ACTIVE LEARNING WITH ARTIFICIAL INTELLIGENCE IN ENGINEERING

APRENDIZAGEM ATIVA COM INTELIGÊNCIA ARTIFICIAL NA ENGENHARIA

APRENDIZAJE ACTIVO CON INTELIGENCIA ARTIFICIAL EN LA EDUCACIÓN EN INGENIERÍA

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Abstract. This paper presents an educational tool designed to support active learning in engineering education by guiding and promoting the ethical use of artificial intelligence. The proposal targets undergraduate engineering students and is grounded in a real classroom context structured through university extension activities and project-based learning. The tool integrates artificial intelligence as a pedagogical support mechanism, assisting students in organizing technical reasoning, structuring disciplinary content, and communicating results, while preserving the central role of critical thinking and instructor mediation. The instructional design includes clearly defined learning activities, intended learning outcomes, assessment criteria, and ethical guidelines for the responsible use of artificial intelligence, to facilitate adoption and adaptation by other educators. Intended learning outcomes encompass the ability to analyze engineering concepts, synthesize technical information from diverse sources, and communicate effectively through written and audiovisual artifacts. The paper describes the instructional structure, activity sequence, and supporting materials required for implementation, thereby promoting straightforward replication in similar educational contexts. Classroom observations indicate increased student engagement, improved organization of technical content, and more reflective use of digital tools when artificial intelligence is explicitly framed as a learning support rather than as an autonomous content generator. The contribution emphasizes the practical, replicable nature of the proposed tool and invites the engineering education community to adapt, apply, and further evaluate the approach across diverse instructional settings.

Keywords: active learning; artificial intelligence; engineering education; project-based learning; digital pedagogy

Resumo. Este artigo apresenta uma ferramenta educacional desenvolvida para apoiar a aprendizagem ativa no ensino de engenharia por meio do uso orientado e ético da inteligência artificial. A proposta é direcionada a estudantes de graduação em engenharia e está fundamentada em um contexto real de sala de aula, estruturado a partir de atividades de extensão universitária e aprendizagem baseada em projetos. A ferramenta integra a inteligência artificial como um mecanismo de apoio pedagógico, auxiliando na organização do pensamento, na estruturação de conteúdos técnicos e na comunicação de resultados, sem substituir o julgamento crítico dos estudantes ou a mediação do docente. O desenho instrucional contempla atividades claramente definidas, resultados de aprendizagem esperados, critérios de avaliação e diretrizes éticas para o uso responsável da inteligência artificial, visando facilitar sua adoção e adaptação por outros professores. Os resultados de aprendizagem incluem a capacidade de analisar conceitos de engenharia, sintetizar informações técnicas a partir de diferentes fontes e comunicar resultados de forma eficaz por meio de artefatos escritos e audiovisuais. O artigo descreve a estrutura das atividades, a sequência didática e os materiais de apoio necessários para a implementação da ferramenta, favorecendo sua replicabilidade em diferentes contextos educacionais. Observações obtidas durante a aplicação em sala de aula indicam aumento do engajamento dos estudantes, melhor organização do conteúdo técnico e uso mais reflexivo das ferramentas digitais quando a inteligência artificial é explicitamente apresentada como apoio ao processo de aprendizagem, e não como geradora automática de conteúdo. A contribuição enfatiza o caráter prático e replicável da proposta e convida a comunidade de educação em engenharia a adaptá-la, aplicá-la e avaliá-la em diferentes realidades institucionais.

Palavras-chave: aprendizagem ativa; inteligência artificial; educação em engenharia; aprendizagem baseada em projetos; pedagogia digital

Resumen. Este artículo presenta una herramienta educativa desarrollada para apoyar el aprendizaje activo en la educación en ingeniería mediante el uso orientado y ético de la inteligencia artificial. La propuesta está dirigida a estudiantes de grado en ingeniería y se fundamenta en un contexto real de aula, estructurado a partir de actividades de extensión universitaria y aprendizaje basado en proyectos. La herramienta integra la inteligencia artificial como un mecanismo de apoyo pedagógico, contribuyendo a la organización del pensamiento, la estructuración de contenidos técnicos y la comunicación de resultados, sin sustituir el juicio crítico de los estudiantes ni la mediación del docente. El diseño instruccional contempla actividades claramente definidas, resultados de aprendizaje esperados, criterios de evaluación y directrices éticas para el uso responsable de la inteligencia artificial, con el propósito de facilitar su adopción y adaptación por parte de otros profesores. Los resultados de aprendizaje incluyen la capacidad de analizar conceptos de ingeniería, sintetizar información técnica procedente de diversas fuentes y comunicar resultados de manera eficaz mediante productos escritos y audiovisuales. El artículo describe la estructura de las actividades, la secuencia didáctica y los materiales de apoyo necesarios para implementar la herramienta, lo que favorece su replicabilidad en diferentes contextos educativos. Las observaciones obtenidas durante su aplicación en el aula indican un aumento del compromiso de los estudiantes, una mejor organización de los contenidos técnicos y un uso más reflexivo de las herramientas digitales cuando la inteligencia artificial se presenta explícitamente como apoyo al proceso de aprendizaje y no como generadora automática de contenidos. La contribución destaca el carácter práctico y replicable de la propuesta e invita a la comunidad de la educación en ingeniería a adaptarla, aplicarla y evaluarla en diferentes realidades institucionales.

Palabras clave: aprendizaje activo; aprendizaje basado en proyectos; educación en ingeniería; inteligencia artificial; pedagogía digital

1. INTRODUCTION

The rapid expansion of artificial intelligence (AI) tools has intensified discussions about innovation, ethics, and pedagogical transformation in higher education. In engineering education, these discussions increasingly extend beyond student learning to include faculty professional development and institutional capacity to integrate emerging technologies in a structured and responsible manner. Although AI technologies offer significant opportunities to enhance teaching, assessment, and student engagement, their effective integration remains a major challenge for many engineering educators. Recent studies indicate that instructors frequently report limited preparation for the pedagogical use of AI, uncertainty regarding ethical and academic integrity issues, and difficulties aligning AI-supported activities with established learning outcomes and assessment practices (Kasneci et al., 2023). Similar concerns have been identified in engineering education, where rapidly evolving AI capabilities are reshaping classroom dynamics and creating new demands on instructors' technological, pedagogical, and ethical competencies (Dewan et al., 2025; Vierhauser et al., 2024).

Furthermore, evidence suggests that institutional readiness often lags behind technological adoption, resulting in fragmented implementation strategies, inconsistent guidance, and limited opportunities for faculty training and collaborative reflection on AI-assisted teaching practices (UNESCO, 2023). As a consequence, engineering educators are increasingly required to make instructional decisions regarding AI use without clear pedagogical frameworks or established institutional support mechanisms. This situation highlights an urgent need for structured approaches that connect faculty development, ethical AI adoption, and active learning practices within engineering education. Recent studies highlight that sustainable adoption of AI in education requires organizational strategies, pedagogical frameworks, and explicit consideration of ethical and societal implications (Luckin et al., 2016; Holmes et al., 2019; Kasneci et al., 2023; UNESCO, 2023).

Active learning methodologies, such as project-based and experiential learning, are widely recognized as effective approaches for promoting meaningful learning, student engagement, and academic achievement in engineering programs and other STEM disciplines (Prince, 2004; Freeman et al., 2014; Felder & Brent, 2016).

However, their successful implementation depends strongly on instructors' pedagogical knowledge, confidence, and ability to design aligned learning activities, assessments, and feedback processes. Research in engineering education consistently indicates that without adequate faculty preparation, even well-established active learning strategies may be adopted superficially or misaligned with intended learning outcomes (Prince, 2004; Kolb, 1984; Biggs & Tang, 2011; Felder & Brent, 2016).

Recent developments in generative artificial intelligence have introduced new opportunities to support active learning environments by assisting instructors and students with activities such as idea generation, project planning, problem exploration, formative feedback, and the organization of complex technical information. Rather than replacing active learning principles, AI tools can enhance learner engagement by facilitating inquiry, reflection, and collaborative knowledge construction when integrated within pedagogically structured activities (Kasneci et al., 2023). In engineering education, emerging evidence suggests that generative AI can support project-based learning by helping students explore alternative solutions, refine technical communication, and engage more effectively in iterative design processes, while maintaining the central role of human judgment and disciplinary reasoning (Vierhauser et al., 2024; Dewan et al., 2025).

Nevertheless, the educational benefits of AI-supported active learning depend on careful instructional design and faculty guidance. Without explicit pedagogical alignment, AI technologies may encourage superficial task completion rather than deeper conceptual understanding. Consequently, engineering educators increasingly require frameworks that connect active learning methodologies with responsible and purposeful AI integration, ensuring that technological support remains aligned with intended learning outcomes and professional competencies (Kasneci et al., 2023; UNESCO, 2023).

When artificial intelligence tools are introduced into teaching practices without structured faculty development, ethical concerns about authorship, transparency, and accountability may leave instructors uncertain about their responsibilities. These challenges include an uncritical reliance on AI-generated outputs, difficulties in evaluating the accuracy and appropriateness of generated content, and potential misalignment between learning objectives, assessment strategies, and instructional practices. Studies in higher education have consistently emphasized that the educational use of generative AI requires careful consideration of ethical, pedagogical, and institutional dimensions to ensure that the adoption of this technology supports, rather than undermines, meaningful learning processes (Holmes et al., 2019; Kasneci et al., 2023; UNESCO, 2023).

Within the faculty development activities that informed the present framework, discussions among engineering educators frequently focused on questions related to responsible AI use, academic integrity, transparency in AI-assisted assignments, and the role of instructor oversight in AI-supported learning environments. These topics emerged during collaborative design activities and reflective exchanges, indicating that participants were not only interested in the technical capabilities of AI tools but also concerned about their pedagogical implications and potential impact on student learning. Similar concerns have been reported in recent studies examining the adoption of generative AI in engineering and higher education contexts (Dewan et al., 2025; Vierhauser et al., 2024; Kasneci et al., 2023).

Another recurring issue concerned the challenge of integrating AI tools into active learning activities without reducing opportunities for critical thinking, problem-solving, and independent knowledge construction. Participants highlighted the need for practical guidance

to help instructors determine when AI could effectively support learning and when excessive reliance on automated outputs might compromise educational objectives. These observations are consistent with international recommendations that emphasize human oversight, critical evaluation of AI-generated content, and the development of AI literacy among both educators and students (UNESCO, 2023; Holmes et al., 2019; Kasneci et al., 2023).

Studies in higher education emphasize that instructors require targeted training and opportunities for critical reflection to evaluate AI tools appropriately and integrate them as pedagogical support rather than substitutes for disciplinary reasoning and professional judgment. Faculty development initiatives have therefore been identified as essential mechanisms for promoting responsible AI adoption, strengthening pedagogical decision-making, and supporting sustainable educational innovation in engineering and higher education settings (Holmes et al., 2019; Kasneci et al., 2023; Dewan et al., 2025).

In this context, faculty development initiatives are supported by research showing their role in fostering institutional growth and confidence in AI integration. Structured training programs, collaborative networks, and communities of practice enable instructors to share experiences, establish common guidelines, and reflect on AI-assisted teaching practices. Educational research indicates that such initiatives support the sustainable adoption of innovation, strengthen pedagogical coherence, and foster institutional learning beyond isolated classroom experiments (Biggs & Tang, 2011; Kolmos et al., 2016; Wenger, 1998).

Recent studies examining the integration of generative artificial intelligence in higher education have reinforced the importance of faculty development as a prerequisite for responsible and pedagogically meaningful adoption. However, much of the existing literature has focused either on the technical capabilities of AI tools or on their impact on student learning, with comparatively less attention devoted to structured approaches that prepare educators to incorporate AI within active learning environments and established instructional frameworks (Kasneci et al., 2023; UNESCO, 2023; Dewan et al., 2025).

This gap is particularly relevant in engineering education, where instructors are expected to balance technological innovation with the development of higher-order cognitive skills, professional judgment, teamwork, and problem-solving competencies. Although communities of practice and professional development programs have been widely recognized as effective mechanisms for supporting educational change, few studies have explicitly connected faculty development, active learning methodologies, ethical AI use, and institutional implementation within a single transferable framework for engineering education (Kolmos et al., 2016; Vierhauser et al., 2024; Dewan et al., 2025).

The framework proposed in this study seeks to address this need by integrating these dimensions into a coherent structure that supports instructor preparation, pedagogical alignment, and responsible AI adoption. Rather than focusing exclusively on technology training or student-facing applications, the framework emphasizes how educators can critically evaluate, adapt, and implement AI-supported teaching practices while maintaining alignment with active learning principles and institutional objectives (Biggs & Tang, 2011; Kasneci et al., 2023; UNESCO, 2023).

This paper addresses these challenges by presenting an educational framework that explicitly links active learning practices with faculty development initiatives focused on the responsible use of artificial intelligence in engineering education. The framework was developed within higher education extension and professional development contexts, emphasizing instructor training, pedagogical alignment, and institutional scalability, which are widely recognized as key factors for sustainable pedagogical innovation in higher education (Biggs & Tang, 2011; Kolmos et al., 2016).

While examples from engineering courses are used to illustrate application contexts, the primary contribution lies in its focus on faculty preparation and the dissemination of

pedagogical practices rather than on discipline-specific instructional outcomes (Prince, 2004; Felder & Brent, 2016). While related student-centered applications have been reported elsewhere, the present contribution focuses exclusively on faculty development and institutional adoption (Luckin et al., 2016; Holmes et al., 2019; UNESCO, 2023).

Positioned within the Tools for Sharing with Community category, this contribution aims to provide higher education institutions and educators with a practical reference for integrating artificial intelligence into active learning through structured faculty development pathways, fostering a sense of shared purpose and collective progress, by highlighting training initiatives, collaborative consortia, and institutional experiences—such as those promoted by the STHEM Brasil Consortium—the paper supports sustainable and ethically grounded AI-supported pedagogical innovation across undergraduate engineering programs and related contexts.

2. METHODOLOGY

The methodological approach adopted in this study is a qualitative descriptive study informed by Design-Based Research (DBR) principles. This methodological choice was considered appropriate because the primary objective was not to measure learning outcomes quantitatively but to develop, describe, and refine an educational tool to support active learning and responsible use of artificial intelligence in engineering education. Design-Based Research has been widely recognized as a suitable approach for investigating educational innovations situated in authentic learning environments while simultaneously generating practical and transferable pedagogical knowledge (Reeves, 2006; Wang & Hannafin, 2005; Anderson & Shattuck, 2012).

Rather than emphasizing student performance metrics, the methodology prioritizes the analysis of instructional design practices, professional development experiences, and collaborative reflection among instructors. This perspective is consistent with qualitative educational research that seeks to understand how pedagogical innovations emerge, are adapted, and are implemented within specific institutional contexts. In engineering education, qualitative and design-oriented approaches have increasingly been employed to investigate active learning initiatives, curriculum innovation, and faculty development processes that cannot be adequately captured by quantitative indicators alone (Biggs & Tang, 2011; Kolmos et al., 2016; Felder & Brent, 2016).

The educational tool described in this paper emerged from teaching, extension, and active learning experiences conducted in engineering education settings, where instructors explored strategies for integrating emerging technologies into project-based and collaborative learning activities. In this sense, the study does not seek to evaluate a formal intervention or test a predefined hypothesis. Instead, it documents the rationale, design decisions, pedagogical structure, and implementation considerations associated with a replicable educational resource intended for adaptation by other educators. This orientation is aligned with Design-Based Research traditions that emphasize iterative development, contextual relevance, and practical applicability in real educational environments (Wang & Hannafin, 2005; Anderson & Shattuck, 2012; Reeves, 2006).

The methodological rationale is also consistent with previous contributions in engineering education that have examined active learning, project-based learning, university extension, and faculty-supported pedagogical innovation as mechanisms for strengthening student engagement and professional formation. Similar perspectives have been reported in studies addressing active methodologies, flipped classrooms, extension-based learning, and engineering education practices developed in authentic instructional contexts (Teixeira et al., 2018; Teixeira et al., 2019; Silva & Teixeira, 2022; Teixeira, 2025).

The framework was developed and implemented within higher education extension and professional development activities involving engineering instructors from different

institutional contexts. The initial development stage was conducted within the STHEM Brasil Consortium as part of a faculty development program focused on artificial intelligence applications in engineering education. Approximately twenty instructors participated in the training activities, including two faculty members from the Federal University of Itajubá (UNIFEI). Participants represented different Brazilian higher education institutions affiliated with the STHEM Brasil Consortium, providing opportunities for interdisciplinary dialogue and the exchange of teaching experiences across distinct academic contexts. Such diversity contributed to the refinement of the framework by exposing participants to multiple perspectives on active learning and AI-supported teaching practices (Wenger, 1998; Kolmos et al., 2016).

Participation was voluntary and based on enrollment in the professional development program, with all participants sharing a professional interest in engineering education, active learning methodologies, and emerging educational technologies (Kasneci et al., 2023; UNESCO, 2023; Dewan et al., 2025).

These activities included workshops, short training courses, and collaborative design sessions focused on active learning methodologies and the responsible use of artificial intelligence. The faculty development process was organized into four training modules, and the present framework emerged primarily from activities conducted during the module dedicated to artificial intelligence in engineering education. The development, refinement, and classroom implementation of the framework occurred over an approximate six-month period, allowing participants to discuss instructional challenges, evaluate pedagogical alternatives, and adapt AI-supported activities to their own teaching contexts (Wang & Hannafin, 2005; Reeves, 2006; Anderson & Shattuck, 2012).

Following the faculty development activities, the framework was implemented and refined in authentic educational settings. Initial applications were conducted through university extension seminars that involved approximately 11 undergraduate engineering students. A subsequent implementation took place in the compulsory undergraduate course Corrosion and Degradation of Materials at UNIFEI, involving approximately seven students. These experiences provided opportunities to evaluate the practical feasibility of integrating artificial intelligence into active learning activities while maintaining instructor guidance and student responsibility for disciplinary reasoning and knowledge construction (Felder & Brent, 2016; Kolmos et al., 2016; Teixeira, 2025).

Faculty development initiatives have been widely recognized as effective environments for fostering pedagogical innovation, particularly when they combine experiential learning, peer interaction, and structured reflection on teaching practices. The collaborative nature of the workshops and implementation activities enabled instructors to exchange experiences, identify common challenges, and reflect on the pedagogical implications of AI-supported learning in engineering education. Similar faculty learning environments have been identified as important mechanisms for supporting sustainable educational innovation and instructional change (Kolb, 1984; Wenger, 1998; Kolmos et al., 2016).

Demographic characteristics such as age, gender, academic rank, and years of teaching experience were not systematically collected because the initiative's primary purpose was to develop and refine an educational tool rather than to profile participants. Consequently, the study emphasizes the educational context, design process, and implementation experiences that informed the framework. This orientation is consistent with Design-Based Research approaches that prioritize the development and iterative improvement of educational innovations in authentic instructional environments (Wang & Hannafin, 2005; Reeves, 2006; Anderson & Shattuck, 2012).

The instructional design of the framework is grounded in the principles of constructive alignment and outcomes-based education and is adapted to the context of faculty training.

Instructors were guided to reflect on the alignment between learning objectives, instructional activities, and assessment strategies when incorporating artificial intelligence into their courses. Educational research emphasizes that such alignment is essential not only for student learning but also for supporting instructors in developing coherent and sustainable teaching practices during periods of pedagogical change (Anderson & Krathwohl, 2001; Biggs & Tang, 2011).

During the faculty development activities, participants engaged in a sequence of structured workshops and collaborative design sessions focused on the pedagogical use of artificial intelligence in engineering education. Initially, instructors examined examples of AI-supported educational activities and discussed the opportunities and limitations of their use in active learning environments. Participants were then invited to identify learning outcomes from their own courses and evaluate how AI tools could support, rather than replace, student reasoning, problem-solving, and disciplinary learning processes (Kasneci et al., 2023; Dewan et al., 2025).

In a subsequent stage, participants worked individually and in small groups to redesign existing learning activities using the principles of the framework. These activities included formulating learning objectives, designing project- and seminar-based tasks, defining assessment criteria, and developing ethical guidelines for AI use. Collaborative discussions encouraged participants to compare instructional strategies, anticipate implementation challenges, and refine proposed activities through peer feedback and reflection (Felder & Brent, 2016; Kolmos et al., 2016; Wenger, 1998).

The framework was subsequently implemented in authentic educational settings through university extension seminars and undergraduate engineering courses. Students were encouraged to use artificial intelligence as a learning support tool for organizing information, generating ideas, technical communication, and project development, while instructors remained responsible for activity design, feedback, and assessment. Observations from these implementations informed iterative refinements of the framework and contributed to the development of practical recommendations for future applications in engineering education (Wang & Hannafin, 2005; Reeves, 2006; Anderson & Shattuck, 2012).

Artificial intelligence tools were introduced during the training activities as pedagogical supports to facilitate instructional planning, organization of learning activities, and reflection on assessment design. Participants were encouraged to critically evaluate the affordances and limitations of AI tools, emphasizing transparency, ethical awareness, and human oversight. This guided approach aligns with international recommendations that emphasize instructor agency and ethical responsibility in the educational use of generative AI (Holmes et al., 2019; Kasneci et al., 2023; UNESCO, 2023).

The faculty development activities primarily employed three generative artificial intelligence platforms: ChatGPT, Microsoft Copilot, and Google Gemini. These tools were selected because they were widely accessible to participants and represented different implementations of large language model technologies currently being adopted in higher education. Rather than focusing on technical comparisons between platforms, the workshops emphasized their pedagogical potential and limitations within engineering education contexts, particularly regarding active learning, project-based learning, technical communication, and instructional design (Kasneci et al., 2023; Dewan et al., 2025; Vierhauser et al., 2024).

During the workshops, instructors explored how AI tools could support the development of learning objectives, the organization of seminar activities, the preparation of project proposals, the structuring of technical reports, and the generation of reflective questions for classroom discussion. Participants were also encouraged to compare AI-generated responses against disciplinary knowledge, course requirements, and professional engineering standards to promote critical evaluation and informed decision-making. This approach reinforced the role of artificial intelligence as a support mechanism for learning rather than as a substitute for

instructor expertise or student reasoning (Felder & Brent, 2016; Kasneci et al., 2023; UNESCO, 2023).

The subsequent classroom implementations followed similar principles. Students used ChatGPT, Copilot, and Gemini to assist in literature exploration, idea generation, content organization, project planning, and preparation of seminar presentations. Additional digital tools, including Canva and other AI-assisted applications selected by student groups, were optionally used to create visual materials and multimedia resources. Regardless of the platform employed, students were required to review, adapt, verify, and contextualize AI-generated content before incorporating it into academic work. These practices were intended to strengthen critical thinking, information literacy, and responsible AI use within engineering education settings (Vierhauser et al., 2024; Dewan et al., 2025; UNESCO, 2023).

Data collection was based on multiple sources of qualitative evidence generated throughout the faculty development and classroom implementation processes. These sources included documented observations recorded during STHEM training activities, reflective discussions among participants, instructional materials produced during collaborative design sessions, student-generated reports and presentations, project documentation, and feedback gathered during seminar discussions and classroom interactions. The use of multiple evidence sources is consistent with qualitative and design-oriented research approaches in engineering education, where authentic educational settings are examined through naturally occurring instructional artifacts and participant engagement rather than controlled experimental procedures (Reeves, 2006; Wang & Hannafin, 2005; Anderson & Shattuck, 2012).

The implementation process also generated educational artifacts that served as analytical units, including seminar reports, presentation materials, records of AI-supported activities, documented prompts, and reflective exchanges between instructors and students. These materials were examined to identify recurring patterns in pedagogical alignment, perceptions of AI-supported learning, implementation challenges, and opportunities to improve instructional design. Similar forms of evidence have been widely used in engineering education research to investigate instructional innovation and active learning environments situated in authentic educational contexts (Kolmos et al., 2016; Felder & Brent, 2016; Prince, 2004).

Data analysis followed an iterative qualitative interpretive process rather than a formal coding protocol. Initially, implementation records, instructional artifacts, and reflective notes were reviewed to reduce the data into meaningful categories related to faculty development, AI integration, active learning practices, and instructional decision-making. Subsequently, recurring themes were identified through repeated examination of the collected materials and comparison of evidence across different sources. This analytical strategy is consistent with qualitative, descriptive, and design-based research approaches, which emphasize understanding educational innovation within its natural context while supporting the progressive refinement of educational interventions (Wang & Hannafin, 2005; Reeves, 2006; Anderson & Shattuck, 2012).

Themes were identified through repeated examination of instructional artifacts, implementation records, reflective discussions, and project documentation. As the analysis progressed, no substantially new pedagogical patterns related to active learning, AI integration, or instructional decision-making were observed across the collected materials. Similarly, successive reviews produced recurring interpretations and did not reveal additional categories beyond those already identified in the different sources of evidence. The analysis was therefore considered sufficiently comprehensive for the study, reflecting principles commonly adopted in qualitative descriptive research, where analytical completeness is established through the recurrence of evidence across multiple data sources rather than through formal statistical criteria (Creswell & Poth, 2018; Merriam & Tisdell, 2016).

To enhance the trustworthiness of the findings, evidence was triangulated across planning documents, implementation records, participant-produced artifacts, classroom observations, and institutional project reports. Rather than relying on a single source of information, interpretations were developed from converging patterns observed across these complementary materials. Such triangulation procedures are commonly recommended in qualitative studies of educational innovation because they strengthen credibility and provide a more comprehensive understanding of complex teaching and learning processes (Creswell & Poth, 2018; Merriam & Tisdell, 2016; Anderson & Shattuck, 2012).

The methodological scope of this contribution is intentionally descriptive and exploratory, consistent with the Tools for Sharing with Community category. The primary objective is to document and share a transferable framework for faculty development rather than to provide experimental validation or causal inference. By emphasizing transparency, contextual description, and replicability, the methodology supports informed adoption and adaptation by other higher education institutions and engineering education communities (Prince, 2004; Kolmos et al., 2014).

3. RESULTS

The implementation of the proposed framework primarily yielded outcomes related to faculty engagement, pedagogical reflection, and institutional learning, rather than direct measurement of student performance. Evidence supporting these observations was derived from reflective discussions during faculty development activities, implementation records, instructional artifacts, seminar outputs, and documented feedback throughout the educational intervention. Collectively, these materials provided insight into how instructors and students engaged with artificial intelligence tools in active learning environments and how pedagogical decisions evolved during the implementation process (Wang & Hannafin, 2005; Reeves, 2006; Anderson & Shattuck, 2012).

Because the study was designed as a qualitative and design-oriented investigation, the findings are presented as recurring implementation patterns identified across multiple sources of evidence rather than as statistically derived outcomes. The objective was to document pedagogical processes, instructional adaptations, and implementation experiences that informed refinement of the proposed framework (Wang & Hannafin, 2005; Reeves, 2006; Anderson & Shattuck, 2012).

Chart 1 summarizes the principal themes that emerged across the different sources of qualitative evidence examined during the study. Although the analysis was not based on a formal coding protocol, repeated examination of workshop records, instructional artifacts, implementation reports, and reflective discussions revealed recurring patterns related to ethical AI use, pedagogical alignment, faculty development, critical evaluation of AI-generated content, and collaborative learning processes. The convergence of these themes across multiple evidence sources contributed to the refinement of the proposed framework and informed the interpretation of the implementation experiences reported in this study.

Chart 1. Recurring themes were identified during faculty development and classroom implementation activities.

Theme	Evidence Sources	Representative Observations	Educational Implications
Responsible use of AI	Workshop discussions, reflective exchanges, and implementation records	Participants frequently emphasized transparency, verification of AI-generated information, and the importance of human oversight in educational activities.	Highlights the need for ethical guidelines and explicit discussion of responsible AI use in engineering education.
Alignment with learning outcomes	Activity redesign exercises, instructional materials, and seminar	Instructors consistently discussed how AI-supported activities should remain connected to intended	Reinforces the role of constructive alignment when integrating AI into

Theme	Evidence Sources	Representative Observations	Educational Implications
	planning documents	learning outcomes and assessment criteria.	active learning environments.
Faculty readiness and pedagogical reflection	Collaborative workshops, implementation feedback, instructional artifacts	Participants reflected on the opportunities and limitations of AI tools and discussed strategies for adapting them to different instructional contexts.	Suggests that faculty development initiatives can support informed pedagogical decision-making.
Critical evaluation of AI-generated content	Classroom implementations, seminar reports, student-generated artifacts	Both instructors and students identified the need to verify, adapt, and contextualize AI-generated outputs before academic use.	Supports the development of critical thinking and information literacy skills.
Collaborative learning and exchange of practices	Faculty development meetings, peer discussions, and implementation records	Participants shared experiences, discussed challenges, and exchanged examples of AI-supported learning activities.	Indicates the importance of communities of practice for educational innovation and institutional learning.

Source: Developed by the author based on Wenger (1998), Wang and Hannafin (2005), Reeves (2006), Kolmos et al. (2016), Creswell and Poth (2018), and Merriam and Tisdell (2016).

The thematic categories summarized in Chart 1 were derived through iterative examination and comparison of multiple sources of qualitative evidence collected throughout the study. Workshop records, instructional artifacts, seminar outputs, implementation reports, project documentation, and reflective discussions were reviewed repeatedly to identify recurring pedagogical concerns and implementation patterns. The analysis focused on the convergence of similar observations across different sources rather than on numerical frequency, thereby identifying themes that consistently appeared in faculty development activities and classroom applications. This interpretive approach is consistent with qualitative descriptive research and design-based studies, in which the objective is to understand educational processes and generate practical knowledge grounded in authentic instructional contexts (Creswell & Poth, 2018; Merriam & Tisdell, 2016; Wang & Hannafin, 2005; Reeves, 2006).

Across the collected materials, recurring observations were identified regarding the need for clearer guidance on responsible AI use, the importance of aligning AI-supported activities with learning outcomes, and the value of maintaining instructor oversight throughout the learning process. These observations emerged consistently during collaborative discussions, activity redesign exercises, and classroom implementations, suggesting that participants viewed artificial intelligence primarily as a pedagogical support mechanism rather than as a replacement for disciplinary reasoning or professional judgment. Similar patterns have been reported in recent studies examining faculty engagement with generative AI in higher education and engineering education contexts (Dewan et al., 2025; Kasneci et al., 2023; Vierhauser et al., 2024).

The qualitative evidence also indicated increased reflection on instructional design decisions, assessment practices, and ethical considerations associated with AI-supported learning. Rather than focusing exclusively on technological adoption, participants frequently discussed integrating AI tools into project-based learning, seminar activities, and collaborative problem-solving tasks while preserving opportunities for critical thinking and student autonomy. These observations are consistent with recommendations emphasizing educator agency, responsible implementation, and pedagogically grounded uses of generative artificial intelligence in higher education (Holmes et al., 2019; UNESCO, 2023; Kasneci et al., 2023).

Because the study was designed to document the development and implementation of an educational framework, the findings should be interpreted as practice-based evidence derived from authentic educational contexts rather than as statistically generalizable outcomes. The

purpose of the analysis was to identify recurring implementation patterns and generate practical insights to inform future applications and evaluations of AI-supported active learning strategies in engineering education (Creswell & Poth, 2018; Merriam & Tisdell, 2016; Anderson & Shattuck, 2012).

One of the most evident outcomes of the structured training initiatives was the promotion of pedagogical reflection on the integration of artificial intelligence into engineering education. Rather than assessing instructor confidence as a measurable construct, the study examined how participants discussed, interpreted, and incorporated AI-supported practices during faculty development activities and subsequent classroom implementations. Evidence for these observations was derived from reflective discussions, collaborative design activities, instructional artifacts, implementation records, and documented feedback generated throughout the educational intervention (Creswell & Poth, 2018; Merriam & Tisdell, 2016; Anderson & Shattuck, 2012).

Through guided discussions, shared design activities, and reflective exchanges, participants demonstrated increasing familiarity with the pedagogical affordances and limitations of generative artificial intelligence tools. Recurring observations across workshop activities and implementation experiences indicated greater attention to aligning learning objectives, instructional strategies, assessment methods, and ethical considerations in the design of AI-supported learning activities. Similar outcomes have been reported in studies showing that faculty development initiatives can support more deliberate and pedagogically informed approaches to AI integration in higher education and engineering education contexts (Dewan et al., 2025; Kasneci et al., 2023; Vierhauser et al., 2024).

Educational research indicates that such alignment is more likely when faculty development programs explicitly address pedagogical coherence and constructive alignment rather than focusing solely on technological features. In this study, discussions frequently focused on how AI tools could support project-based learning, seminar activities, technical communication, and student engagement while preserving instructor oversight and disciplinary reasoning. These observations suggest increased readiness to critically evaluate and adapt AI-supported educational practices rather than evidence of a measured increase in instructor confidence (Biggs & Tang, 2011; Kolmos et al., 2016; Felder & Brent, 2016).

Accordingly, the findings should be interpreted as qualitative evidence of pedagogical reflection, instructional adaptation, and perceived readiness for AI integration. The purpose of the study was not to quantify psychological constructs such as confidence, but rather to document how faculty development experiences contributed to the design, implementation, and refinement of AI-supported active learning strategies in engineering education (Wang & Hannafin, 2005; Reeves, 2006; Creswell & Poth, 2018).

Participation in collaborative networks and communities of practice emerged as an important element during the development and implementation of the proposed framework. Evidence from faculty development activities, collaborative workshops, implementation records, and reflective discussions indicated that participants frequently exchanged teaching experiences, discussed challenges associated with adopting artificial intelligence, and compared alternative strategies for integrating AI into active learning environments. These interactions provided opportunities for collective reflection on pedagogical design, assessment practices, and ethical considerations related to AI-supported teaching in engineering education (Wenger, 1998; Kolmos et al., 2016; Felder & Brent, 2016).

Across workshop discussions and collaborative design activities, recurring observations highlighted three interconnected themes: the need for pedagogical guidance when using generative AI, the importance of aligning AI-supported activities with learning outcomes, and concerns regarding transparency and responsible use of AI-generated content. These themes recurred in discussions of activity planning, seminar development, and implementation

reflections, suggesting that participants viewed AI integration primarily as a pedagogical challenge rather than a purely technological issue (Kasneci et al., 2023; Dewan et al., 2025; UNESCO, 2023).

The inter-institutional nature of the faculty development activities also created opportunities for participants to compare experiences across different educational contexts. Discussions frequently focused on how active learning strategies, project-based activities, and seminar-based approaches could be adapted to incorporate AI tools while maintaining student engagement and disciplinary rigor. Implementation records and instructional artifacts indicated that peer exchange contributed to the refinement of educational activities and encouraged critical evaluation of AI-supported teaching practices (Kolmos et al., 2016; Vierhauser et al., 2024; Dewan et al., 2025).

Previous studies emphasize that communities of practice play a central role in scaling educational innovation by enabling knowledge sharing, mutual support, and collective sense-making among educators. The observations generated during this study are consistent with this perspective, as collaborative interactions appeared to support reflective decision-making and the adaptation of AI-supported activities to local educational needs. These findings should be interpreted as qualitative evidence derived from implementation experiences and participant interactions rather than as statistically generalizable outcomes (Wenger, 1998; Felder & Brent, 2016; Creswell & Poth, 2018).

Beyond the classroom-level implementation, the faculty development activities contributed to broader institutional discussions regarding the educational use of artificial intelligence in engineering education. Evidence from workshop discussions, collaborative exchanges, implementation records, and project documentation indicated increased attention to issues such as transparency, responsible AI use, academic integrity, documentation of AI-assisted activities, and alignment between emerging technologies and educational objectives. These observations suggest a growing institutional awareness of the pedagogical and ethical implications associated with AI adoption in higher education (UNESCO, 2023; Kasneci et al., 2023; Dewan et al., 2025).

Rather than leading to immediate organizational reforms or formal policy changes, the activities encouraged dialogue among instructors about the need for shared expectations, common practices, and future institutional guidance on AI-supported teaching and learning. Discussions frequently addressed questions regarding disclosure of AI use, instructor responsibilities, student accountability, and the role of human oversight in AI-assisted educational activities. Similar concerns have been reported in recent studies examining the integration of generative artificial intelligence into higher education and engineering education environments (Holmes et al., 2019; Kasneci et al., 2023; Vierhauser et al., 2024).

The institutional outcomes observed in this study should therefore be understood primarily as increased awareness, reflection, and dialogue rather than as formally documented organizational change. Although no institutional policies, regulations, or official guidelines were created as a direct consequence of the intervention, discussions generated by faculty development activities highlighted areas where future institutional frameworks and governance mechanisms could be beneficial. Research on educational change suggests that such conversations often represent an important preliminary stage in the long-term development of institutional strategies for educational innovation and technology integration (Biggs & Tang, 2011; Wenger, 1998; UNESCO, 2023).

From this perspective, the findings provide qualitative evidence that faculty development initiatives can support institutional learning processes by creating opportunities for collaborative reflection, knowledge sharing, and collective examination of emerging educational challenges. These observations should be interpreted as indicators of

organizational readiness and awareness rather than evidence of completed institutional transformation (Kolmos et al., 2016; Creswell & Poth, 2018; Merriam & Tisdell, 2016).

The STHEM Brasil Consortium served as one of the faculty development environments in which the proposed framework was initially explored, discussed, and refined. The consortium is a collaborative network of higher education institutions dedicated to faculty development, academic innovation, and active learning initiatives, providing opportunities for interdisciplinary exchange and professional training in emerging educational practices (STHEM Brasil Consortium, 2026a, 2026b).

Rather than evaluating the consortium itself, this study examined how participation in structured professional development activities contributed to the design and implementation of AI-supported active learning strategies in engineering education. Evidence for the analysis was derived from workshop discussions, instructional artifacts, implementation records, reflective activities, and classroom applications conducted after the training experience (Wang & Hannafin, 2005; Reeves, 2006; Anderson & Shattuck, 2012).

Analysis of these materials revealed recurring concerns regarding the alignment of artificial intelligence tools with learning objectives, the need for explicit ethical guidance, and the importance of maintaining instructor oversight throughout AI-supported learning activities. These issues recurred during collaborative design sessions, seminar planning, and implementation reflections, suggesting that participants viewed AI integration primarily as a pedagogical challenge requiring instructional decision-making rather than a purely technological solution. Similar findings have been reported in recent studies examining the adoption of generative artificial intelligence in higher education and engineering education contexts (Kasneci et al., 2023; Dewan et al., 2025; Vierhauser et al., 2024).

The contribution of the STHEM context was therefore evident in the generation of opportunities for collaborative reflection, interdisciplinary dialogue, and the examination of authentic teaching practices. Instructional artifacts and implementation records indicated that participants frequently revised activity designs, refined assessment approaches, and discussed strategies for responsible AI use following collaborative exchanges. These observations suggest that professional development environments can support the iterative improvement of educational innovations by encouraging critical reflection and shared problem-solving among educators (Kolmos et al., 2016; Wenger, 1998; Felder & Brent, 2016).

The findings should not be interpreted as evidence of the effectiveness of the STHEM Brasil Consortium as an institutional program. Instead, they demonstrate how participation in a collaborative faculty development environment informed the refinement of an educational framework designed to support active learning with artificial intelligence in engineering education. This interpretation is consistent with design-based and educational innovation research, in which professional development settings function as contexts for generating, testing, and improving instructional interventions rather than as objects of evaluation themselves (McKenney & Reeves, 2019; Anderson & Shattuck, 2012; Creswell & Poth, 2018).

Taken together, the results indicate that the primary impact of the proposed framework lies in strengthening faculty capacity and institutional readiness for AI-supported active learning. Rather than producing immediate or quantifiable instructional outcomes, the framework contributed to reflective practice, shared understanding, and pedagogical alignment among instructors. These results reinforce the view that faculty development and collaborative networks are key enablers of sustainable and ethically grounded integration of artificial intelligence in engineering education and higher education more broadly (Luckin et al., 2016; Biggs & Tang, 2011; UNESCO, 2023).

4. LIMITATIONS

This study has several limitations that should be considered when interpreting its findings. First, the primary objective was the development, implementation, and documentation of an educational framework designed to support active learning with artificial intelligence in engineering education rather than the formal evaluation of participant outcomes. Consequently, the study did not employ standardized instruments to measure constructs such as instructor confidence, technology acceptance, self-efficacy, or student learning gains. The findings should therefore be interpreted as qualitative evidence derived from authentic educational practice rather than as statistically generalizable results (Creswell & Poth, 2018; Merriam & Tisdell, 2016).

A second limitation relates to the nature of the data collection process. Evidence was obtained from reflective discussions, collaborative design activities, instructional artifacts, implementation records, project documentation, and participant feedback generated during faculty development and classroom implementation activities. Although multiple sources of evidence were examined, the study did not employ formal interview protocols, survey instruments, inter-rater coding procedures, or member-checking processes typically associated with some qualitative research designs. Instead, the analysis followed a qualitative, descriptive, and design-oriented approach focused on identifying recurring implementation patterns and informing iterative refinement of the framework (Wang & Hannafin, 2005; Reeves, 2006; Anderson & Shattuck, 2012).

The implementation context also imposes limitations on transferability. The framework was developed through faculty development activities and subsequently applied within a limited number of engineering education settings, including university extension seminars and an undergraduate engineering course. Institutional characteristics, participant backgrounds, disciplinary culture, and local educational conditions may have influenced the observed outcomes. As a result, the framework's applicability to other contexts should be examined through additional implementations across different institutions, disciplines, and student populations (Kolmos et al., 2016; Felder & Brent, 2016).

Finally, the study focused primarily on pedagogical processes, instructional design decisions, and faculty development experiences associated with the responsible integration of artificial intelligence into active learning environments. Future research should incorporate longitudinal designs, systematic qualitative protocols, and quantitative measures to examine learning outcomes, instructional effectiveness, student perceptions, and organizational impacts in greater depth. Such investigations would provide additional evidence regarding the educational value, scalability, and long-term sustainability of AI-supported active learning approaches in engineering education (Kasneci et al., 2023; Dewan et al., 2025; Vierhauser et al., 2024).

5. CONCLUSION

This paper presents a pedagogical framework that links active learning methodologies with faculty development initiatives to support the responsible integration of artificial intelligence in engineering education. Rather than concentrating solely on student learning outcomes, the contribution emphasized the role of instructors as key agents of pedagogical transformation and the importance of institutional structures that support continuous professional development.

The STHEM Brasil Consortium served as one of the professional development contexts in which the proposed framework was initially discussed, refined, and examined. Rather than being an outcome of the study itself, the consortium provided a structured environment in which engineering educators engaged in collaborative activities related to active learning

methodologies, pedagogical innovation, and the educational use of artificial intelligence. Evidence informing the present framework was derived from faculty development workshops, collaborative design activities, implementation records, instructional artifacts, and subsequent classroom applications rather than from the STHEM program alone.

Analysis of workshop discussions, implementation experiences, and participant-generated materials revealed recurring concerns regarding the alignment of AI-supported activities with learning outcomes, the need for ethical guidance in the use of generative AI, and the importance of maintaining instructor oversight in active learning environments. These observations were identified across collaborative planning activities, seminar development exercises, and classroom implementations, suggesting that participants consistently framed AI integration as a pedagogical issue requiring instructional design decisions rather than as a purely technological challenge.

The contribution of the STHEM context was therefore not evaluated in terms of institutional impact or program effectiveness. Instead, its relevance to the present study lies in providing opportunities for interdisciplinary dialogue, collaborative reflection, and examination of AI-supported teaching practices across different educational contexts. The resulting discussions and educational artifacts contributed to the iterative refinement of the framework and informed recommendations regarding responsible AI integration in engineering education.

Consequently, the findings should be interpreted as qualitative evidence derived from faculty development experiences and authentic educational implementations rather than as an evaluation of the STHEM Brasil Consortium itself. This distinction is important because the study's purpose was to document the development and application of an educational framework, not to assess the effectiveness of a professional development program. Similar approaches have been adopted in design-based and educational innovation research, where professional development environments serve as contexts for generating and refining instructional interventions.

Future developments of this framework will focus on expanding and strengthening faculty participation in professional development initiatives dedicated to artificial intelligence and educational innovation. Collaborative consortia and inter-institutional programs—such as the STHEM Brasil Consortium—provide strategic environments for training higher-education instructors in the pedagogical, ethical, and organizational dimensions of AI-supported teaching. These initiatives contribute to the dissemination of best practices, the formation of communities of practice, and the scaling of innovation across undergraduate and higher education institutions.

By connecting active learning approaches with faculty development and institutional collaboration, this work highlights a sustainable pathway for integrating artificial intelligence into engineering education. The framework encourages higher education institutions to view AI not merely as a technological tool but as a catalyst for pedagogical reflection, professional growth, and long-term educational transformation.

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