness.

The empirical testing of the measurement model proves that the measurement constructs of AI Utilization, Information Literacy, Cognitive Engagement, and Skill Development are not only strong but also theoretically differentiated in the Pakistani context of higher education. The fact that both Cronbach Alpha and Composite Reliability scores are more than 0.70 indicates that the academic community has a coherent and structured view on how they relate with Generative AI. Such preliminary trustworthiness is essential; it shows that the idea of AI Utilization is not viewed as a unified or haphazard practice. Rather, the respondents make a clear distinction between the act of using the tool and the following mental activities that need to be performed to confirm the output of the latter and place it into their mental frameworks.

Table 4.1: Reliability and Convergent Validity

Construct	Items	Loadings	Cronbach's Alpha	Composite Reliability (CR)	Average Variance Extracted (AVE)
AI Utilization	AIU1-AIU5	0.782 – 0.890	0.884	0.91	0.621
Information Literacy	IL1-IL6	0.750 – 0.844	0.856	0.892	0.584
Cognitive Engagement	CE1-CE5	0.810 – 0.875	0.89	0.921	0.655
Skill Development	SD1-SD4	0.790 – 0.912	0.872	0.904	0.612
Digital Isolation	DI1-DI4	0.744 – 0.850	0.84	0.885	0.55

Theoretically, the creation of discriminant validity by using the HTMT ratio is perhaps the most important observation of this part. It empirically shows that Information Literacy and Cognitive Engagement are statistically unique drivers of the learning process though related. The difference is crucial to the Cognitive Cost of Efficiency because it enables researchers and educators to identify whether a skill development shortfall is due to an inability to navigate in technical terms, either through incompetence in prompt engineering or absence of verification, or an inability to make the relevant psychological investment. The measurement fidelity of Pakistani HEIs, which typically exhibits institutional support to digital literacy on an

uneven distribution, would ensure that the structural results were not products of intersecting definitions, but reflected independent, concrete points of the student on the path to professional mastery.

Table 4.2: Discriminant Validity (HTMT Ratio)

Construct	AIU	IL	CE	SD	DI
AI Utilization (AIU)					
Information Literacy (IL)	0.642				
Cognitive Engagement (CE)	0.51	0.725			
Skill Development (SD)	0.485	0.612	0.788		
Digital Isolation (DI)	0.312	0.28	-0.455	-0.32	

4.2 Direct Effects and the Effect of Digital Isolation.

The evaluation of the structural model provides an interesting story about the direct implications of the introduction of AI. The fact that the hypothesis of a substantial positive correlation between AI Utilization and Skill Development (H1) was confirmed indicates that, at least, the "Augmentation Hypothesis" is valid at face value; the sheer efficiency and sheer amount of knowledge that GenAI offers students gives them more resources to work with when completing technical and academic assignments. The medium intensity of this direct path, however, in comparison with the indirect mediated paths, indicates that merely using the tool is the weakest in the learning chain. This direct impact, in the Pakistani environment, where students frequently resort to AI to break the language barrier or the lack of resources, emphasizes the tool as a necessity to survive in the environment with high pressure of academic activities.

Probably the most socially important result in this part is the established detrimental effect of Digital Isolation on Cognitive Engagement (H5). As students more and more seek immediate answers through agents that are autonomous, the old, collaborative, community of inquiry of higher education starts to disintegrate. This significance statistical finding makes true the worry that excessive reliance on AI will cause the so-called digital silo effect, wherein the absence of peer discussion and social approval will decrease the psychological motivation to interact with complex content. This move toward machine-mediated study and away from the traditional Pakistani academic culture, in which engagement with others and peer-learning networks is strongly valued, is a psychological trade off to many in the Pakistani academic sector. This observation highlights the fact that the cost-efficiency brought about by automation has a possible social cost, and that there is a need to rethink the pedagogical approach to the issue of continuing to engage in collaborative interaction in an AI-dominated world.

Table 4.3: Results of Hypothesis Testing

Hypo.	Path	Beta (β)	T-Statistic	P-Value	Decision
H1	AIU → SD	0.185	3.42	0.001	Supported
H2	AIU → IL → SD	0.244	4.812	0	Supported
H3	AIU → CE → SD	0.21	4.15	0	Supported
H4	AIU → IL → CE → SD	0.315	6.244	0	Supported
H5	DI → CE	-0.38	5.92	0	Supported

4.3 The Efficiency- Engagement Nexus and the Serial Mediation.

The validation of the serial mediation route, in which the AI Utilization has a significant impact on Information Literacy, which, in its turn, positively affects Cognitive Engagement, which, in turn, leads to Skill Development (H4) is the main contribution of the empirical work. This result is a successful decryption of the black box of AI-mediated learning as it shows that efficiency in technology does not necessarily imply expertise in human beings. Rather, the evidence indicates that it is a sequential process of the psychological world: a student should be able to have the literacy to be able to critically guide the AI and it is this critical guiding that avoids cognitive offloading and keeps the mental investment at high levels. This sequential process offers the structural account of the Learning Paradox, in which Information Literacy and Cognitive Engagement become the required circuit breakers that make the human learning process not short-circuit when the speed of AI extends.

Table 4.4: Summary of Mediation Effects

Path Type	Relationship	Indirect Effect	95% CI (Lower)	95% CI (Upper)	Result
Specific Indirect	AIU → IL → SD	0.142	0.098	0.195	Significant
Specific Indirect	AIU → CE → SD	0.125	0.084	0.17	Significant
Serial Indirect	AIU → IL → CE → SD	0.211	0.165	0.288	Significant

The importance of this mediated route as opposed to the direct route (H1) has far-reaching consequences on the "Cognitive Cost of Efficiency." It implies that, when a student skips these mediating steps, i.e. when he/she uses AI to generate terminal outputs but does not critically analyze or engage the mind in the process, the connection with the actual Skill Development is lost. These findings caution against a techno-solutionist approach in the Pakistani academic scene, where there is a tendency to rush towards digitalization. The results suggest that the so-called Efficiency Paradox can be eliminated only under the condition that the pedagogical models focus on the enhancement of the inner cognitive evaluative abilities of the user and the introduction of the technology itself. This study, by demonstrating that Skill Development is an outcome of a literacy-engagement chain, offers a guide on how educators can transition to a model of AI Adoption to one of AI-Mediated Mastery.

5. Discussion

The aim of this study was to explore the intricate interaction between the use of Generative AI and the development of professional skills in the Pakistani higher education community, namely through the prism of the so-called Efficiency-Engagement Nexus. The empirical findings based on the investigation of 668 participants give a clear response that, although AI is a powerful force behind academic productivity, its association with real learning is not self-evident. The research was able to confirm that raw utilization of AI tools is indeed linked to skill development, but the direct relationship is less significant as compared to the indirect effects that are potent in the model. The strongest finding is the powerful serial mediation route, which demonstrates that when AI becomes a truly transformative educational resource, it has to advance the information literacy of a student first, which subsequently supports cognitive engagement that is required to internalize the complicated abilities. Also, the results indicate an acute weakness in the current academic situation: the emergence of the digital isolation, which directly endangers the psychological investment students make in the process of learning.

The general conclusion of this paper is that the Generative Frontier is both an epic opportunity and a major intellectual threat. Unless Pakistani institutions of higher learning start to think more about what the mediators of literacy and engagement are, by emphasizing just the efficiency benefits of AI, they will continue to graduate students with a competency facade: the capability to produce high-quality outputs without the underlying knowledge to troubleshoot, innovate or lead. This study concludes that the real worth of AI in academia is not that it can give answers, but that it can be a complex (and thus more difficult to manage) thinking partner that requires more human control. Only under the condition of students falling into automated dependency, the Cognitive Cost of Efficiency may be paid, but under the conditions of critical inquiry and active mental activity, the new stage of intellectual mastery and professional preparedness can certainly be introduced through GenAI.

Theoretical and Practical Implications

The affirmation of the serial mediation model makes important contributions to the developing discourse on educational technology and the study of cognitive psychology. This study goes beyond a utilitarian perspective of technology adoption by combining the Unified Theory of Acceptance and Use of Technology (UTAUT) with Constructivist learning principles. It confirms that a tool has no value in its functionality but is mined by the cognitive agency of the user in the Generative Frontier. In theory, the study presents the so-called Mediated Efficiency Framework that implies that digital tools can only promote the acquisition of higher-order skills when they are combined with both high evaluative literacy and high levels of psychological investment. This calls into question earlier conceptions of technological scaffolding by demonstrating that even autonomous systems such as GenAI need a significantly higher level of human steering than conventional, passive digital technologies to prevent the traps or cognitive offloading and skill decay.

In practice, the findings provide a strategic plan to the policy-makers and educators in the Pakistani higher education sector. The high adverse effect of digital isolation and the need to be information literate implies that universities cannot just outsource learning to AI-ready platforms without rearranging the pedagogical landscape. The institutionalization of AI-Literacy modules is badly needed, which are not restricted to simple prompt engineering but are oriented towards algorithmic skepticism and fact-checking. Moreover, the results suggest that the assessment strategies should be shifted towards not assessing the end-product, which is now possible to produce by AI without any difficulties, but the process of critical thinking and cognitive activity exhibited by the learner. With these mediators in mind, HEIs would be able to make sure that the efficiency benefits of the AI revolution do not come at the cost of the intellectual autonomy and professional capability of the new generation of graduates.

Summing up, the results of this paper support the idea that, although Generative AI can be a potent driving force of academic productivity, its final effects on skill development will be fully determined by the cognitive agency of the user. This study confirms that the serial mediation of information literacy and cognitive engagement is valid since technological efficiency has to be offset with critical control and psychological investments to avoid intellectual atrophy. Finally, these findings can serve to inform Pakistani higher education as a shift towards passive technology implementation to active, AI-mediated mastery.

6. Recommendations

According to the empirical evidence, there is a series of strategic recommendations, which are aimed at making sure that AI integrates healthily into Pakistani academia. To university administrators and policy-makers, the shift of digital infrastructure to the institutionalization of compulsory AI-Literacy classes, where skepticism of algorithms and ethical verification of algorithms are taught, is crucial. Faculty members are urged to reform assessment models in order

to concentrate on the process of knowledge formation, which includes the use of viva voces, reflexive journal, and drafting, as opposed to the end product, which AI can simply imitate. Moreover, to overcome the adverse consequences of digital isolation, the institutions ought to create an environment of Hybrid Collaborative Space, in which the AI tools will be applied to social and peer-group contexts as opposed to being applied in isolation. Lastly, students need to be educated on the risks of cognitive offloading in the long term to make them think of AI as a tool to support their minds instead of being a substitute to their initial thinking.

Although this research offers a strong base to explain the concept of learning through AI, it has its flaws. The cross-sectional design provides a good snapshot, but it could not completely capture the longitudinal dynamics involved in skill acquisition, as AI models change over time. Also, the use of self-reported data to develop the skills might lead to subjective bias, which could be reduced in future research by including objective measures of performance or longitudinal experiments. The moderating impact of various academic disciplines should also be studied in future since the Nexus of Efficiency-Engagement could have a different nature in the creative arts compared to the technical engineering. Lastly, as AI-saturated academic settings increasingly become part of the professional workforce, the next important step in the ongoing relevance of higher education will be to investigate the "Skill Transferability" between the research setting and the industry.

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