Supporting Global Teamwork through AI-Mediated Collaboration

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Introduction

Collaborative problem-solving has become an essential educational outcome, preparing students to tackle ill-structured, interdisciplinary challenges [1]. Yet teamwork in classrooms often proves uneven: some voices dominate while others are marginalized, leading to conflicts and miscommunication [2]. While these difficulties appear interpersonal on the surface, they are often rooted in a deeper challenge, such as students' limited metacognitive capacity to recognize, monitor, and regulate their collaborative behaviors [3]. Learners may not notice how their assumptions shape interaction, or may fail to evaluate whether chosen approaches are effective for the group. Traditionally, instructors and mentors have played the role of scaffolding students' metacognition during group projects, encouraging reflection and guiding regulation [4]. However, in large and diverse classrooms, the availability of personalized mentoring is limited; therefore, digital technologies provide a potential bridge to foster metacognition among learners [5], [6], [7].

Recent work in AI-enhanced learning has demonstrated how AI can fundamentally reshape collaborative learning by personalizing learning pathways, strengthening interaction quality, and supporting real-time group processes. Kok et al. [8] highlight that AI technologies can tailor learning experiences, offer dynamic feedback, and enrich peer communication within collaborative settings. A systematic review by Tan, Lee, and Lee [9] similarly shows that AI tools elevate collaborative learning by improving interaction quality, delivering immediate feedback, and adapting support to the evolving needs of learners. These developments align with broader findings in Computer-Supported Collaborative Learning, where digital tools are increasingly recognized for their ability to facilitate rich, interactive learning environments [10]. Emerging models of student-AI collaboration also illustrate how AI can participate more actively in learning by mediating communication, offering insights, and helping guide group reasoning [11]. At the same time, perspectives from distributed cognition remind us that learning unfolds across people, tools, and environments [12], emphasizing the importance of AI systems that engage meaningfully within group interactions rather than functioning solely as analytical back-end processors [8]. Yet most current systems still remain largely invisible to learners, offering cognitive scaffolds but limited support for the socioemotional and metacognitive dimensions of collaboration that are essential for shared regulation and productive teamwork. These gaps highlight a need for AI systems that move beyond assessment or automated hints toward more participatory roles prompting reflection, encouraging real-time regulation, and helping teams monitor how their interactions shape outcomes. EMPA, a collaborative AI mentor, is designed in response to this evolving landscape. This approach aligns with ABET Student Outcome 5, emphasizing students' capacity to collaborate in teams that practice effective leadership, cultivate an inclusive atmosphere, and define collective goals.

With this background, our guiding research question is:

How can an AI collaborative partner mediate students' metacognitive processes to support teamwork learning?

By addressing this question, we aim to contribute to the computer-supported collaborative learning (CSCL) community by demonstrating how AI can serve not only as a reflective prompt, but as a partner that strengthens students' learning-to-learn capacities in collaborative contexts.

Theoretical Grounding: Metacognition and AI-Supported Learning

Metacognition is commonly defined as "thinking about one's thinking" and encompasses both knowledge and regulation of cognitive processes [13]. Metacognitive knowledge refers to awareness of strategies, tasks, and personal assumptions that shape learning [6]. Metacognitive regulation involves monitoring progress, making adjustments, and evaluating outcomes in the midst of activity. Together, these processes allow learners to adapt effectively when facing complex and uncertain tasks. Teamwork provides a fertile but demanding context for metacognition. Collaborative projects introduce unpredictability in communication, coordination, and cultural expectations. Learners who can recognize how group dynamics are unfolding (monitoring), evaluate the effectiveness of their strategies (evaluating), and shift approaches when necessary (regulation) are better positioned to contribute productively. However, these skills rarely emerge without explicit scaffolding. Prior research demonstrates that guided reflection and structured prompts can enhance metacognitive engagement in collaborative settings, but scaling such supports remains difficult for instructors managing large cohorts [4], [6]. EMPA addresses this challenge by embedding metacognitive scaffolding directly into the learning process. Building on Schön's [14] concepts of reflection-in-action and reflection-on-action, EMPA extends reflection into the broader cycle of metacognitive regulation. Reflection-in-action aligns with monitoring and adjustment during activities, while reflection-on-action aligns with evaluating and consolidating learning afterward. By situating reflection within metacognition, EMPA reframes teamwork learning as not only a matter of collaboration but also of cultivating adaptive, self-regulated learners.

System Architecture: Scaffolding Metacognition with EMPA

1. AI Foundation

Figure 1 showcases the system architecture of EMPA. At the core of EMPA is a fine-tuned large language model (LLaMA-3 3B Instruct) adapted using QLoRA methods to balance memory efficiency with quality of feedback [15]. LoRA adapters were trained on structured records where synthetic student inputs were paired with model-authored scaffolds, focusing on two outcomes:

- **Metacognitive knowledge scaffolding** - prompting learners to articulate assumptions, identify cultural perspectives, and connect concepts to teamwork dilemmas.
- **Metacognitive regulation scaffolding** - nudging learners to monitor group dynamics, adjust strategies during interaction, and evaluate the effectiveness of decisions.

The model was trained to generate only the scaffolding portions of dialogue, ensuring EMPA consistently acted as a **metacognitive mentor** rather than reproducing student input.

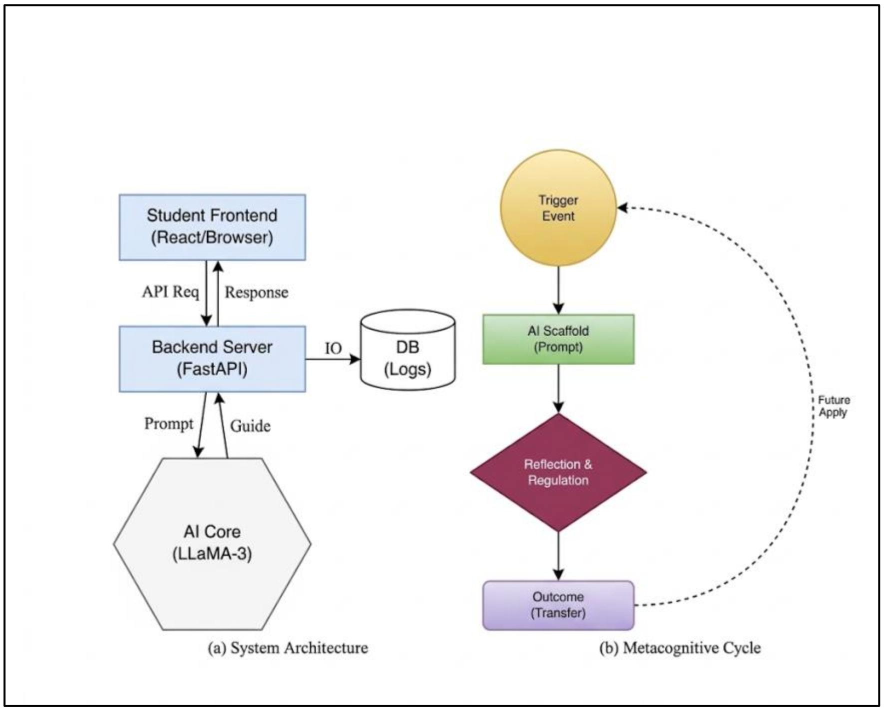

Figure 1: System Architecture and Metacognitive Cycle for EMPA

2. Learner Interface

The student experience is delivered through a modular, browser-based platform (React frontend, FastAPI backend, Supabase database). Six sequential modules guide learners through progressively complex teamwork challenges:

1. Recognizing assumptions in collaboration
2. Meeting EMPA as a partner
3. Monitoring group interactions
4. Understanding cultural perspectives
5. Regulating through empathy and strategy shifts
6. Evaluating collaboration and transferring lessons

Each module integrates case scenarios, video-based dilemmas, reflective prompts, and interactive quizzes. The chatbot sidebar (see Figure 2) functions as a space where EMPA engages learners in dialogue, alternating between scaffolding **knowledge** (“What assumptions might be influencing this teammate’s behavior?”) and **regulation** (“What adjustments could you make in the moment to include this perspective?”).

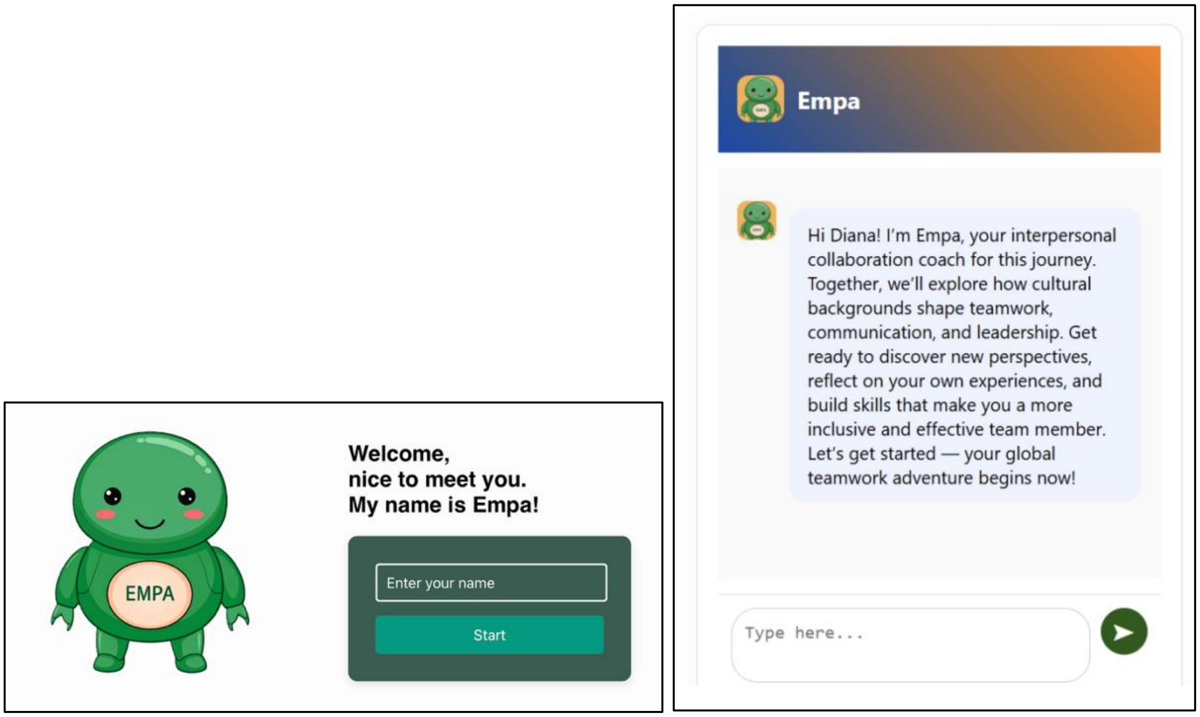

Figure 2: Welcome Page and EMPA interface

3. Backend and Data Management

The backend manages user profiles, conversation logs, and progress tracking. Each chat begins with a system persona prompt defining EMPA as a *collaborative mentor for metacognition*, not just a generic chatbot. Learner logs are preserved to allow EMPA to build on prior insights, reinforcing evaluation and transfer across modules.

Methods

Participants and Context

The participants in this study were six undergraduate teaching assistants (UGTAs) supporting a large-enrollment cybersecurity course at a major U.S. research university. The course enrolls approximately 200 undergraduate students each semester and is taught in a project-based, team-oriented format where collaboration, peer coordination, and iterative problem-solving are central to the learning experience. Because teamwork is an integral part of the course structure, UGTAs play a critical instructional role as they facilitate team activities during labs, supporting conflict resolution, guiding students through project milestones, and modeling effective communication practices.

All six UGTAs completed the full sequence of learning activities with EMPA, the AI Mentor used in this study. These participants represented diverse disciplinary backgrounds within computing and engineering, and all had prior experience working with student teams in technical, high-stakes learning environments. Their participation provided a unique window into how individuals with advanced content expertise but varied pedagogical preparation engage in metacognitive reflection when interacting with AI-mediated guidance. The EMPA interaction tasks mirrored the kinds of teamwork and intercultural scenarios UGTAs routinely encounter in the cybersecurity course, making their reflections particularly relevant to understanding metacognitive processes in authentic instructional settings.

Data Collection:

The data was collected through recorded interactions between the participant and the AI Mentor, EMPA. Each interaction captured both the participant's written responses and the EMPA's feedback during the learning activities. These exchanges served as the primary data source, reflecting participants' thought processes, reflection depth, and engagement with intercultural and teamwork-related prompts. Additional metadata, such as timestamps and activity identifiers, were also collected to contextualize the sequence and duration of interactions

Data Analysis: The data was analyzed qualitatively using a deductive thematic analysis approach, guided by established frameworks of metacognitive knowledge and metacognitive regulation [13]. The analysis aimed to identify how participants demonstrated awareness and control of their cognitive processes while engaging with the AI Mentor. Each interaction transcript between the participant and the AI Mentor was carefully reviewed to locate instances of metacognitive engagement, specifically behaviors and reflections that indicated planning (setting goals, anticipating challenges), monitoring (tracking understanding or progress), and evaluating (assessing outcomes or strategies). These predefined categories provided a structured lens for coding and interpretation. Thematic coding was carried out in multiple rounds to ensure reliability and depth. During the first cycle, excerpts were coded according to the metacognitive framework, highlighting moments where participants articulated self-awareness or adjusted strategies in response to the AI Mentor's prompts. In the second cycle, patterns were refined to reveal how participants transferred or adapted these skills across tasks and contexts. The analysis emphasized both the process (how learners engaged in reflective regulation) and the content (what aspects of their cognition they became aware of), offering insights into the development of metacognitive thinking during AI-mediated learning.

Trustworthiness and Rigor

To ensure the credibility and rigor of the qualitative analysis, several strategies were employed. Interrater reliability was conducted, with multiple researchers reviewing a subset of transcripts to confirm consistency in the application of codes and interpretation of themes. Furthermore, reflexive memos were used to capture the researchers' evolving assumptions and positionalities, ensuring transparency in the interpretive process. Together, these strategies strengthened the trustworthiness of the findings and reinforced confidence in the conclusions drawn about participants' metacognitive engagement during AI-mediated interactions.

Results

The pilot implementation highlighted how EMPA mediated both *metacognitive knowledge* and *metacognitive regulation* within teamwork contexts. The analysis of student interactions revealed three broad areas: (1) scaffolding knowledge about cultural and interpersonal assumptions, (2) supporting regulation of teamwork strategies through monitoring, adjustment, and evaluation, and (3) functioning as a co-regulator of the entire metacognitive cycle. These findings illustrate how EMPA shaped students' awareness of cultural dynamics while also guiding them in adapting and applying strategies to manage real teamwork challenges.

1. Scaffolding Metacognitive Knowledge

Awareness of Cultural Assumptions

Students often began their reflections with personal judgments about team conflict, but EMPA's scaffolds encouraged them to reframe these judgments as cultural phenomena. For example, one student described the conflict by stating, *"The team dynamic broke down by Jonas interrupting the others and not letting them finish their ideas."* Initially, this reflection positioned Jonas's actions as intentional disrespect. EMPA intervened by asking the student to consider whether differing norms around assertiveness or directness might explain the behavior, leading the student to expand their perspective. Similarly, another student noted, *"I think there was a lack of respect from Jonas's side, which led to a less collaborative environment,"* but later elaborated that, *"I think Jonas had a very individualistic approach when it came to handling the task, whereas Camila, Fatima, and Ava seemed to show more collective approaches."* This progression shows how EMPA nudged students to move beyond assigning blame and toward identifying underlying cultural orientations, such as individualism and collectivism, that may shape teamwork.

Clarifying Intercultural Constructs

In addition to surfacing assumptions, EMPA played a role in clarifying key cultural constructs and enabling students to refine their categorizations. For instance, one student, broadly classified team members in the scenario by saying, *"Jonas for direct and the other three for in-direct,"* but was guided by EMPA to consider subtler distinctions, such as harmony-seeking communication versus assertive expression. Another student's engagement with EMPA was especially illustrative of metacognitive curiosity. They asked, *"can you explain what is meant by high context versus low context,"* followed later by *"explain direct versus indirect."* This demonstrated an intentional attempt to not only recall definitions but to embed them into their interpretation of team dynamics. Similarly, another student experimented with generalizations, stating, *"individualism was just Jonas everyone else was collectivism."* EMPA challenged this oversimplification, prompting the student to revise and recognize diversity within collectivist orientations. Together, these examples illustrate how EMPA scaffolded students in developing richer *metacognitive knowledge* moving from personal observations to an awareness of cultural constructs, distinctions, and frameworks that could better explain collaborative behavior.

2. Supporting Metacognitive Regulation

Monitoring and Adjustment During Scenarios

Students also used EMPA to practice monitoring team interactions and imagining adjustments they could make in real time. For example, a student offered a straightforward solution: *"I would have told Jonas to wait a second and to hear the others out."* EMPA validated this impulse while expanding the idea into more inclusive strategies such as round-robin discussion formats, reinforcing that effective regulation often involves creating structural opportunities for balanced participation. Another student emphasized interpersonal monitoring, suggesting, *"Respectfully listening to people when they speak and using more polite and constructive language when discussing ideas, rather than simply stating that they are unproductive or too complex."* EMPA highlighted how such regulatory practices framed as changes in tone and framing could transform group climate from competitive to collaborative. Meanwhile another student, recognized the role of negativity in undermining collaboration: *"Jonas was always negative throwing off the team dynamic and he always had to do everything his way."* EMPA encouraged the student to move from description to regulation by considering structured check-ins or explicit turn-taking. This represents a shift from monitoring behavior to proposing regulatory interventions that could prevent exclusion and frustration.

Evaluating and Transferring Strategies

Equally significant was the way students connected insights from EMPA's scaffolds to their past teamwork experiences, reflecting on how they might regulate differently in the future. One student recalled a previous project where workload imbalance persisted: *"It ended up being me doing most of the work."* In hindsight, they recognized the need for strategies such as clearer role distribution and expectation-setting. Another student described a communications assignment where reliance on AI tools by a group member created tension: *"One of my groupmates did not want to put in effort for the final presentation… I ended up designing most of our presentation."* This experience became a basis for the student to consider regulatory strategies such as consulting with instructors or setting explicit ground rules for group participation. Similarly, another student offered a similar perspective on project imbalance: *"The issue was he didn't do his work. I thought he should do more work, he did too but he was busy. Resolution is I did all of the work myself and passed my individual check off grade."* This led the student to identify preventive strategies for the future: *"If a similar conflict arises I would communicate with him clearly the project deadline and expected work from each of us because I can't be thrown under the bus."* These examples show that students did not treat EMPA interactions as isolated exercises; instead, they drew connections to lived experiences and articulated strategies for regulating collaboration in future contexts.

Discussion

This study examined how EMPA, an AI-based collaborative partner, mediated students' metacognitive engagement in teamwork learning. Rather than serving as a passive feedback system, EMPA prompted students to surface cultural assumptions, clarify intercultural constructs, monitor and adjust their collaboration strategies, and evaluate past teamwork experiences with a view to transferring lessons to future contexts. The findings illuminate how AI can be situated as a co-regulator of metacognition, operating alongside learners to scaffold both awareness and regulation. In this section, we discuss the implications of these findings across four domains: (1) extending mentoring for metacognition through AI, (2) integrating cultural awareness into self-regulated learning, (3) conceptualizing AI as a co-regulator of collaboration, and (4) implications for CSCL design and teamwork education.

AI as an Extension of Mentoring for Metacognition

Mentoring has long been recognized as essential for developing students' reflective and regulatory capacities in teamwork [10]. Instructors often encourage learners to pause, analyze dynamics, and adopt strategies that enhance inclusivity and collaboration. Yet in large classrooms, individualized mentoring is difficult to scale. Students who struggle with communication breakdowns or inequitable contributions may not receive the timely scaffolds needed to regulate effectively. EMPA addresses this limitation by embedding metacognitive scaffolds within the flow of student learning. The system provided just-in-time prompts that validated learners' initial insights and extended them toward regulatory strategies [8], [9]. For example, when a student suggested asking a dominant peer to pause and listen, EMPA reinforced this instinct but elaborated with structural techniques such as round-robin participation. This dialogic expansion exemplifies how AI can act as an always-available mentor, encouraging deeper monitoring and adjustment than students might achieve on their own. What distinguishes EMPA from traditional reflection prompts or survey-based feedback is its dialogic nature. By engaging in conversational scaffolding, EMPA models the kinds of probing questions, clarifications, and strategic suggestions that a human mentor might offer [11]. In doing so, it transforms mentoring from a scarce resource into a more scalable practice, extending opportunities for students to rehearse reflective and regulatory skills. Importantly, the findings also suggest that students responded to EMPA's prompts not as impersonal instructions but as interactive invitations to think differently [12]. This indicates the potential for AI to humanize mentoring processes when carefully designed to foreground empathy and constructive dialogue.

Integrating Cultural Awareness into Self-Regulated Learning

A distinctive contribution of this work lies in EMPA's integration of intercultural frameworks within the metacognitive cycle. Much of the self-regulated learning (SRL) literature emphasizes individual monitoring, strategy use, and evaluation. Yet in team contexts, regulation cannot be separated from cross-cultural aspect. Communication breakdowns, unequal participation, and conflicting work orientations often stem from divergent cultural norms [16], [17] rather than deficiencies in motivation or skill. By prompting students to consider cultural constructs such as individualism versus collectivism or direct versus indirect communication, EMPA guided them to reframe conflict from interpersonal failings to culturally situated differences. For example, students who initially viewed assertive teammates as "disrespectful" came to recognize that directness can be a valued style in some contexts. Similarly, the clarification of time orientations enabled learners to see how prioritizing deadlines versus relationship-building reflected differing but legitimate approaches to collaboration. This integration expands the scope of SRL research by positioning *metacognitive knowledge* not only as awareness of strategies or tasks, but also as awareness of cultural assumptions that shape team dynamics [18]. Learners who can identify these cultural factors are better positioned to regulate effectively, because they can select strategies that are sensitive to both interpersonal and cultural dimensions of collaboration [19], [20]. Thus, EMPA illustrates how AI can bridge SRL with intercultural competence development, aligning with calls in higher education for students to be prepared for global, diverse workplaces.

AI as a Co-Regulator of Collaborative Learning

The concept of co-regulation is typically used to describe the ways peers, instructors, or mentors share responsibility for supporting metacognition in collaborative settings. This study extends the concept to include AI as a legitimate co-regulator. EMPA did not simply deliver content or evaluate correctness; it participated actively in learners' reflective cycles. By responding to student reflections with scaffolds that prompted monitoring, adjustment, or evaluation, EMPA co-constructed strategies with the learner. For example, when a student described a peer's negativity, EMPA did not stop at agreement but suggested structural tools such as regular check-ins. When another student recalled carrying the workload in past projects, EMPA prompted consideration of future strategies like role clarification and explicit deadlines. In these exchanges, EMPA modeled regulatory practices that learners could internalize and transfer, embodying the principles of co-regulation. This reconceptualization of AI as a co-regulator has important theoretical implications. It challenges binary views of regulation as either self-directed or externally imposed, suggesting instead that AI can occupy a middle space where regulation is shared, scaffolded, and gradually internalized by learners. Moreover, the study shows that AI-mediated co-regulation is not limited to cognitive strategies but can extend to socio-emotional and cultural dimensions of collaboration, an area often under-supported in team-based learning.

Implications for CSCL and Teamwork Education

For the CSCL community, the findings offer several design insights. First, AI systems for collaboration should be framed not as evaluators but as dialogic partners that sustain reflective and regulatory practices. EMPA's conversational scaffolds exemplify how AI can encourage learners to articulate their reasoning, reconsider assumptions, and adopt inclusive strategies. Second, the integration of cultural constructs suggests that effective AI for teamwork must account for the socio-cultural as well as cognitive dimensions of collaboration. This requires moving beyond generic prompts toward context-sensitive scaffolds that foreground diversity and inclusion.

For educators, the study provides a potential pathway to scale mentoring in teamwork-intensive courses. Embedding AI partners like EMPA could normalize metacognitive reflection, giving all students access to guidance that might otherwise be limited to a few. Importantly, this does not imply replacing human mentorship. Rather, it suggests a blended model where instructors provide depth and relational insight, while AI ensures breadth and consistency of support. Such an approach could be especially valuable in courses where teamwork is frequent but mentoring capacity is constrained, such as large project-based or interdisciplinary classes.

Conclusion

This study positions EMPA as an AI-mediated co-regulator of metacognition in teamwork learning. By scaffolding awareness of cultural assumptions, prompting monitoring and adjustment during scenarios, and supporting evaluation and transfer to lived experiences, EMPA demonstrated the potential of AI to extend mentoring capacity and foster adaptive collaboration skills. Rather than framing reflection as an individual responsibility, EMPA enabled metacognition to become a shared process, co-constructed between human and AI. For educators and researchers, the findings highlight both opportunity and responsibility. AI systems like EMPA can make reflective and regulatory practices more accessible, but they must be designed with care to respect learner agency, cultural diversity, and the complex realities of collaboration. For the CSCL field, this work suggests a broader vision: AI not only as a tool for delivering content or analyzing interactions, but as an active partner in cultivating the metacognitive and intercultural competencies essential for 21st-century teamwork.

Limitations and Future Directions

As a small-scale pilot, this study necessarily has limitations. Only six students were involved, and interactions were confined to controlled scenarios rather than integrated into ongoing coursework. While the findings illustrate EMPA's potential, they cannot be generalized without further study. Future research should expand to larger and more diverse cohorts, examining how AI-mediated metacognition unfolds across disciplines, class sizes, and cultural contexts. Another limitation lies in the interpretive role of EMPA's prompts. While students generally accepted and extended EMPA's feedback, some may view AI interventions as intrusive or overly directive. Exploring students' perceptions of agency and trust in AI co-regulators is therefore critical. Additionally, future work should investigate how AI scaffolds interact with peer dynamics whether students adopt AI-suggested strategies collaboratively, resist them, or adapt them to fit group norms. Finally, the technical design of EMPA raises questions for future refinement. The balance between personalized scaffolding and cultural sensitivity is delicate; prompts must avoid stereotyping while still encouraging learners to consider cultural perspectives. Iterative testing, co-design with students, and alignment with intercultural pedagogy will be necessary to ensure the system's continued relevance and inclusivity.

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