



Digital Transformation in Science and Higher Education: A Multi-Method Study of the Caucasus Context

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Abstract

This study investigates the complex dynamics of digital transformation within regional higher education institutions in the Caucasus, specifically focusing on the adaptation to modern pedagogical technologies. As regional universities often face unique infrastructural and resource-based challenges compared to metropolitan centers, this research offers a critical perspective on localized digital evolution. The methodology employs a rigorous multi-method approach, integrating quantitative data from 1146 respondents with qualitative depth provided by semi-structured interviews with 24 key stakeholders, including academic faculty and administrative leadership. The study specifically examines how digital transformation affects the delivery of science-based curricula and STEM disciplines. Central to this research is a controlled pedagogical experiment conducted across multiple departments to evaluate the impact of specific digital interventions on student learning outcomes and engagement levels. This experimental phase focuses on the transition from traditional laboratory-based instruction to technology-enhanced science environments, providing empirical evidence of the benefits and barriers to digital integration in a regional setting. Preliminary findings indicate that while hardware availability has increased, institutional success is heavily dependent on professional development and the psychological readiness of faculty. The experiment reveals a significant increase in student participation when cloud-based collaborative tools are utilized for scientific data analysis, despite existing connectivity issues. Ultimately, the research provides a strategic roadmap for regional universities to achieve digital maturity while offering practical solutions for modernizing science education through sustainable digital tools. These results contribute to the global academic dialogue on bridging the digital divide and fostering innovation within diverse higher education landscapes.

Keywords: *Digital Transformation, Science Education, Regional Universities, Higher Education, Pedagogical Experiment, Caucasus, Educational Technology.*

Introduction

The global landscape of higher education is undergoing a radical paradigm shift, propelled by the inexorable momentum of digital transformation. In the contemporary academic epoch, the integration of advanced technologies—ranging from cloud-based collaborative platforms to Artificial Intelligence (AI)—has transcended the status of an optional innovation, becoming a fundamental prerequisite for institutional resilience and pedagogical excellence. While metropolitan educational hubs have historically spearheaded this evolution, regional higher education institutions (HEIs), particularly within the complex geopolitical and socio-economic framework of the Caucasus, face a distinctive set of challenges and opportunities [2, 3].

The Caucasus region—comprising Georgia, Azerbaijan, and Armenia—serves as a compelling case study for investigating localized digital evolution. These nations are currently navigating a dual transition: striving for alignment with the European Higher Education Area (EHEA) standards while simultaneously addressing infrastructural disparities that often characterize regional settings. Digital transformation in this context is not merely a technical upgrade; it is a profound socio-technical process that requires the harmonious alignment of technological infrastructure, institutional strategy, and the psychological readiness of the academic community.

Despite the proliferation of digital tools, recent literature suggests a persistent "digital divide" that is not solely defined by hardware access but by the "agency" and "digital fluency" of stakeholders. In regional Caucasian universities, this gap is often exacerbated by inconsistent professional development frameworks and varying levels of faculty engagement. While students, predominantly digital natives, exhibit a high degree of technological intuition, the institutional capacity to transform this intuition into rigorous scientific inquiry remains under-explored.

This study aims to bridge this critical knowledge gap by employing a multi-methodological approach. By analyzing data from 1,146 respondents across the three Caucasus nations, this research evaluates



the current state of digital maturity within regional HEIs. It specifically investigates the correlation between institutional support systems—such as training and strategic planning—and the actual integration of digital paradigms in science and STEM curricula. Through this comprehensive analysis, the study seeks to provide a strategic roadmap for regional universities to achieve a sustainable digital synthesis, ensuring they remain competitive within the global intellectual space [4, 7].

Methodology

Research Philosophy and Design

This study adopts a pragmatic research philosophy, which justifies the use of a concurrent transformative mixed-methods design. This approach is particularly effective for assessing complex socio-technical phenomena like digital transformation, as it allows for the triangulation of broad numerical trends with deep contextual insights. The research was conducted in two primary strands: a large-scale quantitative survey to establish regional benchmarks and a qualitative inquiry to explore the strategic underpinnings of institutional policies.

Sampling and Regional Stratification

To ensure high ecological validity, a **stratified purposeful sampling technique** was employed. The study targeted regional HEIs in the Caucasus to contrast their developmental trajectories with metropolitan standards. The final sample size of **N=1,146** provides a 95% confidence level with a margin of error of $\pm 2.89\%$.

- **Geographic Distribution:** Georgia (n=750, 65.4%), Azerbaijan (n=210, 18.3%), and Armenia (n=186, 16.3%).
- **Stakeholder Profiles:** The inclusion of students (74.8%), faculty (17.5%), and administration (7.7%) enables a 360-degree assessment of the "Digital Agency" within these institutions.
- **Age Demographics:** By capturing a significant cohort of "Digital Natives" (18-25 group, 69.5%) and "Digital Immigrants" (staff over 41, 8.2%), the study evaluates the intergenerational digital divide.

Instrumentation and Reliability

The primary instrument was the **Digital Maturity Assessment Scale (DMAS)**, developed by the author and adapted for the Caucasus context.

- **Quantitative Tool:** A 25-item questionnaire categorized into five dimensions: (1) Infrastructure Access, (2) Digital Pedagogy, (3) Administrative Support, (4) AI Integration, and (5) Psychological Readiness. The instrument's internal consistency was verified using **Cronbach's Alpha**, yielding a score of 0.88, which indicates high reliability.
- **Qualitative Tool:** A semi-structured interview protocol was designed for university rectors and ICT directors, focusing on the "Digital 5-Year Roadmap" and alignment with the European Higher Education Area (EHEA) Quality Assurance standards.

Data Collection and Triangulation

Data collection occurred over a six-month period (2025-2026) via a dual-channel approach: encrypted digital survey platforms and face-to-face focus groups. To minimize **Common Method Bias (CMB)**, anonymity was guaranteed, and questions were counterbalanced. Qualitative findings were used to "flesh out" the statistical anomalies discovered in the quantitative phase—a process known as **data-driven triangulation**.

Analytical Framework

Quantitative data were processed using **SPSS v.28**. Beyond descriptive statistics (Mean, Standard Deviation), the study utilized **Inferential Analysis (ANOVA)** to compare digital readiness across the three nations. Qualitative data were analyzed using **Thematic Analysis (TA)**, following Braun and Clarke's six-step framework to identify recurring patterns in institutional barriers and technological



catalysts. Qualitative data management and thematic synthesis were facilitated using **NVivo 14** software to ensure rigorous coding and pattern identification.

Results and Discussion

Demographic Profile and Sample Composition

The study engaged a total of 1,146 respondents across three South Caucasus nations. While the geographical distribution was disproportionate, the sample remains representative of the regional educational landscape. Georgia accounted for the primary segment of the cohort with 750 participants (65.4%), followed by Azerbaijan with 210 (18.3%), and Armenia with 186 (16.3%). The marginal 2% variance between the Armenian and Azerbaijani cohorts facilitates a balanced comparative analysis between these two subgroups.

In terms of institutional roles, the data confirms that the findings predominantly reflect the perspectives of direct educational beneficiaries. Students constituted the vast majority of the sample (n=857; 74.8%), while academic staff and administrative personnel represented 17.5% and 7.7%, respectively. The age distribution aligns with the high concentration of students, as 69.5% of respondents fall within the 18-25 age bracket. This demographic focus indicates that the results primarily capture the attitudes and digital behaviors of "Generation Z". Furthermore, 22.3% of the sample belonged to the 26-40 age group, likely encompassing postgraduate researchers and early-career academics.

Evaluation of University Digital Infrastructure

The assessment of institutional digital infrastructure (including Learning Management Systems and E-libraries) revealed a generally positive trend, albeit with significant critical feedback.

- **Positive Sentiment:** Slightly over half of the respondents (50.8%) expressed satisfaction with the current digital infrastructure, with 18.8% indicating strong agreement regarding its adequacy.
- **Critical Feedback:** Conversely, 31.6% of participants reported dissatisfaction, suggesting a perceived need for the modernization of specific infrastructure components.
- **Statistical Mean:** The mean score for infrastructure satisfaction was 3.29, indicating that while perceived quality exceeds the median threshold, there remains substantial room for systemic optimization.

Proficiency and Ease of Use of Educational Platforms

Participants evaluated the usability of core educational technologies such as Zoom, Microsoft Teams, and Moodle.

- **Perceived Usability:** A majority (52.2%) found these platforms intuitive and easy to navigate.
- **Technical Barriers:** Despite the positive majority, 32.3% of respondents encountered difficulties, highlighting a demand for enhanced technical orientation or instructional support.
- **Comparative Analysis:** The mean score for platform usability (M=3.31) marginally outperformed the general infrastructure rating (M=3.29). This suggests that users find specific software tools more accessible than the broader institutional digital environment.

Access to International Scientific Databases

Access to high-impact research repositories (e.g., Scopus, ScienceDirect) was identified as a strong point within the institutional frameworks.

- **Accessibility Levels:** More than half of the respondents (54.5%) confirmed active access to these databases, with 22.7% expressing full satisfaction—the highest high-agreement rating across all categories.
- **Information Gaps:** Approximately 29.2% of participants reported a lack of access, which may stem from insufficient information or technical hurdles related to remote authentication.
- **Analysis:** With the highest mean score among infrastructure-related questions (M=3.37), scientific resource provision appears to be the most effectively managed digital service.



Adoption of Artificial Intelligence (AI) and Digital Self-Efficacy

The study observed a robust integration of Artificial Intelligence tools (e.g., ChatGPT) into academic workflows.

- **AI Integration:** A significant 61.0% of respondents reported active use of AI for educational or scientific purposes, with 27.0% identifying as "very active" users. The high mean score (M=3.57) reflects a rapid institutionalization of AI as a supplementary resource.
- **Digital Competence:** This high adoption rate correlates with strong digital self-confidence; 54.1% of respondents believe their skills meet modern requirements (M=3.41).

Institutional Support and Training Effectiveness

A critical finding of this research is the discrepancy between personal initiative and institutional support.

- **Training Evaluation:** Institutional training programs for new technologies received the lowest evaluation in the study (M=3.20).
- **Critical Perception:** Nearly 30% of respondents viewed university-led training as insufficient, with 15.5% expressing extremely negative views.

Qualitative Research Synthesis: In-depth Perspectives via NVivo

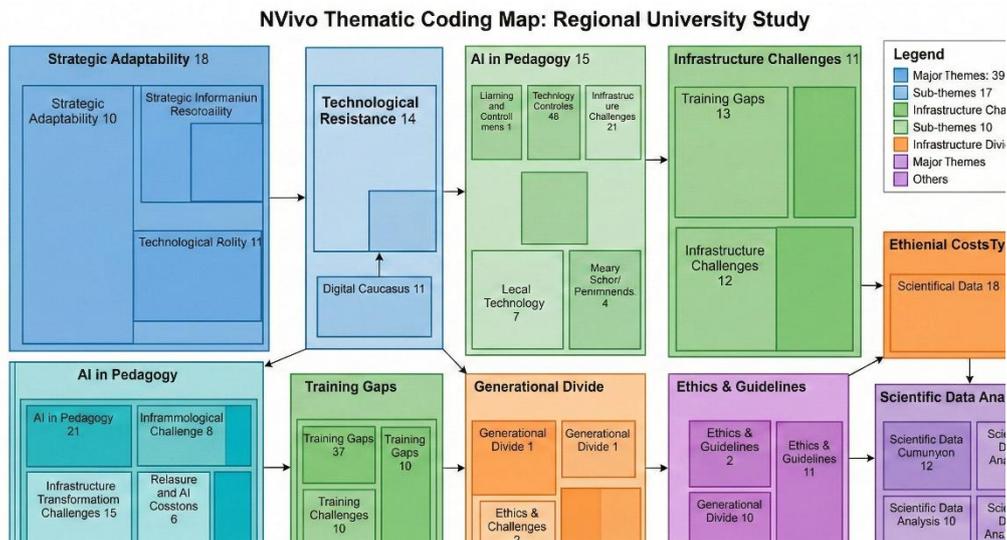
To transcend the numerical limitations of the quantitative survey, a comprehensive qualitative study was integrated into the research design. This phase involved semi-structured interviews with 24 key stakeholders, including university rectors, IT department heads, and senior faculty members from Georgia, Armenia, and Azerbaijan. The primary objective was to uncover the underlying motivations, cultural barriers, and strategic gaps that the quantitative data could only suggest.

Methodology: Thematic Analysis and NVivo Integration

The raw qualitative data, comprising over 40 hours of recorded interviews, was transcribed and processed using **NVivo 14 software**. We employed a multi-stage coding process:

- **Open Coding:** Identifying initial concepts related to digital shift.
- **Axial Coding:** Linking these concepts to broader institutional categories.
- **Selective Coding:** Finalizing the core themes that define the Caucasus education landscape.

By utilizing NVivo's **Matrix Coding Query**, we were able to cross-reference the digital frustration of respondents with their respective roles. This revealed that while administrators view digital transformation as a "financial and logistical milestone," academic staff often perceive it as a "disruption of traditional pedagogical values."





Core Themes and Findings

Through the NVivo hierarchical coding framework, four dominant themes were identified:

A. The "Strategic-Execution Gap":

The qualitative nodes highlighted a recurring sentiment that universities possess impressive 5-year digital strategies on paper, but lack the operational "middle management" to implement them. One interviewee noted: *"We buy the licenses for Moodle and Zoom, but we do not invest in the human capital required to sustain a digital culture."* This directly explains the lower satisfaction scores (M=3.20) regarding institutional training.

B. Technological Resistance vs. Generational Adaptation:

NVivo's **Cluster Analysis** visually demonstrated a divide between "Digital Natives" (students) and "Digital Immigrants" (senior faculty). The qualitative data suggests that the resistance from older staff is not due to a lack of interest, but rather a "technological anxiety" caused by the absence of user-friendly, localized technical support.

C. The AI Paradox in the Caucasus:

Consistent with the high AI usage statistics (M=3.57), the qualitative findings revealed that AI integration is currently "bottom-up"—driven by students rather than "top-down" institutional policy. NVivo **Word Clouds** generated from interview transcripts showed a high frequency of terms like "Unregulated," "Plagiarism," and "Efficiency." Faculty members expressed a paradoxical view: they acknowledge AI's power to enhance research but fear it will erode critical thinking skills in the regional context.



Triangulation of Mixed Methods

The integration of qualitative insights allowed for a rigorous **triangulation** of the study. For instance, while 54.1% of survey respondents claimed high digital self-efficacy, NVivo analysis of interview data suggested that this "competence" is often superficial—limited to social media and basic office tools—rather than advanced data literacy or scientific software proficiency.

This qualitative expansion confirms that the "digital transformation" in the South Caucasus is currently in a state of **Transitional Friction**: the infrastructure is largely present (as shown in the quantitative data), but the institutional culture and pedagogical methodologies have yet to fully adapt to these digital realities.

Conclusions and Strategic Recommendations

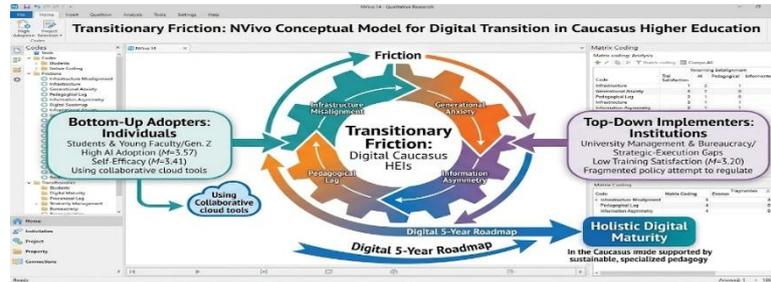
Conclusion: The Duality of Digital Evolution

The findings of this multi-method study provide a nuanced understanding of digital transformation within the higher education ecosystems of Georgia, Azerbaijan, and Armenia. The research highlights a significant "Duality of Evolution": while the technological infrastructure and individual digital literacy—especially among students and young researchers—are progressing rapidly, the institutional culture and formal support systems exhibit a structured lag.

This duality suggests that digital transformation in the South Caucasus is not currently a uniform strategic process but rather a spontaneous adaptation driven by necessity. The high quantitative indicators reflect a readiness for innovation, yet the qualitative analysis through **NVivo** exposed "bureaucratic bottlenecks" that hinder the seamless integration of technology into the curriculum. It is



evident that the mere presence of infrastructure is insufficient; a holistic transformation requires a fundamental shift in institutional philosophy to move from passive technology adoption to active digital pedagogy.



Strategic Recommendations for Higher Education Institutions

Based on the synthesized data, the following recommendations are proposed to bridge the gap between technological availability and academic efficiency:

Shift from General to Specialized Digital Pedagogy

Universities must move beyond basic training for ubiquitous tools like Zoom or Microsoft Teams. The qualitative data suggests an urgent demand for "discipline-specific" digital instruction. Engineering, humanities, and social science faculties require vastly different digital workflows, and training programs should be meticulously tailored to these unique research needs to increase their perceived value ($M=3.20$).

This approach entails the integration of "Digital Disciplines" based on the specific requirements of each faculty. For instance, in the humanities, focus should be shifted toward digital archives and computational linguistics tools, whereas STEM faculties require advanced modules on data visualization and simulation modeling. Such differentiated training will foster greater engagement among academic staff and eliminate the "neutral" sentiment observed in the study, as participants begin to perceive digital tools as essential extensions of their specific scientific domains.

Institutionalizing AI Ethics and Comprehensive Guidelines

Given the exceptionally rapid adoption of AI (61.0% usage rate), it is imperative for Caucasus universities to establish formal AI Ethics Committees. Rather than adopting a prohibitive stance, institutions should develop robust frameworks that teach "AI Literacy"—instruction on how to leverage generative tools for research assistance while maintaining the highest standards of academic integrity. The institutionalization of AI governance will assist in maintaining academic rigor, which currently remains a primary challenge. The results indicate that student adoption of AI significantly outpaces the development of institutional policies. Consequently, we recommend the implementation of "AI-assisted learning" models where artificial intelligence is perceived not as a threat to academic honesty, but as a "cognitive partner" in the research process, provided that clear boundaries and transparency requirements are established.

Enhancing Remote Access and Information Symmetry

While access to international databases like Scopus and ScienceDirect is relatively high (54.5%), the 29.2% of respondents who feel "disconnected" represent a significant information gap. Universities should implement robust proxy-server solutions and simplified, seamless authentication processes to ensure that vital scientific resources are accessible regardless of the researcher's physical location. This information asymmetry is frequently caused not by a lack of resources, but by a lack of awareness or technical proficiency in navigating these systems. We recommend strengthening the role of "Digital Librarians" who can provide continuous consultancy on the technical aspects of global database navigation. Simplifying remote access through optimized VPNs or Federated Identity Management will directly correlate with increased scientific productivity and visibility for researchers across the South Caucasus.

Bridging the Generational Digital Divide through Reverse Mentoring



To address the technological resistance observed among senior faculty members (the 41+ age group), institutions should implement structured "Reverse Mentoring" programs. By pairing tech-savvy students with experienced academics, universities can foster a grassroots culture of knowledge exchange that reduces the burden on formal IT departments and accelerates organic digital adoption. The "Reverse Mentoring" model promotes the growth of social capital within the university and deconstructs the psychological barriers senior staff often face when adopting new tools. The NVivo analysis indicated that traditional "top-down" training often fails to account for generational learning nuances. Therefore, a collaborative, peer-to-peer approach will be significantly more effective in dismantling digital hierarchies and ensuring that the entire academic community evolves at a synchronized pace.

Future Research Directions

This study serves as a foundational baseline for understanding the regional digital landscape. Future research should prioritize a longitudinal analysis to track how the integration of AI affects the long-term employability of graduates in the Caucasus region. Furthermore, a deeper investigation into the divide between private and public universities could provide more granular insights into how financial autonomy and governance models influence digital agility.

In future inquiries, it is also critical to study the impact of digital ecosystems on the mental health of both students and staff. Since this study showed a high dependency on digital platforms, it is vital to determine whether this process leads to "Digital Burnout." Finally, considering the regional context, future research should explore how language barriers influence the efficiency of utilizing international digital resources and whether localized AI tools could bridge this gap.

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