Applied Digital Verification and Analytics Architecture for Structured Competence Modeling in Digital Learning Environments

Bekzod Baydjanov[1], Bakhtiyorjon Madaliev[1] and Joanna Dudek[2]
[1]*Faculty of Pedagogy, Fergana State University, Murabbiylar Str. 19, 150100 Fergana, Uzbekistan*
[2]*Friedrich-Alexander-Universität Erlangen-Nürnberg, Schlossplatz 4, 91054 Erlangen, Germany*
baybekzod@gmail.com, bakhtiyor1697@gmail.com, joanna.dudek@fau.de

Keywords: Information-Analytical Competence, Digital Pedagogy, Applied Educational Technology, Media Literacy, Information Verification, Performance-Based Assessment, Learning Analytics, Quasi-Experimental Design.

Abstract: This study presents a reproducible applied IT-based digital verification and analytics system designed to model and measure the development of information-analytical competence through a structured LMS-driven workflow architecture in algorithm-mediated information environments characterized by misinformation, manipulation, and information overload. Professional readiness in such contexts requires systematized source investigation, cross-source corroboration, and evidence-grounded decision modeling supported by traceable digital procedures rather than passive information access. The proposed system operationalizes information-analytical competence as an executable workflow-based construct integrating verification routines (CRAAP/SIFT protocols), structured reasoning artifacts, and analytics-ready performance logs within a controlled platform configuration. The architecture includes digital artifact generation (search logs, argument maps, rubric-scored outputs), standardized CSV export via LMS gradebook and form-response modules, anonymized dataset aggregation using pseudonymized identifiers, and baseline-adjusted statistical modeling. The system was deployed across three universities ($N = 448$) under a fixed configuration protocol and evaluated using a quasi-experimental pre-test/post-test design with ANCOVA specification in SPSS 27.0 (post-test as dependent variable, group as fixed factor, pre-test as covariate). Results indicate statistically significant competence gains in the Experimental Group compared to a non-workflow configuration ($F(1,445) = 31.84$, $p<.001$; $d \approx 0.85$), with strongest effects in analytically structured and reflective dimensions. The findings validate the feasibility of a scalable, workflow-driven applied IT framework that integrates LMS-based execution, structured data pipelines, artifact-level traceability, and reproducible learning analytics for competence modeling in digital education systems.

1 INTRODUCTION

Future professionals increasingly operate within algorithm-driven digital ecosystems shaped by search engines, social media platforms, and continuously circulating online data streams. In such environments, effective decision-making depends not merely on access to information, but on systematized source verification, manipulation detection, cross-document comparison, and evidence-grounded reasoning supported by structured digital procedures. Contemporary digital competence frameworks define information and data literacy, critical evaluation, and responsible digital action as core operational capabilities within digitally mediated systems [1]. Accordingly, information-analytical competence is conceptualized in this study as a measurable, workflow-driven construct integrating structured information retrieval, analytical processing, and accountability mechanisms within platform-based environments.

From a systems perspective, effective decision modeling requires the integration of data processing routines, evaluative protocols, and controlled execution logic into reproducible workflows. However, empirical evidence from digital learning environments reveals a gap between expected competence specifications and observable user performance. Participants frequently rely on superficial credibility indicators-such as interface design, engagement metrics, or affective framing-rather than structured verification algorithms. Research on civic online reasoning documents persistent weaknesses in source tracing, cross-verification, and multi-document evidence integration [2]. Furthermore, studies on information overload demonstrate that algorithmically curated information streams can distort judgement, amplify bias, and promote shallow processing behaviors [3]. These findings highlight the need for formalized, replicable verification workflows that transform abstract evaluative principles into traceable and measurable digital operations.

To address this gap, the present study designs and empirically validates a reproducible applied digital verification and analytics architecture implemented within a learning management environment. Rather than framing verification as an isolated instructional technique, the system operationalizes information-analytical competence as a staged digital workflow architecture that generates traceable artifacts and analytics-ready datasets. The deployment was executed through a controlled multi-session implementation cycle and evaluated using a quasi-experimental pre-test/post-test specification across three institutions (N = 448). By integrating workflow-based verification protocols, structured artifact generation, standardized CSV export procedures, and baseline-adjusted statistical modeling, the system aligns with policy-level priorities emphasizing information safety, digital responsibility, and data-informed governance within national digital education strategies [4].

2 LITERATURE REVIEW

Contemporary research in digital learning systems conceptualizes engagement with online information not as an isolated technical skill, but as a multidimensional configuration of cognitive, evaluative, and accountability-oriented processes operating within algorithmically mediated digital ecosystems. Digital competence frameworks explicitly define information and data literacy as a foundational domain integrating structured retrieval protocols, systematic source validation procedures, and controlled information management routines [5], [6]. Within this systems-oriented perspective, competence is not determined by mere tool access, but by observable, reproducible, and loggable behaviors such as cross-verification, credibility scoring, contextual parsing, and evidence-based decision modeling. This operational framing enables competence to be modeled as a traceable and measurable construct embedded within digital architectures.

Media literacy research further substantiates this position by demonstrating that effective evaluation requires structural awareness of how information is produced, framed, distributed, amplified, and monetized across platform infrastructures [7], [8]. Empirical analyses of algorithmic ranking systems indicate that content visibility is frequently driven by engagement metrics rather than epistemic reliability, increasing systemic exposure to misleading or manipulative data. Consequently, digital competence development must extend beyond interface familiarity toward structured evaluative algorithms and reproducible reasoning workflows in networked environments [3]. Such findings justify the integration of formalized verification pipelines capable of mitigating algorithmic distortion and reducing superficial processing patterns.

Evidence from civic online reasoning studies consistently indicates that users rely on superficial interface cues-such as visual design, popularity indicators, or affective tone-rather than corroborative analysis and lateral validation strategies [2]. Experimental assessments reveal persistent weaknesses in claim tracing, source authentication, and multi-document evidence synthesis. These empirical limitations support the incorporation of verification-oriented workflow architectures within applied digital systems. Protocols such as CRAAP and SIFT translate abstract evaluative principles into structured and replicable execution sequences involving source investigation, cross-source corroboration, contextual validation, and credibility assessment [9]. When embedded within platform-based configurations, such protocols transform evaluation into observable digital operations rather than intuitive judgement.

Research on information overload further demonstrates that algorithm-driven content streams intensify cognitive bias and reduce reflective processing, particularly under high-density information exposure [10]. This systemic condition reinforces the need for structured verification workflows that regulate analytic engagement and constrain heuristic shortcuts. From an applied IT perspective, verification routines acquire additional analytical value when embedded within digital infrastructures that generate traceable artifacts-such as timestamped search logs, structured argument maps, and rubric-scored analytical outputs-thereby enabling standardized data capture, cohort-level aggregation, and learning analytics modeling.

At the same time, competence modeling cannot be confined to procedural validation alone. Structured reasoning frameworks emphasize controlled inference generation, evidentiary weighting, and iterative model refinement as central elements of analytic processing [11]. Systems-oriented competence theory further asserts that operational capability emerges through repeated execution within defined workflow environments rather than through declarative knowledge acquisition alone [1]. National digital education strategies emphasize responsibility-oriented and accountability-driven interaction with information infrastructures in institutional contexts [4]. Collectively, these theoretical and empirical strands provide a coherent foundation for modeling information-analytical competence as a staged, workflow-executable, artifact-generating, and analytically measurable construct within applied digital system architectures aligned with Applied IT and learning analytics frameworks.

3 METHODOLOGY

This study employed a quasi-experimental pre-test/post-test specification to validate a reproducible applied digital verification and analytics architecture under controlled multi-site deployment conditions. Participants were allocated to Experimental (EG) and Control (CG) cohorts based on intact institutional group configurations; randomization was not feasible. Baseline equivalence was established using pre-test measurement and statistically controlled through ANCOVA, with post-test score specified as dependent variable, group as fixed factor, and pre-test score as covariate. This baseline-adjusted configuration reduces selection bias and enables accurate estimation of system-level effects. All statistical modeling, reliability estimation, and effect size calculations were conducted using SPSS 27.0. The study tested three hypotheses: H1 - the proposed workflow-driven instructional architecture improves information-analytical competence relative to a non-workflow configuration; H2 - the greatest improvements occur in the analytically structured and reflective-evaluative dimensions; and H3 - the performance-based execution metric (PT-4) improves more rapidly than the self-report indicator (IACS-35).

The system was deployed across three institutions (N = 448) using a standardized 30-session execution protocol designed to activate structured verification workflows, generate digital artifacts, and accumulate analytics-ready datasets. Rather than representing a conventional instructional structure, the deployment cycle functioned as a controlled runtime environment for workflow execution, artifact logging, rubric-based scoring capture, and data aggregation. Information-analytical competence was operationalized as a rule-governed digital execution construct embedded within a platform-based workflow architecture.

Within the Experimental Group, CRAAP- and SIFT-based verification routines [9] were embedded into structured task configurations, including lateral validation, cross-source corroboration, claim triangulation, and evidence-weighted justification procedures. Each workflow iteration produced timestamped digital artifacts recorded within Google Classroom, which served as the system's orchestration and artifact-management layer. Generated outputs included structured search logs, argument maps, rubric-scored analytical submissions, and version-controlled portfolio records. The Control Group operated under a non-workflow configuration without structured artifact generation, limiting measurable trace capture.

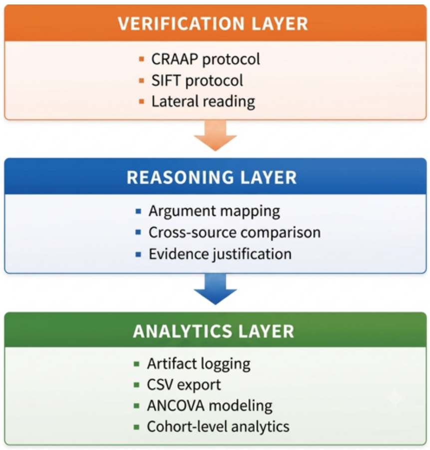

Figure 1: Architecture of the applied verification and analytics system.

Figure 1 presents the high-level system architecture, illustrating the LMS-based workflow activation layer, artifact generation module, CSV export mechanism, anonymization process, and statistical modeling stage. This configuration establishes a reproducible end-to-end pipeline linking platform-executed verification routines to quantitative outcome validation.

Artifact-level data extraction was implemented using Google Classroom's gradebook and assignment management modules. Rubric-based scores and submission metadata were exported via the "Download all grades as CSV" function, while performance-task responses collected through integrated Google Forms were exported using the native CSV export option. No external API integration was employed; data extraction followed a fixed manual protocol to ensure institutional compliance and reproducibility.

The exported dataset included pseudonymized participant identifiers, institutional codes, group assignment (EG/CG), workflow task identifiers, artifact types, submission timestamps, rubric-based evaluation scores, and aggregated competence indicators (PT-4 and IACS-35). Personally identifiable information was removed prior to export. CSV files were merged using student_id and task_id as primary linkage keys, producing a standardized analytics-ready dataset. This data pipeline enabled cross-site aggregation and baseline-adjusted inferential modeling.

Table 1: Digital pedagogy system structure.

Component	Core Digital Workflow	Generated Artifact
Informational	Structured source search & filtering	Search log (timestamped CSV)
Analytical	Cross-source verification & triangulation	Argument map (documented trace)
Practical	Evidence-based task execution	PT-4 structured output
Reflective	Justification & iterative revision	Portfolio entry (versioned)
Axiological	Ethical evaluation & responsibility	Rubric-based score record

Table 1 specifies the workflow-to-artifact mapping within the system architecture.

Table 2: Google classroom exported dataset schema.

Field Name	Description	Data Type
student_id	Anonymized (hashed) participant identifier	String
institution_id	University code (1-3)	Integer
group_type	Experimental (EG) or Control (CG)	Categorical
task_id	Workflow task identifier	Integer
artifact_type	Log / Argument Map / PT-4 / Portfolio	String
submission_time	Timestamp of submission	Datetime
rubric_score	Criterion-based evaluation score	Float
iacs_pre	Pre-test IACS-35 score	Float
iacs_post	Post-test IACS-35 score	Float
pt4_score	Performance task (PT-4) score	Float

Table 2 defines the exported dataset schema used for statistical modeling. Each record represents an artifact-level execution trace linked to anonymized identifiers and workflow stages. Variable encoding and field definitions were standardized across institutions to ensure compatibility and reproducibility. Group type was consistently encoded (EG/CG), and rubric-based scores were captured directly within the LMS before CSV export to SPSS 27.0.

Competence modeling utilized two integrated measures: IACS-35 (pre/post numeric indicators) and PT-4 performance outputs evaluated via analytic rubric. Internal consistency (Cronbach's α) and inter-rater reliability (Cohen's κ) were calculated to ensure measurement stability. ANCOVA specification included post-test score as dependent variable, group as fixed factor, and pre-test score as covariate, with effect size estimated using Cohen's d based on adjusted means. This configuration ensures that outcome validation is grounded in artifact-level behavioral traces and reproducible statistical procedures rather than descriptive instructional reporting.

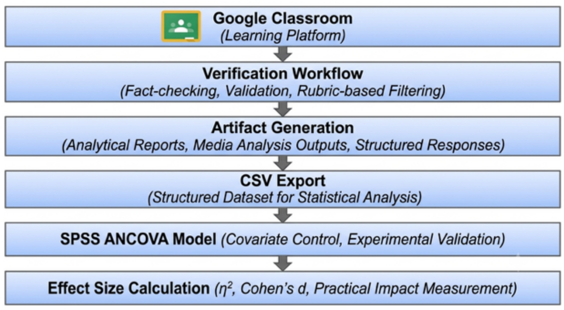

Figure 2: Applied digital verification and analytics system architecture.

Figure 2 illustrates the detailed operational data pipeline, including workflow execution within Google Classroom, artifact logging, standardized CSV export, anonymized dataset aggregation, and baseline-adjusted ANCOVA modeling. The final analytical layer includes effect size computation, enabling quantification of system impact through a reproducible applied IT architecture.

4 DATA ANALYSIS AND RESULTS

Baseline equivalence between the Experimental Group (EG) and Control Group (CG) was verified using independent samples t-tests on pre-test scores (Fig. 3, Table 3). No statistically significant differences were observed ($p > .05$), confirming initial group comparability prior to system deployment and supporting the internal validity of subsequent modeling. Post-deployment outcomes were analyzed using ANCOVA, with post-test competence score specified as the dependent variable, group assignment as the fixed factor, and pre-test score as the covariate. This baseline-adjusted specification enabled estimation of the net system-level effect. All statistical modeling, reliability diagnostics, and effect size calculations were conducted using SPSS 27.0 under standardized parameter configurations to ensure reproducibility.

Table 3: Adjusted mean scores (post-test).

Group	N	Mean	SD	Adjusted Mean
EG	224	82.4	6.8	81.9
CG	224	74.1	7.3	74.8

Baseline-adjusted comparisons indicated a statistically significant performance advantage for the Experimental Group. After covariate correction, overall Information-Analytical Competence scores were significantly higher in the EG compared to the CG ($F(1,445) = 31.84$, $p < .001$). The estimated effect size was substantial (Cohen's $d \approx 0.85$), exceeding conventional medium-effect thresholds and indicating strong practical and system-level significance. From an applied IT perspective, this magnitude of effect reflects the measurable impact of structured workflow activation and artifact-level analytics monitoring on competence outcomes.

Component-level ANCOVA modeling demonstrated that the largest adjusted gains occurred in analytical-interpretative and reflective-evaluative dimensions. These components directly correspond to the system's embedded verification workflows, including cross-source corroboration, structured reasoning documentation, and iterative evidence justification. The distribution of gains confirms that executable verification routines, when formalized within a digital workflow architecture, produce quantifiable improvements in evaluative processing.

Psychometric diagnostics further confirmed measurement reliability. Internal consistency of the IACS-35 instrument was high (Cronbach's $\alpha = .88$), indicating strong inter-item coherence. Inter-rater reliability for the performance-based task (PT-4), estimated using Cohen's kappa, reached $\kappa = .81$, reflecting substantial agreement and supporting scoring stability. These reliability coefficients reinforce the statistical robustness of the outcome model.

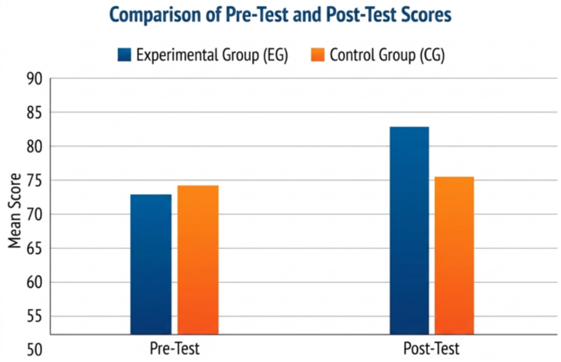

Figure 3: Baseline-adjusted competence gains across.

From an applied IT standpoint, competence validation extended beyond test-based metrics to artifact-level behavioral traces generated within the workflow environment. The Experimental Group produced structured digital artifacts-including timestamped search logs, argument maps, rubric-scored analytical outputs, and versioned portfolio entries-which were exported in standardized CSV format and aggregated for cohort-level modeling. These analytics-ready datasets enabled cross-site comparison across three institutions and ensured that statistical findings were grounded in observable verification execution rather than solely on self-reported indicators. In contrast, the Control Group did not generate comparable workflow artifacts, limiting evaluation to conventional score-based metrics without integrated trace data. The convergence of statistically significant adjusted mean differences, substantial effect size, strong reliability indices, and artifact-based analytics evidence provides multi-layered empirical validation of the applied digital verification and analytics architecture. The findings demonstrate that embedding structured verification workflows within a reproducible data pipeline configuration produces measurable competence gains under real institutional deployment conditions.

5 DISCUSSION

The present study evaluated whether a workflow-driven applied digital verification and analytics architecture produces higher levels of information-analytical competence than a non-workflow configuration under authentic institutional deployment constraints. Baseline-adjusted modeling confirmed that the Experimental Group achieved significantly higher post-test outcomes than the Control Group (ANCOVA $p < .001$), with a substantial effect size ($d \approx 0.85$). From a systems perspective, this magnitude of impact reflects not only statistical differentiation but the measurable performance effect of embedding executable verification workflows within a traceable, LMS-integrated, and analytics-enabled digital pipeline. The findings support H1 and indicate that competence development is more effectively facilitated when operational processes are formalized as integrated workflow architectures rather than implemented through fragmented or non-documented task execution.

H2 is reinforced by the component-level distribution of gains. The largest adjusted improvements were observed in analytical-interpretative and reflective-evaluative dimensions, which directly correspond to the system's core verification protocols, including cross-source corroboration, structured reasoning documentation, and iterative evidence validation. This alignment demonstrates structural coherence between architectural design and measurable performance outcomes. The observed behavioral improvements are consistent with civic online reasoning research emphasizing corroboration, lateral validation, and source tracing as prerequisites for reliable judgement in digital ecosystems [2]. The empirical convergence between workflow execution logic and quantifiable competence growth strengthens the explanatory validity of the system configuration.

H3 is substantiated by the differential improvement pattern between PT-4 (performance-based execution metric) and IACS-35 (self-report indicator). The stronger gains in PT-4 suggest that observable verification behaviors, captured as artifact-level traces, improved more rapidly than participants' subjective competence perception. This pattern aligns with established models of critical thinking assessment, where performance tasks measure enacted analytic operations, whereas self-report instruments reflect gradual recalibration of internal evaluation thresholds [11]. From an applied IT perspective, the artifact-generating workflow appears to accelerate measurable behavioral competence prior to stabilization of subjective self-assessment.

The comparatively smaller gains observed in the axiological-motivational dimension are theoretically consistent with staged competence modeling frameworks emphasizing progressive value stabilization. Responsibility-oriented interaction with digital information infrastructures typically requires extended exposure and iterative execution cycles within controlled system environments [1]. Procedural configuration alone is unlikely to immediately recalibrate motivational parameters, which consolidate over longer temporal intervals.

From an applied IT standpoint, the contribution of the system extends beyond domain-specific sequencing. By transforming digital task execution into structured and reproducible workflows-generating verification logs, argument maps, rubric-scored outputs, and version-controlled portfolio artifacts-the architecture enables analytics-ready evaluation grounded in traceable behavioral data. These standardized datasets support cohort-level aggregation, cross-site comparability, and reproducible statistical validation. Deployment across three institutions under a fixed configuration protocol further demonstrates system scalability and transferability, aligning with broader digital competence and learning analytics strategies [5]. Consequently, the findings validate not only operational effectiveness but also the feasibility of workflow-based, artifact-driven competence modeling within scalable applied digital system architectures.

6 CONCLUSIONS

This study validated a structured applied digital verification and analytics architecture implemented within Google Classroom as the primary workflow orchestration, artifact-management, and data-capture environment. Using a quasi-experimental pre-test/post-test design across three universities ($N = 448$), the research operationalized information-analytical competence as a measurable, workflow-executable construct supported by traceable digital artifacts and analytics-ready datasets rather than solely by declarative indicators.

The proposed system formalized digital task execution into a reproducible applied IT configuration. Google Classroom functioned as the coordination and control layer through which verification workflows were deployed, logged, versioned, and exported. Within this environment, structured verification protocols (CRAAP and SIFT) were embedded into assignment logic and evaluation cycles, enabling structured source investigation, lateral validation, cross-source corroboration, triangulation, and evidence-based justification. Each execution stage generated timestamped, platform-recorded artifacts, including structured search logs, argument maps, rubric-scored analytical outputs, and version-controlled portfolio records.

Crucially, these artifacts were treated as analyzable behavioral traces rather than auxiliary outputs. Google Classroom grading modules and submission metadata enabled structured rubric-score capture, while artifact-level records were exported in standardized CSV format for statistical modeling. The dataset included anonymized (hashed) participant identifiers, institutional codes, group assignment (EG/CG), task identifiers, submission timestamps, artifact classifications, rubric scores, and aggregated competence indicators (PT-4 and IACS-35). Personally identifiable information was removed prior to modeling to ensure compliance with ethical and institutional requirements. This export-and-analysis pipeline enabled cross-site aggregation, cohort-level comparability, and baseline-adjusted ANCOVA modeling in SPSS 27.0 under reproducible parameter settings.

After covariate adjustment, the Experimental Group demonstrated significantly higher post-test competence levels compared to the non-workflow configuration ($p < .001$; $d \approx 0.85$). The magnitude of effect reflects measurable system-level performance impact. The strongest gains were observed in analytical-interpretative and reflective-evaluative dimensions, directly corresponding to the embedded verification workflow logic within the Google Classroom environment. The faster improvement in PT-4 performance relative to IACS-35 self-report metrics indicates that observable verification execution stabilized prior to shifts in subjective competence perception, consistent with performance-based analytic assessment models [11].

From an applied IT perspective, the principal contribution lies in demonstrating that information-analytical competence can be modeled as a structured digital workflow architecture integrating artifact generation, standardized data capture, and reproducible analytics pipelines. The integration of Google Classroom as a workflow engine ensured scalability, standardized protocol enforcement, timestamp integrity, rubric synchronization, and exportable trace data suitable for inferential validation. The architecture aligns with digital competence standards emphasizing demonstrable information and data literacy [1] and with analytics-informed system design principles within broader digital learning infrastructures [12].

The cross-institutional deployment further demonstrates structural scalability and transferability. Because the workflow logic relies on platform-level assignment structuring, rubric standardization, and CSV-based data extraction rather than institution-specific customization, the configuration can be replicated across comparable higher education infrastructures. This corresponds with research on digital competence modeling [10] and aligns with policy priorities emphasizing responsible digital engagement and information safety [4].

Nevertheless, several limitations must be acknowledged. The use of intact academic cohorts constrained randomization, platform-mediated execution may introduce contextual variability despite standardized workflow configuration, and the relatively short deployment period limits evaluation of long-term stabilization-particularly in responsibility-oriented dimensions. Future research should extend the architecture through longitudinal trace tracking, multi-level modeling, automated analytics dashboard integration, and deeper pipeline automation to capture evolving competence trajectories within scalable digital systems.

Overall, the findings confirm that modeling information-analytical competence as a structured, workflow-based, artifact-generating, and analytically measurable construct provides a reproducible applied IT framework for scalable competence modeling within digital education. By linking verification routines, behavioral traces, standardized data pipelines, and statistical modeling, the proposed architecture helps bridge the gap between abstract digital competence frameworks and observable performance outcomes, while offering a transferable design for evidence-based monitoring and continuous improvement in higher education.

REFERENCES

[1] M. Vuorikari, S. Kluzer, and Y. Punie, DigComp 2.2: The Digital Competence Framework for Citizens. Luxembourg: Publications Office of the European Union, 2022.

[2] S. McGrew, J. Breakstone, T. Ortega, M. Smith, and S. Wineburg, “Can students evaluate online sources? Learning from assessments of civic online reasoning,” Theory & Research in Social Education, vol. 46, no. 2, pp. 165-193, 2018.

[3] A. Bawden and L. Robinson, “The dark side of information: Overload, anxiety and other paradoxes,” Journal of Information Science, vol. 45, no. 3, pp. 1-13, 2022.

[4] B. K. Baydjanov, “Improving the system of preparing future teachers to develop students’ information security skills,” Ph.D. dissertation abstract, Fergana State Univ., Fergana, Uzbekistan, 2022.

[5] UNESCO, Global Media and Information Literacy Assessment Framework: Country Readiness and Competencies. Paris, France, 2021.

[6] M. Spante et al., “Digital competence and digital literacy in higher education research,” Education and Information Technologies, vol. 23, no. 3, pp. 1-22, 2022.

[7] R. Hobbs, Media Literacy in Action: Questioning the Media. London, UK: Bloomsbury Academic, 2021.

[8] R. Hobbs and J. Coiro, “Designing digital literacy instruction,” Reading Research Quarterly, vol. 58, no. 2, pp. 1-19, 2023.

[9] M. Caulfield, Web Literacy for Student Fact-Checkers. Pressbooks, 2017.

[10] J. Wineburg and S. McGrew, “Lateral reading and the nature of expertise,” Educational Researcher, vol. 48, no. 4, pp. 1-12, 2019.

[11] P. A. Facione, Critical Thinking: What It Is and Why It Counts, 2023 update. Hermosa Beach, CA, USA: Insight Assessment, 2023.

[12] OECD, Digital Education Outlook 2023: Towards an Effective Digital Education Ecosystem. Paris, France: OECD Publishing, 2023.