



Volume 23 (2026), pp. 1-25
*American Journal of STEM Education:
Issues and Perspectives*
eISSN 30.3-1190 | Print ISSN: 3069-0072
<https://doi.org/10.32674/5xhcsr85>

Bridging the AI Use–Competence Gap: Implications for AI Literacy in STEM Graduate Education

Marina Falasca

I.E.S. en Lenguas Vivas “Juan Ramón Fernández”, Argentina

<https://orcid.org/0000-0002-6585-6251>

ABSTRACT

Generative artificial intelligence (AI) is transforming graduate research and academic work; however, increased use does not necessarily lead to critical evaluation or responsible engagement. This study examines the gap between graduate students’ AI use and their evaluative, ethical, and rhetorical engagement with AI-generated outputs. Using a survey-based exploratory case study design, the study draws on data from 50 graduate students across four national contexts, complemented by open-ended responses and contextual observations. Findings reveal high levels of AI use alongside limited verification practices, ethical uncertainty, and a tendency to view AI outputs as neutral or authoritative, indicating a persistent use–competence gap. The study proposes a holistic AI literacy framework with implications for curriculum, assessment, and policy.

Keywords: AI literacy, digital literacy, generative artificial intelligence, graduate education, Higher education

© Author(s), 2026. Published by Star Scholars Press.

This article is distributed under the Creative Commons Attribution 4.0 International License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited. <https://creativecommons.org/licenses/by/4.0/>

INTRODUCTION

The rapid integration of sophisticated artificial intelligence (AI) systems—particularly Large Language Models (LLMs) and generative AI (GenAI)—has compelled universities to reconsider what constitutes graduate competence in contemporary higher education (Francis et al., 2025). Participation in academic, professional, and civic life increasingly depends not only on access to AI tools, but on the capacity to engage with them critically, ethically, and strategically. These capacities are commonly captured under the umbrella of AI literacy (AIL), broadly defined as the competencies required to evaluate AI technologies critically, communicate and collaborate effectively with AI systems, and use AI responsibly across academic, professional, and everyday contexts (Long & Magerko, 2020).

Despite widespread recognition of AI literacy as a core twenty-first-century competency (Lintner, 2024), its systematic integration into graduate-level curricula remains uneven. Prior research highlights persistent conceptual ambiguity and a lack of pedagogically actionable frameworks tailored to higher education (Bauer, 2025; Zhou & Schofield, 2024). While existing models identify important dimensions such as technical knowledge, ethical awareness, and critical thinking, they often do not fully address how generative AI reshapes epistemic judgment, academic communication, and professional responsibility.

Emerging evidence further reveals a growing disconnect between graduate students' widespread use of generative AI tools and their capacity to engage with them critically and responsibly (Kasneji et al., 2023). Students increasingly rely on AI for drafting, summarization, analysis, and decision support, yet many lack systematic practices for verifying AI-generated information, identifying bias or hallucinations, or critically evaluating the rhetorical and persuasive dimensions of machine-generated discourse. As a result, AI is frequently treated as a productivity tool rather than as a socio-technical system requiring sustained evaluative judgment—a use–competence gap that raises important concerns regarding academic rigor, epistemic reliability, and responsible knowledge construction.

This study addresses this gap by examining patterns of AI use among STEM and STEM-related graduate students and identifying discrepancies between frequency of use and critical engagement across evaluative, ethical, and rhetorical dimensions. In doing so, it makes three key contributions. First, it provides empirical evidence of the use–competence gap, demonstrating that high levels of AI use are not consistently accompanied by practices of verification, ethical reasoning, or critical interpretation. Second, it reconceptualizes AI literacy as an integrated, multidimensional competence, arguing that effective engagement with generative AI requires the interaction of evaluative, ethical, and communicative capacities rather than the accumulation of isolated technical skills. Third, it introduces rhetorical AI literacy as a critical yet underdeveloped dimension of

graduate competence, foregrounding the need to understand how AI-generated discourse constructs meaning, authority, and credibility in academic contexts.

By advancing this integrated perspective, the study contributes to ongoing efforts to align graduate education with the demands of AI-mediated knowledge environments and provides a conceptual and empirical foundation for rethinking curriculum design, assessment practices, and institutional policy. Specifically, the study addresses the following research questions:

RQ1: What patterns characterize STEM and STEM-related graduate students' use of generative AI in academic tasks?

RQ2: What gaps emerge between this use and students' verification, evaluative, ethical, and rhetorical practices?

RQ3: How do these gaps inform the development of AI literacy in STEM and STEM-related graduate education?

LITERATURE REVIEW

This section synthesizes recent scholarship from higher education research, industry reports, and AI ethics literature to examine how artificial intelligence is reshaping expectations for graduate competencies. Rather than offering an exhaustive review, it is purposefully structured in alignment with the study's objectives and guiding research questions, focusing on three interrelated strands. Collectively, these strands highlight the need to move beyond functional uses of AI toward the development of integrated evaluative, ethical, and rhetorical competencies.

AI Use and Emerging Graduate Competencies

Artificial intelligence is transforming—rather than replacing—the competencies expected of university graduates. Industry and policy reports emphasize that graduates must engage with AI systems not merely as tools, but as socio-technical systems requiring critical interpretation and responsible use. This includes the ability to evaluate AI-generated outputs, recognize uncertainty and bias, and integrate machine-generated information into human judgment and decision-making processes.

Beyond technical interaction, employers increasingly highlight the importance of ethical reasoning in AI-mediated contexts, including awareness of data privacy, fairness, transparency, and accountability. Graduates are also expected to communicate effectively in AI-mediated environments and to collaborate within human–AI systems by strategically distributing cognitive labor. Collectively, these expectations extend beyond traditional digital literacy (UNESCO, 2023) toward what has been described as AI fluency: a

multidimensional competence encompassing conceptual understanding, ethical awareness, and meta-cognitive control (UNESCO, 2024; Manuel, 2025).

However, these professional expectations presuppose a foundational form of AI literacy developed within higher education. This includes not only operational competence, but also the ability to evaluate AI outputs critically, interpret their communicative effects, and maintain intellectual agency in AI-assisted work. Such demands place growing pressure on universities to move beyond ad hoc exposure to AI tools and toward more systematic, integrated approaches to graduate preparation.

Limitations of Current AI Literacy Approaches

Despite growing recognition of AI literacy as a core competency, many higher education responses continue to frame AI primarily as a technical tool or discrete topic. Curricular approaches often prioritize functional proficiency—such as prompt design, tool familiarity, or generalized ethical guidelines—while underemphasizing how AI reshapes cognitive processes, epistemic judgment, and academic communication (Kasneji et al., 2023). As a result, students may become efficient users of AI without developing the capacity to evaluate its outputs critically or to engage with it responsibly.

More fundamentally, existing AI literacy frameworks tend to adopt a predominantly skills-based orientation, emphasizing what students can do with AI while under-theorizing how they know, interpret, and judge AI-generated knowledge claims (Long & Magerko, 2020; Lintner, 2024). In this sense, the role of epistemic judgment—the capacity to assess the credibility, limitations, and constructed nature of AI outputs—remains insufficiently developed in current models. As generative AI increasingly mediates knowledge production, this omission becomes particularly consequential in academic contexts where validity, interpretation, and argumentation are central.

Emerging scholarship suggests that effective AI literacy requires the integration of multiple competency domains rather than isolated skill development (León et al., 2025). These include cognitive capacities (e.g., critical analysis and evidence-based reasoning), ethical capacities (e.g., responsibility, fairness, and bias awareness), and communicative capacities (e.g., rhetorical awareness and audience sensitivity) (Dwivedi et al., 2023). When these domains are addressed separately, AI literacy risks becoming fragmented, limiting students' ability to apply evaluative and ethical judgment consistently across contexts.

A particularly underdeveloped dimension in existing models is the rhetorical aspect of AI use. While current frameworks acknowledge communication as a competency, they rarely engage with how AI-generated discourse actively constructs meaning, frames arguments, and projects authority (Gottschling, 2025). Generative AI systems do not simply produce information; they generate language that can appear coherent, neutral, and authoritative, often masking its probabilistic

and constructed nature. The relative absence of this discursive and rhetorical perspective in AI literacy frameworks limits their ability to account for how students interpret and evaluate AI-generated texts in practice.

Empirical Evidence of the Use–Competence Gap

While expectations for AI fluency continue to expand, empirical research consistently reveals a gap between students' frequent use of AI tools and their capacity to engage with them critically. Studies show that graduate students regularly use generative AI for tasks such as summarizing texts, drafting assignments, analyzing data, and preparing presentations (Xu et al., 2025). However, this widespread use is often accompanied by limited verification practices and reduced engagement in higher-order cognitive processes.

Systematic reviews indicate that high-frequency AI use may be associated with declines in critical thinking, largely due to processes of cognitive offloading, whereby independent reasoning is replaced by reliance on automated outputs (Gerlich, 2025; Ilgun Dibek et al., 2025). Over time, this reliance may weaken students' capacity for reflection, evaluation, and knowledge construction, raising concerns about academic integrity and epistemic reliability (Lund et al., 2025).

Students likewise demonstrate a limited and often fragmented understanding of how AI systems generate outputs, how biases can be embedded through training data, and how rhetorical framing shapes interpretation (Kasneci et al., 2023). Their engagement with AI tends to remain at a functional level, with little awareness of the underlying mechanisms or the epistemic implications of machine-generated content. At the same time, considerable uncertainty persists regarding appropriate AI use, authorship, and verification practices, frequently resulting in inconsistent or uncritical application.

Taken together, the literature reveals a persistent tension: although AI literacy is widely recognized as essential, existing approaches remain conceptually fragmented and empirically underdeveloped, particularly in relation to how students interpret, evaluate, and make judgments about AI-generated knowledge. In STEM graduate education, this gap is particularly consequential. There is limited research on how students interrogate AI-generated models, code, or data outputs; how they interpret the rhetorical framing of AI-assisted analyses; and how they make ethical decisions in contexts where accuracy, safety, and accountability are at stake.

Addressing this gap requires closer empirical attention to how STEM graduate students actually engage with AI in authentic academic tasks. Accordingly, the present study examines patterns of AI use among STEM and STEM-related graduate students, identifies discrepancies between frequency of use and levels of critical engagement across evaluative, ethical, and rhetorical dimensions, and outlines implications for curriculum design, assessment practices, and institutional policy.

METHODOLOGY

Research Design and Participants

This study employed an exploratory survey-based case study design to examine how graduate students engage with generative artificial intelligence (AI) tools in academic contexts. The study was designed to generate empirically grounded insights into emerging AI-assisted practices rather than to test causal relationships or evaluate specific interventions. Consistent with its exploratory orientation, the study sought to identify patterns, tensions, and areas of uncertainty that may inform future theory development and more systematic investigation.

The primary source of evidence consisted of survey data collected from 50 graduate students enrolled in STEM, education, and STEM-related interdisciplinary programs across four national contexts: Argentina, Bangladesh, Pakistan, and Singapore. Participants were recruited through graduate-level webinars, online conference sessions, and panel discussions focused on AI in higher education, resulting in a convenience-based international sample. While this recruitment strategy enabled the inclusion of participants from diverse academic and geographical backgrounds, the sample size and composition do not support discipline-specific or cross-national comparisons. Accordingly, the findings should be interpreted as exploratory insights into graduate students' engagement with generative AI rather than as representative of particular national or disciplinary populations.

To enrich the interpretation of survey findings, the study also incorporated qualitative responses to open-ended survey questions and contextual observations from academic events where AI in higher education was discussed. These supplementary sources were used to provide illustrative examples and contextual understanding of participants' experiences and perceptions, rather than as independent and equally weighted strands of evidence.

All participants reported prior experience with generative AI tools (e.g., ChatGPT or comparable systems), making them an appropriate population for examining AI use beyond initial adoption. Participation was voluntary and anonymous, and no identifying personal information was collected.

To provide contextual support, survey data were complemented by observations from publicly accessible academic events on AI in higher education. These observations offered additional insight into how AI tools are presented, discussed, and interpreted within academic communities.

Aligned with the study's research questions, the design focused on: (a) identifying patterns of AI use, (b) examining gaps between frequency of use and evaluative, ethical, and rhetorical practices, and (c) providing empirical grounding for the conceptualization of AI literacy in graduate education. Descriptive characteristics of the sample are summarized in Table 1.

Table 1
Socio-Demographic Characteristics of Participants (N = 50)

Variable	Category	n	%
Country of Study	Argentina	14	28
	Bangladesh	12	24
	Pakistan	13	26
	Singapore	11	22
Field of Study	Engineering / Computer Science	18	36
	Education	15	30
	Interdisciplinary STEM Programs	17	34
Graduate Level	Master’s Program	32	64
	Doctoral Program	18	36
Prior Experience with Generative AI Tools	Regular use (weekly or more)	45	90
	Occasional use	5	10

Data Collection

Survey Development and Content Validation

Because no existing instrument captured the integrated dimensions of Media Literacy, Critical AI Literacy, and Rhetorical AI Literacy examined in this study, the survey was developed specifically for exploratory and construct-generating purposes. Item development was informed by established AI literacy scholarship (Long & Magerko, 2020; Lintner, 2024; Zhou & Schofield, 2024), UNESCO’s AI Competency Framework for Students (UNESCO, 2024), and emerging literature emphasizing the evaluative, ethical, and communicative dimensions of AI engagement in higher education (Deng & Sun, 2026; HersHKovitz et al., 2025; Reicho et al., 2026). The survey was also informed by the holistic AI literacy

framework proposed in this study, which conceptualizes AI literacy as the interaction of Media Literacy, Critical AI Literacy, and Rhetorical AI Literacy (Falasca, 2025).

Survey items were developed deductively to operationalize these dimensions and to explore how graduate students engage with AI-generated information, navigate ethical questions related to AI use, and interpret the authority and credibility of AI-generated discourse. The instrument included items addressing AI usage practices (4 items), Media Literacy (5 items), Critical AI Literacy (5 items), and Rhetorical AI Literacy (4 items), together with open-ended questions designed to elicit participants' reasoning, concerns, and perceptions regarding AI-assisted academic work.

As this was an exploratory, construct-generating study, formal psychometric validation procedures, including pilot testing, expert review, and reliability analysis, were not undertaken. Consequently, the instrument should be understood as an exploratory measure designed to identify emerging patterns and generate hypotheses rather than as a validated assessment of AI literacy competencies. Future research should examine the reliability and construct validity of the instrument using larger and more diverse samples.

Survey Instrument Structure

The survey served as the primary data source and was designed to capture the dimensions outlined above through a combination of Likert-scale, multiple-choice, and open-ended items. Specifically, three thematic areas guided the survey design:

1. AI usage practices: frequency and purposes of AI use in academic tasks (e.g., drafting, summarization, coding, analysis)
2. Evaluation and critical awareness: verification practices, trust in AI outputs, and awareness of bias or hallucinations
3. Ethical and rhetorical awareness: perceptions of appropriate AI use, authorship responsibility, and interpretation of AI-generated discourse

Survey items included Likert-scale responses, multiple-choice questions, and open-ended prompts to capture both reported behaviors and underlying reasoning processes, as illustrated in Table 2. Importantly, items within the rhetorical AI literacy dimension were designed to capture not only surface-level perceptions of AI-generated discourse, but also students' implicit awareness of how such discourse constructs authority, neutrality, and credibility. For instance, perceiving AI-generated text as "objective" may signal limited recognition of its rhetorical framing rather than an inherent property of the text itself.

Table 2*Survey Instrument Structure and Operationalization of AI Literacy Dimensions*

AI Literacy Dimension	Survey Focus	Sample Survey Items	Response Format
Media Literacy	Evaluation of credibility and reliability of AI-generated information	“I verify AI-generated information using academic sources.” “I am aware that AI systems may generate inaccurate or fabricated information.”	Likert scale
Critical AI Literacy	Ethical awareness and responsible use of AI in academic contexts	“Students should disclose when AI tools assist in academic writing.” “Using AI for brainstorming differs from using AI to generate complete academic responses.”	Likert scale
Rhetorical AI Literacy	Understanding how AI-generated discourse constructs meaning and authority	“AI-generated academic text often appears neutral or objective.” “AI explanations may present arguments that appear authoritative but require critical evaluation.”	Likert scale + open-ended
AI Usage Practices	Frequency and purpose of AI use in academic tasks	“How frequently do you use AI tools for drafting academic text?” “Which tasks do you use AI for? (e.g., summarization, coding, data analysis)”	Multiple choice

To provide contextual support, observational data were collected from four publicly accessible academic events (July–December 2025), totaling approximately ten hours. These included webinars, conference sessions, and panel discussions where AI tools were demonstrated or discussed in academic contexts. Field notes were recorded using a structured template focusing on verification practices, ethical reasoning, and the perceived authority of AI-generated outputs. These observations were not treated as formal ethnographic data but were used to contextualize and support the interpretation of survey findings.

Data Analysis

Consistent with the survey-based exploratory case study design, quantitative survey findings served as the primary source of evidence, while qualitative responses and observational data were used to contextualize and enrich the interpretation of the results. This approach enabled the identification of both broad patterns of AI use and the reasoning, uncertainties, and interpretive practices that shaped participants' engagement with generative AI.

Quantitative survey responses were analyzed using descriptive statistics (frequencies and percentages) to identify trends in AI use, verification practices, ethical awareness, and perceptions of AI-generated content. Particular attention was given to the relationship between frequency of AI use and reported evaluative practices in order to examine evidence of a potential use–competence gap.

Qualitative data derived from open-ended survey responses were analyzed through iterative thematic coding. Initial codes were generated inductively from participants' responses to capture recurring practices, concerns, and areas of uncertainty related to AI use. Through multiple rounds of review and comparison, these codes were refined and grouped into broader themes aligned with the study's analytical focus: (1) verification and epistemic uncertainty, (2) ethical ambiguity regarding AI use and authorship, and (3) reliance on AI-generated outputs and rhetorical authority. Table 3 presents illustrative examples of the coding process.

Table 3
Illustrative Coding Process

Representative Response	Initial Code	Final Theme
“I always check AI answers against journal articles before using them.”	Verification practice	Verification and epistemic uncertainty
“AI is useful, but I am never completely sure whether the information is accurate.”	Accuracy uncertainty	Verification and epistemic uncertainty
“Sometimes I trust the summary, but other times I double-check the original source.”	Conditional trust	Verification and epistemic uncertainty
“I am not sure when AI use should be disclosed in assignments.”	Disclosure uncertainty	Ethical ambiguity regarding AI use and authorship

“Using AI for brainstorming seems acceptable, but writing entire sections feels different.”	Boundary negotiation	Ethical ambiguity regarding AI use and authorship
“It is difficult to know where assistance ends and authorship begins.”	Authorship uncertainty	Ethical ambiguity regarding AI use and authorship
“AI explanations sound very objective and professional.”	Perceived neutrality	Reliance on AI-generated outputs and rhetorical authority
“The responses often look trustworthy because they are well structured.”	Perceived credibility	Reliance on AI-generated outputs and rhetorical authority
“AI explanations can sound convincing even when I do not know if they are correct.”	Persuasive authority	Reliance on AI-generated outputs and rhetorical authority

Coding was conducted by the author through multiple rounds of iterative review and constant comparison across responses. During this process, codes and thematic categories were refined to improve conceptual clarity and consistency. Instances of overlap or ambiguity were revisited and re-examined until stable thematic patterns were established. As coding was conducted by a single researcher, the resulting themes should be understood as analytically informed interpretations rather than independently validated classifications.

Observational field notes were analyzed using the same thematic framework, focusing on verification practices, ethical reasoning, and rhetorical interpretation. These observations were not treated as an independent dataset; rather, they were used to provide contextual support for the survey findings and to illustrate how AI use was discussed, demonstrated, and normalized within academic settings.

The analysis was further informed by an explicit interpretive stance, acknowledging that the identification and organization of themes were shaped by the researcher's conceptual framework and prior work on AI literacy. Accordingly, the findings are understood as analytically constructed rather than purely emergent, consistent with the exploratory and theory-generating orientation of the study.

Given the exploratory nature of the research, the analysis prioritized the identification of descriptive trends and illustrative patterns rather than statistical generalization. Quantitative findings and qualitative insights were therefore interpreted together to provide a contextually grounded account of graduate students' engagement with generative AI in academic environments.

RESULTS

The analysis of survey responses, open-ended comments, and observational data revealed consistent patterns in graduate students' engagement with generative artificial intelligence (AI). Across data sources, participants reported frequent use of AI tools, accompanied by considerable variation in verification practices, uncertainty regarding ethical boundaries, and divergent perceptions of the reliability and authority of AI-generated outputs.

Patterns of AI Use in Academic Tasks (RQ1)

Participants reported using generative AI tools for a range of academic tasks. As shown in Table 4, the most frequently reported uses include generating explanations of complex concepts (88%), summarizing academic readings (84%), and drafting academic text (72%). Additional reported uses include coding assistance (46%) and data analysis support (38%).

Table 4

Reported Uses of Generative AI in Academic Tasks (N = 50)

Academic Task	Percentage of Students Reporting Use
Drafting academic text	72%
Summarizing readings	84%
Generating explanations of complex concepts	88%
Coding assistance	46%
Data analysis support	38%

Note. Percentages represent the proportion of participants who reported using generative AI tools for the specified academic task at least occasionally.

Open-ended responses provided further insight into how participants used AI tools when engaging with academic material. Many reported relying on AI-generated summaries or explanations when approaching unfamiliar or complex topics. For instance, one participant noted, “I usually ask AI to summarize the topic first so I can understand the basics before reading the full article” (Participant 18).

Observational data from academic events also documented the integration of AI-generated content into scholarly interactions. During webinars, conference sessions, and panel discussions, participants were observed referencing AI-

generated explanations when clarifying concepts, summarizing readings, or responding to questions. In several instances, AI-generated text was displayed or read aloud as part of presentations, and participants drew on these outputs during group discussions.

Verification Practices and Evaluative Gaps (RQ2)

As shown in Table 5, fewer than half of respondents reported regularly verifying AI-generated outputs, and 36% indicated consistent critical evaluation of AI-generated summaries.

Table 5
Descriptive Summary of Graduate Students’ AI Usage Patterns and Evaluation Practices

Survey Indicator	Percentage of Respondents
Frequent use of AI for academic tasks	~90%
Regular verification of AI outputs	<50%
Uncertainty about ethical boundaries of AI use	64%
Perception of AI-generated text as neutral/objective	56%
Consistent critical evaluation of AI-generated summaries	36%

Likewise, open-ended responses included references to verification behaviors and uncertainties regarding the accuracy of AI-generated information. For example, one participant stated: “AI gives quick explanations, but I’m never fully sure if the information is accurate unless I double-check it with academic sources” (Participant 14).

Ethical Uncertainty in AI-Assisted Academic Work (RQ2)

Survey results indicated that 64% of participants reported uncertainty regarding acceptable uses of AI in academic contexts, particularly in relation to authorship, originality, and disclosure (see Table 5). Similarly, open-ended responses reflected uncertainty about when AI use requires acknowledgment or attribution. As one participant noted, “Using AI for brainstorming feels acceptable, but generating full responses raises questions about authorship and originality” (Participant 27).

Observational data from webinars, conference sessions, and panel discussions further documented recurring questions related to disclosure practices and the boundaries between acceptable assistance and reliance on AI-generated content. Moreover, field notes captured instances in which participants sought clarification on when AI use should be acknowledged, as well as differing perspectives on how such practices relate to academic integrity.

Perceptions of AI-Generated Text and Rhetorical Awareness (RQ2)

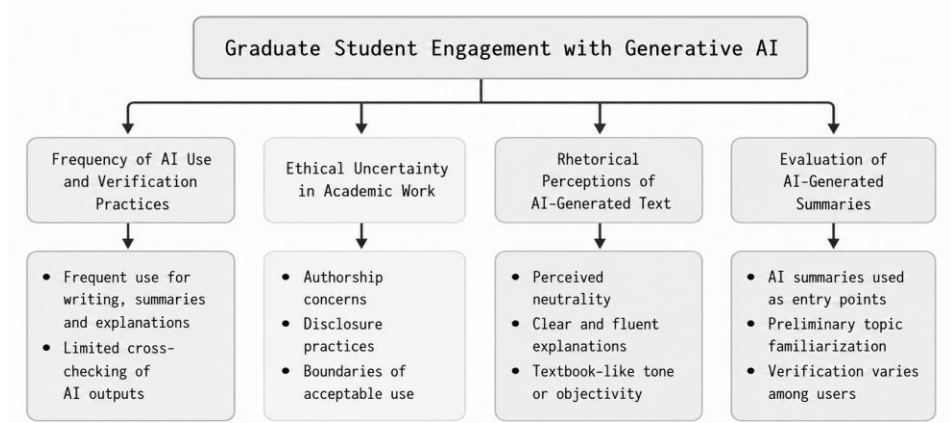
The survey revealed that 56% of participants described AI-generated outputs as “neutral” or “objective” (see Table 4). Open-ended responses further included descriptions of AI-generated text as clear, structured, and easy to understand. For example, one participant noted: “The explanations often sound very clear and objective, almost like they were written in a textbook” (Participant 31).

Observational data similarly documented positive responses to the clarity, organization, and readability of AI-generated explanations during academic sessions, with field notes recording instances in which participants commented on the structured presentation of information and its usefulness for understanding complex topics.

Summary of Reported Patterns

Across survey responses, qualitative comments, and observational data, several recurring patterns were documented. Participants reported frequent use of AI tools across a range of academic tasks, including generating explanations, summarizing readings, and drafting text. Responses also showed variation in verification practices, with differences in how consistently AI-generated outputs were checked or evaluated. Participants reported uncertainty regarding the ethical boundaries of AI use, particularly in relation to authorship, disclosure, and acceptable levels of assistance. In addition, survey and qualitative data included descriptions of AI-generated text as clear, well-structured, and, in many cases, objective. These patterns are summarized in Figure 1.

Figure 1
Dimensions of Graduate Students’ Engagement with Generative AI Tools



Taken together, these findings provide empirical support for the three dimensions of the proposed framework. Variability in verification practices reflects challenges associated with Media Literacy, particularly the evaluation of credibility and reliability. Participants' uncertainty regarding disclosure, authorship, and responsible AI use illustrates issues related to Critical AI Literacy. Finally, the tendency to perceive AI-generated text as neutral, objective, and authoritative highlights the importance of Rhetorical AI Literacy and the need to develop greater awareness of how AI-generated discourse constructs meaning and credibility.

DISCUSSION

The findings of this exploratory study reveal a consistent pattern in STEM and STEM-related graduate students’ engagement with generative AI tools: widespread and routine use alongside uneven critical, ethical, and evaluative engagement. Consistent with RQ1, AI is often embedded in academic workflows, particularly for explanation, summarization, and drafting tasks, while findings related to RQ2 point to variation in verification practices, ethical uncertainty, and differing perceptions of AI-generated content. Together, these patterns indicate a use–competence gap, in which the rapid integration of AI into academic work outpaces the development of the competencies required for critical and responsible engagement. This aligns with recent research highlighting similar tensions between high AI use and limited evaluative and ethical engagement (Banihashem et al., 2025; Xu et al., 2025). In STEM contexts, where AI is increasingly used in

tasks such as coding, modeling, and data analysis, this gap has particular implications for the reliability and accountability of AI-assisted work.

Seen in this light, the challenge is no longer simply one of access to or adoption of AI technologies, but of how students learn to engage with them in informed and responsible ways. The findings therefore speak directly to RQ3—how these gaps can inform the development of AI literacy in graduate education—by showing that current challenges cannot be addressed through isolated or tool-focused approaches alone. Instead, they point toward the need for more integrated forms of AI literacy that bring together evaluative, ethical, and interpretive capacities in coherent and practice-oriented ways, particularly in disciplines where AI outputs may inform technical decision-making.

Interpreting the Use–Competence Gap

The findings of this study reveal a clear disparity between the frequency of AI use and the depth of students' engagement with AI-generated outputs. Participants reported widespread reliance on AI for tasks such as summarizing, drafting, and explaining content, reflecting its integration as a routine support tool within academic workflows. However, this frequent use is not consistently accompanied by systematic practices for critically evaluating or verifying AI-generated material. This pattern is especially significant in STEM-related tasks, where AI outputs may inform coding decisions, data interpretation, or model construction, and where insufficient verification can have direct consequences for the validity of results.

This gap is further reflected in three interrelated dimensions that emerge from the findings. First, verification practices appear inconsistent, raising questions about how students assess the reliability of AI-generated information in the presence of known risks such as hallucinated content or fabricated references, particularly in contexts involving data analysis, coding, or simulation outputs. Second, a substantial proportion of participants reported uncertainty regarding ethical boundaries, including questions related to authorship of AI-assisted code, responsibility for AI-supported analytical decisions, and expectations around disclosure. Third, many participants described AI-generated outputs as neutral or objective, suggesting limited attention to the rhetorical construction of machine-generated discourse, which may obscure limitations in technically framed explanations or analyses.

These dimensions suggest that generative AI is not only augmenting academic tasks but also reshaping how knowledge is accessed, processed, and represented. When AI-generated outputs are treated as informationally stable rather than as constructed responses, processes of evaluation and interpretation may become partially displaced. This dynamic resonates with literature on cognitive offloading, in which reliance on automated systems can reduce engagement in higher-order

reasoning processes (Gerlich, 2025). It may also indicate a gradual transfer of evaluative responsibility from learners to AI systems, whereby students become less engaged in independently assessing the validity and limitations of knowledge claims (Kasneci et al., 2023). As a result, students may come to rely on AI-generated responses as epistemic authorities rather than as provisional and probabilistic outputs requiring ongoing scrutiny and interpretation.

Toward a Holistic AI Literacy Framework

Addressing RQ3 more directly, these findings indicate that the challenges associated with generative AI cannot be addressed through isolated or tool-focused approaches to AI literacy. Instruction centered solely on functional skills—such as prompt engineering or tool use—does not necessarily equip students to evaluate credibility, navigate ethical dilemmas, or interpret AI-generated discourse. Similarly, abstract discussions of AI ethics may remain disconnected from the situated practices through which students engage with AI in academic contexts.

Notably, the reported use of AI for coding assistance and data analysis suggests that AI is not only supporting general academic tasks but is also embedded in technical workflows. This reinforces the need to conceptualize AI literacy in ways that address not only general academic use, but also the specific demands of STEM practice.

Instead, the empirical patterns identified in this study suggest that these challenges cluster around three interrelated domains: evaluation of information, ethical reasoning, and interpretation of discourse. Addressing these domains requires an integrated approach that moves beyond fragmented skill development toward a more comprehensive conceptualization of AI literacy.

In response, this study advances a holistic AI literacy framework that integrates three complementary competencies: Media Literacy, Critical AI Literacy, and Rhetorical AI Literacy (Falasca, 2025). This framework positions AI literacy as a multidimensional graduate competence that supports informed, responsible, and reflective engagement with AI systems.

Conceptualizing AI Literacy for STEM Graduate Education

The holistic AI literacy model presented in Figure 2 builds on this interpretation by conceptualizing AI engagement as the dynamic interaction of evaluative, ethical, and communicative competencies (Falasca, 2025). Rather than treating AI literacy as a set of discrete technical skills, the model frames it as an integrated capacity that enables users to critically interpret AI-generated outputs, make informed ethical judgments regarding their use, and understand how meaning is constructed and communicated through AI-mediated language. This perspective is particularly relevant in STEM graduate education, where artificial

intelligence is increasingly embedded in research, engineering design, software development, data analysis, and scientific inquiry.

Media Literacy provides the evaluative foundation of the framework. Traditionally associated with the analysis of digital information environments, media literacy involves understanding how information is produced, circulated, and interpreted (Livingstone, 2004). In AI-mediated contexts, this competence extends to evaluating the credibility of AI-generated outputs, verifying claims, and recognizing that coherence and fluency do not guarantee accuracy. For STEM graduate students, evaluative literacy is essential when using AI tools to generate code, interpret datasets, summarize scientific literature, or support modeling and simulation tasks. Engineering students may employ generative AI to propose design alternatives or optimize system performance, yet they must critically assess whether suggested solutions satisfy technical specifications, safety requirements, and real-world constraints. Similarly, data science students must evaluate AI-generated analyses and visualizations by examining underlying assumptions, methodological rigor, and data quality. In laboratory settings, researchers using AI to summarize findings or identify patterns in experimental data must verify the accuracy and reproducibility of generated interpretations rather than accepting them uncritically.

Critical AI Literacy represents the ethical dimension of the model. As AI systems increasingly shape academic and professional practices, graduates must be able to identify potential biases, assess the implications of AI use, and maintain accountability for AI-assisted work. This includes navigating questions of authorship, responsibility, and transparency in the use of generative tools (Karapetyan, 2025). In STEM disciplines, ethical considerations often extend beyond academic integrity to encompass broader societal consequences. Engineering graduates must consider the safety, sustainability, and social implications of AI-assisted design decisions. Computer scientists developing AI-enabled applications must address issues related to algorithmic bias, fairness, privacy, and transparency. Data scientists are required to critically examine how training data, model selection, and automated predictions may reinforce existing inequities or produce discriminatory outcomes. In laboratory-based research, ethical AI literacy involves maintaining transparency regarding AI-assisted analyses, ensuring reproducibility, and preserving the integrity of scientific reporting. Across these contexts, critical AI literacy enables students to move beyond technical functionality and consider the wider consequences of AI-mediated decision-making.

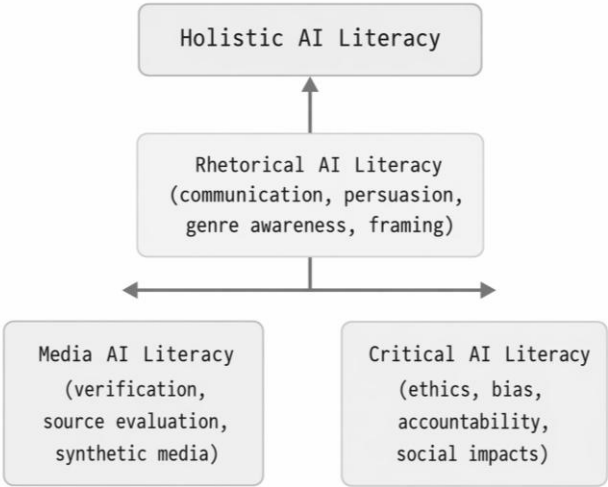
Rhetorical AI Literacy addresses the interpretive and communicative dimension of AI-generated discourse. Because generative AI produces language through probabilistic processes, its outputs may appear persuasive without necessarily reflecting disciplinary rigor. Developing rhetorical awareness enables students to analyze how AI-generated language frames arguments, constructs

authority, and shapes meaning (Gottschling, 2025). Within STEM contexts, rhetorical literacy is increasingly important as professionals are expected to communicate complex technical processes to diverse audiences. Computer science students using AI coding assistants, for example, must be able to explain, justify, and document the rationale behind AI-generated code. Engineers are often required to communicate how AI-supported simulations, predictions, or design recommendations informed project decisions. Data scientists must articulate model assumptions, limitations, and levels of uncertainty to stakeholders who may lack technical expertise. Likewise, researchers employing AI tools in laboratory settings must transparently describe how AI contributed to experimental design, data analysis, or manuscript preparation. Rhetorical AI literacy therefore supports not only the interpretation of AI-generated discourse but also the effective communication of AI-assisted work.

In STEM contexts, these competencies collectively support the development of higher-order capacities required for responsible professional practice. Epistemic judgment enables students to critically evaluate AI-generated models, simulations, code, and analyses by assessing their validity, limitations, and underlying assumptions. Ethical agency supports responsible decision-making in situations where AI applications may influence safety, equity, sustainability, or scientific integrity. Communicative control allows graduates to clearly explain, document, and justify the role of AI in research and professional workflows. Together, these capacities help students engage with AI as critical users rather than passive consumers.

From this perspective, the framework positions AI literacy as integral to STEM expertise rather than supplementary to it. The evaluative dimension (Media Literacy) supports the critical interrogation of datasets, algorithms, simulations, code, and research outputs; the ethical dimension (Critical AI Literacy) guides responsible decision-making in contexts involving bias, accountability, safety, and risk; and the communicative dimension (Rhetorical AI Literacy) enables graduates to effectively articulate how AI has been used in engineering design, software development, data analysis, and scientific experimentation. Together, these interdependent dimensions reflect the complexity of contemporary STEM practice, where engaging with AI involves not only technical proficiency but also critical interpretation, ethical reasoning, and transparent communication.

Figure 2
Holistic AI Literacy Framework Integrating Evaluative, Ethical, and Rhetorical Competencies for Responsible Engagement with Generative AI in Graduate Education



LIMITATIONS

This study has several limitations that should be considered when interpreting its findings. The relatively small, self-selected sample limits statistical generalizability, making the results exploratory rather than conclusive. Although participants represented four national contexts, uneven distribution prevents systematic cross-national comparison, with the international scope instead reflecting contextual diversity.

The sample also combined students from education, STEM-related interdisciplinary programs, engineering, and computer science. This heterogeneity means findings should be interpreted as indicative of broader STEM-related trends rather than discipline-specific patterns, which would require more fine-grained sampling.

In addition, the survey instrument was designed for this study and has not undergone formal psychometric validation, so results should be understood as preliminary indicators of AI literacy-related practices and perceptions rather than validated measures. Similarly, qualitative coding was conducted by a single researcher; although iterative refinement was used, the lack of inter-rater procedures may have influenced thematic interpretation. Observational data were

also drawn from publicly accessible academic events and used only to contextualize survey findings rather than as a standalone dataset.

Overall, these constraints highlight the exploratory nature of the study and the need for future research with larger samples, validated instruments, multiple coders, and more systematic comparative designs. Such work would help refine the proposed AI literacy framework and deepen understanding of how AI literacy develops across diverse institutional, disciplinary, and cultural contexts.

CONCLUSION AND IMPLICATIONS

The rapid integration of generative artificial intelligence into academic and professional contexts raises fundamental questions about the competencies graduate education should cultivate in AI-mediated knowledge environments. This study addressed these questions by examining patterns in graduate students' engagement with generative AI tools and identifying a consistent misalignment between frequency of use and levels of evaluative, ethical, and rhetorical engagement. Across data sources, the findings document widespread reliance on AI for academic tasks alongside limited verification practices, ethical uncertainty, and varied perceptions of AI-generated outputs, pointing to a persistent use–competence gap.

In response, this study advances a holistic AI literacy framework that integrates three complementary dimensions: Media Literacy, Critical AI Literacy, and Rhetorical AI Literacy. This framework contributes to current scholarship by reframing AI literacy as a foundational graduate competence rather than a narrow technical skill. It emphasizes the need for students to evaluate AI-generated outputs as synthetic media, to exercise ethical responsibility in AI-assisted work, and to critically interpret how AI-generated discourse constructs meaning and authority.

These findings carry important implications for STEM graduates as they enter increasingly AI-mediated professional environments. From a curricular perspective, AI literacy needs to be embedded within disciplinary training—whether in engineering, data science, health sciences, or other STEM fields—rather than treated as a generic or tool-based add-on. Graduates must be able not only to use AI tools, but to critically evaluate outputs, identify limitations, and assess the reliability of AI-generated models, simulations, or analyses in high-stakes contexts. Integrating structured analytical tasks into STEM coursework can help students develop these competencies in ways that are directly aligned with professional problem-solving. For example, students might be required to generate code or data interpretations using AI tools and then systematically verify outputs against authoritative sources, document potential errors or biases, and justify final decisions in a reflective technical report.

The study also suggests the need to rethink assessment practices in STEM education. As AI tools become standard in technical workflows, evaluating students solely on final products (e.g., code, reports, designs) is no longer sufficient. Instead, assessment should foreground the reasoning processes behind those outputs. Practices such as documenting how AI tools were used in coding or modeling tasks, annotating AI-generated contributions, and incorporating iterative design or debugging processes can help ensure that graduates retain epistemic responsibility for their work. This is particularly critical in STEM fields, where errors or overreliance on AI can have significant real-world consequences.

At the institutional level, the findings highlight the importance of clear, discipline-sensitive policies on AI use. For STEM graduates, ambiguity around issues such as authorship of AI-assisted code, validation of AI-generated data, or ethical responsibility in automated decision-making can translate into professional risk. Institutions should therefore establish guidelines that address verification standards, transparency in AI use, and accountability in collaborative human–AI work. When aligned with curriculum and assessment, such policies can better prepare STEM graduates to engage responsibly, critically, and ethically with AI in their future careers.

Overall, the study highlights that meaningful engagement with generative AI in graduate education depends on the development of integrated competencies that extend beyond technical proficiency. Preparing students for AI-mediated knowledge environments requires cultivating their ability to evaluate information critically, navigate ethical complexities, and interpret the rhetorical dimensions of AI-generated discourse. By conceptualizing AI literacy as a multidimensional and transferable graduate competence, this study offers a foundation for supporting more critical, reflective, and responsible engagement with AI across disciplinary contexts.

FUTURE RESEARCH DIRECTIONS

The exploratory nature of this study highlights several priorities for future research. First, replication with larger and more purposively structured samples would enable discipline-specific and cross-national analyses and provide a more comprehensive understanding of how AI literacy manifests across diverse STEM contexts. Such studies could examine whether patterns of AI use and evaluative practices vary across disciplinary cultures, institutional settings, and national contexts.

Second, longitudinal research is needed to investigate how AI literacy competencies develop over time during graduate education. Following students across different stages of their academic trajectories would provide insight into how repeated interaction with generative AI influences evaluative judgment,

ethical reasoning, and rhetorical awareness, as well as the extent to which these competencies can be cultivated through formal instruction.

Third, future intervention studies should examine the effectiveness of curriculum designs informed by the holistic AI literacy framework proposed in this study. In addition, the survey instrument developed for this exploratory investigation should be subjected to systematic psychometric validation. Studies involving larger and more diverse populations could evaluate the reliability and construct validity of measures associated with Media Literacy, Critical AI Literacy, and Rhetorical AI Literacy, thereby providing stronger empirical foundations for future research and practice.

AI DISCLOSURE STATEMENT

AI tools (e.g., ChatGPT) were used to assist with language refinement, figure generation, and overall organization of the manuscript. The author takes full responsibility for the content of the manuscript, including the integrity of the data, the validity of the analyses, and the accuracy of all references and citations.

REFERENCES

- Bauer, N. F. (2025). Does ChatGPT increase language homogenization? In C. Vaih-Baur, V. Mathauer, E.-I. von Gamm, & D. Pietzcker (Eds.), *KI in Medien, Kommunikation und Marketing: Wirtschaftliche, gesellschaftliche und rechtliche Perspektiven* (pp. 11–31). Springer.
- Deng, X. (N.), & Sun, R. (2026). Exploring ethical concerns and affordances of generative AI in higher education: Perspectives of underserved students. *Research and Practice in Technology Enhanced Learning*, 22, 011. <https://doi.org/10.58459/rptel.2027.22011>
- Dwivedi, Y. K., Kshetri, N., Hughes, L., Slade, E. L., Jeyaraj, A., Kar, A. K., Baabdullah, A. M., Koohang, A., Raghavan, V., Ahuja, M., Albanna, H., Raman, R., & Wright, R. (2023). “So what if ChatGPT wrote it?” Multidisciplinary perspectives on opportunities, challenges and implications of generative conversational AI for research, practice and policy. *International Journal of Information Management*, 71, Article 102642. <https://doi.org/10.1016/j.ijinfomgt.2023.102642>
- Falasca, M. (2025). From passive consumption to critical use: A holistic AI literacy model for high school EFL students. *TESOL-SPAIN Journal*, 2. <https://www.tesol-spain.org/en/news/9/129/volume-2-autumn-2025---making-meaningful-connections.html>
- Francis, N. J., Jones, S., & Smith, D. P. (2025). Generative AI in higher education: Balancing innovation and integrity. *British Journal of Biomedical Science*, 81, 14048. <https://doi.org/10.3389/bjbs.2024.14048>

- Gerlich, M. (2025). *AI tools in society: Impacts on cognitive offloading and the future of critical thinking*. *Societies*, 15(1), Article 6.
<https://doi.org/10.3390/soc15010006>
- Gottschling, M. (2025). Towards rhetorical AI literacy: Presenting a conceptual framework. *Argumentation et Analyse du Discours*, 35.
<https://doi.org/10.4000/14yaw>
- Hershkovitz, A., Tabach, M., Reich, Y., Lurie, L., & Cholcman, T. (2025). *Framing and evaluating task-centered generative artificial intelligence literacy for higher education students*. *Systems*, 13(7), Article 518.
<https://doi.org/10.3390/systems13070518>
- Karapetyan, T. (2025). *Algorithmic discrimination in public policy: A case study of the Dutch childcare benefits scandal* (Master's thesis, Charles University).
- Kasneci, E., Sessler, K., Küchemann, S., Bannert, M., Dementieva, D., Fischer, F., Gasser, U., Groh, G., Günnemann, S., Hüllermeier, E., Krusche, S., Kutyniok, G., Michaeli, T., Nerdel, C., Pfeffer, J., Poquet, O., Sailer, M., Schmidt, A., Seidel, T., ... Kasneci, G. (2023). ChatGPT for good? On opportunities and challenges of large language models for education. *Nature Human Behaviour*, 7(10), 1838–1846. <https://doi.org/10.1038/s41562-023-01647-6>
- León, C., Lipuma, J., & Oviedo-Torres, X. (2025). Artificial intelligence in STEM education: A transdisciplinary framework for engagement and innovation. *Frontiers in Education*, 10, Article 1619888.
<https://doi.org/10.3389/educ.2025.1619888>
- Lintner, T. (2024). A systematic review of AI literacy scales. *npj Science of Learning*, 9, Article 50. <https://doi.org/10.1038/s41539-024-00264-4>
- Livingstone, S. (2004). Media literacy and the challenge of new information and communication technologies. *The Communication Review*, 7(1), 3–14.
<https://doi.org/10.1080/10714420490280152>
- Ilgun Dibek, M., Sahin Kursad, M., & Erdogan, T. (2025). Influence of artificial intelligence tools on higher order thinking skills: a meta-analysis. *Interactive Learning Environments*, 33(3), 2216–2238.
- Long, D., & Magerko, B. (2020). What is AI literacy? Competencies and design considerations. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (pp. 1–16). ACM.
<https://doi.org/10.1145/3313831.3376727>
- Lund, B., Mannuru, N. R., Teel, Z. A., Lee, T. H., Ortega, N. J., Simmons, S., & Ward, E. (2025). Student perceptions of AI-assisted writing and academic integrity: Ethical concerns, academic misconduct, and use of generative AI in higher education. *AI in Education*, 1(1), 2.
<https://doi.org/10.3390/aieduc1010002>

- Manuel, C. C. J. (2025). The impact of AI on inclusivity in higher education: A rapid review. *Education Sciences*, 15(9), Article 1255.
- Reicho, M., Otrell-Cass, K., Ebner, M., Brünner, B., Freinhofer, D., & Irfan, J. (2026). Generative AI literacy across education and business: Competencies, obstacles, and benefits—A systematic literature review. *International Journal of Educational Technology in Higher Education*, 23(1). <https://doi.org/10.1186/s41239-026-00596-8>
- UNESCO. (2023). *Guidance for generative AI in education and research*. UNESCO Publishing. <https://www.unesco.org/en/articles/guidance-generative-ai-education-and-research>
- UNESCO. (2024). *AI competency framework for students*. UNESCO. <https://doi.org/10.54675/JKJB9835>
- Xu, B., Wu, L., Yuan, Y., Xian, L., & Wang, W. (2025). Exploring the application of AI chatbot tools in higher education: Evidence from the Duke University student survey. *Safety Emergency Science*, 1(2), 9590013.
- Zhou, X., & Schofield, L. (2024). Developing a conceptual framework for artificial intelligence (AI) literacy in higher education. *Journal of Learning Development in Higher Education*, 31. <https://doi.org/10.47408/jldhe.vi31.1354>
-

Bio

MARINA FALASCA, M.Ed., M.A., is a Professor, Researcher, and PhD candidate in International Education from Argentina. Her work focuses on global citizenship education, the internationalization of higher education, and virtual exchange. Her current research examines the pedagogical integration of generative artificial intelligence in higher education, with particular emphasis on AI literacy, ethical and responsible use, and the evolving role of AI in shaping teaching, learning, and academic practices across virtual exchange and international learning contexts. She is the recipient of the Klett Award 2024, the Global Education Prize AAICEP 2025, and the *Educa Latinoamérica* 2026 Award for Innovation in Higher Education. Email: marina.falasca@bue.edu.ar