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SPECIAL TOPIC ARTICLE

From learning optimization to learner flourishing: Reimagining AI in Education at the Institute for Student-AI Teaming (iSAT)

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Abstract

The Institute for Student-AI Teaming (iSAT) addresses the foundational question: *how to promote deep conceptual learning via rich socio-collaborative learning experiences for all students*?—a question that is ripe for AI-based facilitation and has the potential to transform classrooms. We advance research in speech, computer vision, human-agent teaming, computer-supported collaborative learning, expansive co-design, and the science of broadening participation to design and study next generation AI technologies (called AI Partners) embedded in student collaborative learning teams in coordination with teachers. Our institute

ascribes to theoretical perspectives that aim to create a normative environment of widespread engagement through responsible design of technology, curriculum, and pedagogy in partnership with K–12 educators, racially diverse students, parents, and other community members.

INTRODUCTION

What should the classroom of the future look like? And what is the role of AI in these classrooms of the future?

Research on how people learn has converged toward a perspective of learning as fundamentally interactive, collaborative, and supported by tasks that are authentic to students' identities and interests (NASEM, 2018). Research has also documented the conditions that promote inclusive learning and honor diversity (Langer-Osuna, 2017). This rich body of research has profoundly influenced national standards in math, science, and educational reform efforts aimed at developing skills for the 21st century workforce (Fiore, Graesser, & Greiff, 2018).

Yet, the dominant approach to incorporating artificial intelligence in education (i.e., AIED) has primarily focused on an entirely different vision where students individually interact with technology that "optimizes" learning (Grandbastien et al., 2016). This 50+ year-old vision has been implemented via traditional adaptive computer-based learning, intelligent tutoring systems, recommender systems, and more recently, in teacher dashboards. Generative AI, including large language models like Chat-GPT, GPT-4, and Bard, are very attractive to this vision because they can potentially address several persistent problems including authoring content, assessment of open-ended responses, question answering, and adaptive coaching (D'Mello & Graesser, in press). However, doing so risks reinforcing a 20th century vision of learning centered around *individual optimization* (i.e., helping individual students achieve mastery in narrow domains) rather than a 21st century vision focused on *collaborative flourishing* (co-constructing knowledge using disciplinary practices and 21st century skills across domains).

Accordingly, the Institute for Student-AI Teaming (iSAT) aims to reframe the role of AI in education, expanding from a current emphasis on intelligent tools supporting personalized learning through unimodal, individualized, unidimensional, instruction toward a future where AI is viewed as a social, collaborative AI Partner (Figure 1) that collaborates with students and teachers to make learning more effective, engaging, and equitable. Given the importance of maintaining U.S. leadership in AI, and the excitement and concerns ushered forth by generative AI, we have selected AI-education as the focal domain for our research; our AI-enhanced curricula support diverse students to learn about, create, and critique AI technologies, and to think critically about the role of AI in society.

OUR VISION: AI PARTNERS HELPING TEACHERS ORCHESTRATE CLASSROOMS FOR COLLABORATIVE LEARNING

In our envisioned future, classrooms have been transformed into knowledge-building communities, where student-AI teams engage in inquiry, critical thinking, and collaborative problem-solving as they investigate a scientific phenomenon, solve real-world problems, or develop solutions to a design challenge. Distinguishing characteristics of these communities are the ways in which teachers, students, and AI Partners systematically construct conversations that probe deep and sustained reasoning, enable all students to share and build on each other's ideas, and collaboratively solve challenging problems. In some cases, the AI Partner intelligently participates in conversations among small groups of students, facilitating their sense making and supporting them when they might get stuck. Other times, the students are teaching the AI Partner or are engaging it in peer learning. In all cases, the AI Partner communicates naturally by understanding students' speech, facial expressions, eye gaze, and gestures. Its algorithms extract meaningful information from these signals in real-world classrooms, while avoiding the pitfalls of bias and inequity. And it is socially sensitive so that students do not feel like they are being surveilled or monitored, but instead have a trusting relationship with the AI Partner.

In these future classrooms, AI Partners have not replaced the teacher. Rather, the AI Partners have been co-designed with educators (and students) to complement and augment the teachers to do what they are best at—the care and nurture of their students. Thus, AI helps teachers orchestrate effective learning experiences at the individual, small group, and whole class levels. For example, it extracts insightful nuggets from student small group conversations, such as moments when students are pushing

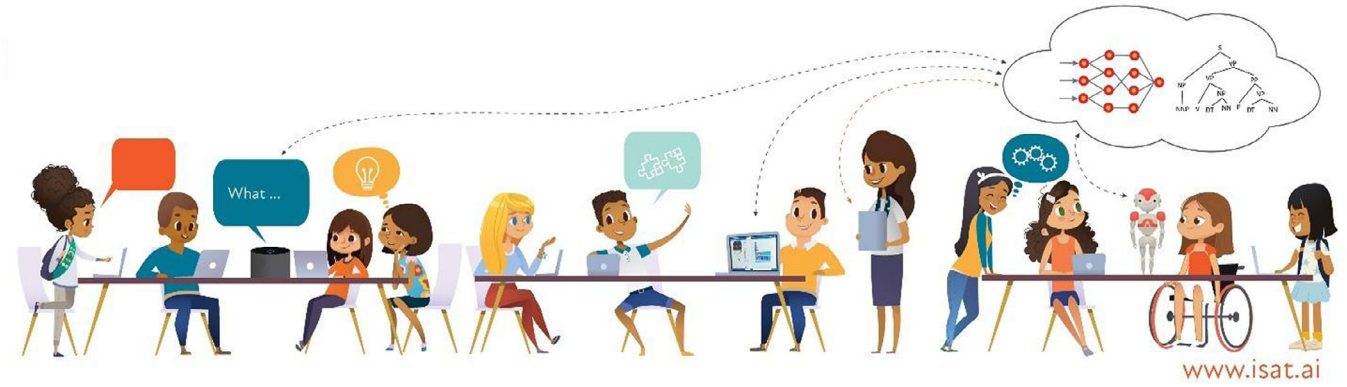

FIGURE 1 An AI Partner (disembodied voice on left, embodied virtual agent in middle, robot on the right) collaborates with student teams and helps teachers orchestrate collaborative learning in classrooms.

each others' thinking and provides these to the teacher to facilitate whole-class discussions.

As a result of scaling these student-AI teams across a large number of classrooms in the future, there has been deeper student engagement and persistence in STEM, more inclusive classroom cultures, and significant increases in student learning outcomes, practices, and 21st century skills of collaboration and critical thinking.

WHY, WHO, & SO WHAT?

Rationale

The rationale for our Institute is five-fold.

Foundational AI to power AI Partners. Advances for understanding collaborative discourse, such as speech recognition, natural language processing, computer vision, and multimodal integration, form the basic building blocks for the AI Partners. However, foundational AI research is needed to enable these technologies to robustly address challenges unique to the classroom context where communication is noisy, multiparty, multimodal, and situated in the real-world, something that existing generative AIs do not address.

Integrative knowledge on student-AI teaming. The education and learning sciences have developed extensive knowledge on human–human collaborative learning, whereas the human–computer interaction, AI, and related communities have been exploring the foundations of human-agent teaming. There is a need to integrate and extend these knowledge bases to advance foundational research on the new science of student-AI teaming.

New methods for design. The field of AI currently lacks methods and processes to ensure that AI technologies reflect the needs, interests, and values of diverse community stakeholders. Accordingly, new methods are needed to empower students with diverse identities to envision, co-create, critique, and apply AI learning technologies.

Ethical & responsible AI. Given the broad societal impacts of AI, it is imperative that developers of AI innovations, especially for use by students and other vulnerable populations, embody a culture of ethical and responsible AI. But too often the term "ethics" and "responsible" serve as useful talking points and design afterthoughts rather than foundational design principles. There is a need to develop and study methods for enacting responsible and ethical AI in real-world AI technology design.

Emergence through convergence. Our goal of "reimagining AI" implies a type of emergence—or the birth of something new where the whole is greater than the sum of its parts—through the convergence of seemingly disparate lines of research and expertise, an effort that requires major initiatives in multidisciplinary integration.

Team & organization

Our team integrates more than 80 researchers and students from nine geographically distributed universities with our K–12 partners, including diverse students, teachers, and parents from two school districts and nonprofits with expertise in working with diverse youth. The team is *organized* as follows.

Strand 1 (Understanding & facilitating collaborations) is advancing foundational AI research in speech processing, natural language understanding, computer vision, and multimodal processing to develop AI models that can monitor and support collaborative learning at multiple levels including the content, the conversational dynamics, gestures, and social signals.

Strand 2 (Orchestrating interactions with AI) is developing the nascent science of student-AI teaming, including novel conceptual frameworks and interaction paradigms which specify how to orchestrate effective student and

teacher interactions with AI grounded in team science, collaborative practices, and learning outcomes.

Strand 3 (Broadening participation with co-design) is developing new methods for engaging culturally, ethnically, and gender diverse students and educators in AI-technology design, along with co-designing, implementing, and studying middle and high school STEM curriculum materials supporting broadening participation in AI education.

Institute-wide (nurturing convergence research) is integrating research across the strands, providing cross-strand services (data, annotation, technology), and coordinating the development and testing of the AI Partners.

The *Community & Outreach Hub* is promoting collaboration, knowledge sharing, and integration across the Institute, with its external partners, and the public at large.

Anticipated outcomes

Our anticipated outcomes are in eight areas as shown in Table 1.

TABLE 1 Anticipated outcomes of the Institute.

Research outcomes: AI Partners that embody	Strategic impacts
Foundational AI for multimodal, multiparty, multicurricular collaboration in classrooms	Over 5000 culturally, ethnically, and gender diverse K–12 students with new capacity to participate in AI learning and innovation
A new science of student-AI teaming including new frameworks for collaboration and classroom orchestration	A multiorganizational, multidisciplinary research community with new AI research capacity
New methods for broadening participation in the design of AI systems including new ethical design frameworks	Knowledge transfer to interdisciplinary research communities and communities of practice
Innovative AI-enabled curricula that enable middle and high school educators to integrate AI education into their classrooms	National nexus point for responsible design of AI technologies with diverse stakeholders

SELECTIVE EXAMPLES OF ADVANCES IN FOUNDATIONAL, USE-INSPIRED RESEARCH, & BROADER IMPACTS

Understanding and mitigating the impact of automatic speech recognition (ASR) errors

We addressed whether contemporary ASR systems, which are benchmarked on adult speech in idealized conditions, can be used to transcribe child speech in classroom settings. We found that state-of-the-art models (Google Speech and Whisper ASR) have very high word error rates on classroom data. However, downstream natural language understanding models that rely on embedding-based semantic representations have a much higher tolerance for ASR errors than those that also analyze semantic structure (Cao et al., 2023). Further, fine-tuning large ASR models on a combination of different child speech datasets resulted in improvements in ASR accuracy.

Advances in integration of gesture and content analysis with collaboration constructs

A significant fraction of what is said cannot be understood without seeing what students are doing with their hands and their bodies (e.g., "that one there" [pointing]—Figure 2A). To address this, we extended the Abstract Meaning Representations (AMR) linguistic annotation scheme to incorporate the meanings of gesture in Gesture-AMR (GAMR) (Brutti et al., 2022). In parallel, we developed NICE—*Nonverbal Interactions in Collaborative-Learning Environments*—a coding scheme to analyze nonverbals signals at a higher level of abstraction (e.g., are teammates engaged even if they are not speaking much?). We unified GAMR and NICE to analyze nonverbal behaviors grounded in collaboration constructs.

Development of the collaborative learning and teaming framework

We organized the collaborative learning literature into a framework that incorporates different levels of interaction ranging from the individual to the team. We further advanced basic research aimed at addressing two major gaps in the literature: (1) first-person event-level coding and segmentation of collaboration for the purpose of imbuing coding schemes with users' perceptions of the unfolding collaboration; and (2) development of real-time metrics for tracking how team interactions both influence and are influenced by student team members, teachers, and a potential AI Partner.

(A) Situated grounding in small group collaborations

(B) Students voices in design of the AI Partners

(C) Students collaborating in the Sensor Immersion curriculum unit

FIGURE 2 Examples of research and education activities.

New design methodology for escaping institutional gravity in expansive design

Co-design to (re)-imagine institutional contexts (and the technologies embedded within them) are impeded when participants' frame of reference is constrained by institutional realities. To address this, we developed a three-step design process to temporarily escape institutional gravity in expansive design by: (1) experiencing familiar alternate spaces; (2) creating speculative spaces with inexpensive materials (Figure 2B); and (3) bringing speculative spaces into existing institutions. This methodology created the conditions for youth to propose novel designs for AI Partners.

New instructional materials to facilitate high-quality AI learning opportunities for nearly 4000 diverse students to develop, use, and critique AI systems

We co-designed (with educators) three curriculum units (Sensor Immersion, Self-driving Cars, and AI in Games unit) where students explored and programmed environmental sensors (Figure 2C), analyzed and visualized complex data streams, trained interactive bots, critiqued game design, and built models of neural networks. We then trained dozens of teachers to orchestrate high-quality learning opportunities with these units for nearly 4000 students, the majority of whom are from historically underrepresented groups. Data from these implementations is used to train the machine-learning models underlying the AI Partners and learn how to embed them in the curricula.

RESPONSIBLE & ETHICAL AI

We adopt the responsible innovation framework (RIF), which "means taking care of the future through collective stewardship of science and innovation in the present" (Stilgoe, Owen, & Macnaghten, 2013). As elaborated below, this framework is reflected in all our work.

Building shared values

We held a virtual kick-off retreat with goals of developing a sense of how our disciplinary lenses, positionalities, and life experiences shape what we notice in classrooms and how we see the potential of AI for learning, with a particular focus on the lens of AI justice.

Learning Futures Workshops (LFWs)

These intense, multi-day or multi-week engagements provide a space for diverse people to come together to envision possible futures for learning and to explore the role of AI in those futures. We have held three workshops with both students and teachers.

Participatory design & co-design

We use participatory design methods that empower school and community stakeholders with diverse identities to participate in AI-related research and development. Further, we co-design (with educators) and study innovative middle and high school units supporting AI education.

Adaptive conjecture mapping

We co-developed and used adaptive conjecture mapping (Chang & Dickler, 2023) which is graphical representation that connects the back-end decisions (e.g., what AI can sense), front-end decisions (e.g., how to interact with users), the mediating processes (what cognitive, behavioral, and affective processes arise from the interactions), and the intended outcomes, including both positive and negative.

(A) Initial student created design

(B) Interface for co-negotiated community agreements (CAs)

(C) CoBi visualization of CAs as colors of flowers and noticing

FIGURE 3 Design sketches of the Community Builder AI Partner (CoBi).

Design sprints

In multiple-day in-person/hybrid meetings, our interdisciplinary teams organized design activities centered around incorporating the inputs from the various stakeholders (especially students) into the design of the AI Partners.

Reflexivity

Lastly, we investigate the extent to which our Institute lives up to its commitment to the principles of responsible innovation by examining our engagement with diverse stakeholders, our uptake of their ideas in design, and the values of our own members.

PUTTING IT ALL TOGETHER: COBI—THE COMMUNITY BUILDER AI PARTNER

We originally imagined a key role for the AI Partner was to help keep students together and on track when working in small groups, thereby addressing a chief challenge of teachers who assign small group collaborative work. Initially, youth themselves said they wanted something that could keep other students on task, until asked whether they would want such a partner to intervene in their own actions. After some probing, we learned they wanted a partner that could affirm their ideas, to recognize their contributions, and support them during collaborations. However, it was challenging for youth to imagine what good collaboration could look like beyond what they had experienced in school. Hence, we took them to a housing coop where the membership turned over on a regular basis, but where a common community feeling existed. They met a person who had the role of "community builder," and the youth got really interested in the idea of shifting the narrative from AI policing their behavior to supporting their self-adherence to mutually agreed community agreements. They wondered if the AI Partner could help them to generate and maintain such agreements and developed a design sketch to embody their ideas (Figure 3A).

Across many subsequent design sessions, including interviews with teachers and students, conjecture mapping, storyboarding, and prototyping, we developed our first AI Partner—the Community Builder or CoBi. CoBi helps students and teachers to co-negotiate classroom agreements along four dimensions: being respectful, being equitable, being committed to community, and moving thinking forward (Figure 3B). As students engage in collaborative learning, CoBi analyzes student discourse for evidence, or "noticings" of the agreement categories using our fine-tuned models for speech diarization, speech recognition, and discourse classification; eventually the models will also incorporate nonverbal information. The results are aggregated across student groups (to protect student privacy), and then visualized at the classroom level. Figure 3C shows a sketch of a qualitative and expansive visualization by way of a growing tree animation where the noticings are shown as flowers that bloom. Teachers use CoBi to guide students to reflect on the extent to which their collaborative discourse was aligned with their co-negotiated community agreements and to discuss any discrepancies. In future versions, students will have the opportunity to interrogate the underlying NLU models as a means for transparency, trust building, fostering agency, and to understand the strengths and limitations of AI.

In addition to CoBi, we are also developing AI Partners that support and engage in collaborative conversations with students (Cao et al., 2023). Our next steps with these partners involve user testing and refinement, testing for evidence of their effectiveness in promoting collaboration and learning, and scaling more broadly to classrooms across the nation.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict.

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REFERENCES

Brutti, R., L. Donatelli, K. Lai, and J. Pustejovsky. 2022. "Abstract Meaning Representation for Gesture." In Proceedings of the Thirteenth Language Resources and Evaluation Conference, Marseille, France.

Cao, J., R. Dickler, M. Grace, J. Bush, A. Roncone, L. Hirshfield, M. Walker, and M. Palmer. 2023. "Designing an AI Partner for Jigsaw Classrooms." *Workshop on Language-Based AI Agent Interaction with Children (AIAIC'2023)*, Los Angeles, CA.

Cao, J., A. Ganesh, J. Cai, R. Southwell, M. Perkoff, M. Regan, K. Kann, J. Martin, M. Palmer, and S. K. D'Mello. 2023. "A Comparative Analysis of Automatic Speech Recognition Errors in Small Group Classroom Discourse." In *Proceedings of the ACM International Conference on User Modeling, Adaptation and Personalization (UMAP 2023)*, 250–62, ACM.

Chang, M. A., and R. Dickler. 2023. *A Conjecture Mapping Primer for Computer Scientists: Merging Learning Theories and Technical Research* (CIRCLS Rapid Community Report Series, Issue).

D'Mello, S. K., and A. C. Graesser. 2023. "Intelligent Tutoring Systems: How Computers Achieve Learning Gains That Rival Human." In *Handbook of Educational Psychology*. 4th Edition.

Fiore, S. M., A. Graesser, and S. Greiff. 2018. "Collaborative Problem-Solving Education for the Twenty-First-Century Workforce." *Nature Human Behaviour* 2(6): 367–369.

Grandbastien, M., R. Luckin, R. Mizoguchi, and V. Aleven. 2016. "Preface to the IJAIED 25th Anniversary Issue." *International Journal of Artificial Intelligence in Education* 26: 1–3.

Langer-Osuna, J. M. 2017. "Authority, identity, and collaborative mathematics." *Journal for Research in Mathematics Education*, 48(3): 237–47.

NASEM. 2018. *How People Learn II: Learners, Contexts, and Cultures*. washington, DC, National Academies Press.

Stilgoe, J., R. Owen, and P. Macnaghten. 2013. "Developing a Framework for Responsible Innovation." *Research Policy* 42(9): 1568–80.

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