



SPECIAL TOPIC ARTICLE

The AI Institute for Engaged Learning

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Funding information

National Science Foundation,
Grant/Award Number: DRL-2112635

Abstract

The EngageAI Institute focuses on AI-driven narrative-centered learning environments that create engaging story-based problem-solving experiences to support collaborative learning. The institute's research has three complementary strands. First, the institute creates narrative-centered learning environments that generate interactive story-based problem scenarios to elicit rich communication, encourage coordination, and spark collaborative creativity. Second, the institute creates virtual embodied conversational agent technologies with multiple modalities for communication (speech, facial expression, gesture, gaze, and posture) to support student learning. Embodied conversational agents are driven by advances in natural language understanding, natural language generation, and computer vision. Third, the institute is creating an innovative multimodal learning analytics framework that analyzes parallel streams of multimodal data derived from students' conversations, gaze, facial expressions, gesture, and posture as they interact with each other, with teachers, and with embodied conversational agents. Woven throughout the institute's activities is a strong focus on ethics, with an emphasis on creating AI-augmented learning that is deeply informed by considerations of fairness, accountability, transparency, trust, and privacy. The institute emphasizes broad participation and diverse perspectives to ensure that advances in AI-augmented learning address inequities in STEM. The institute brings together a multistate network of universities, diverse K-12 school systems, science museums, and nonprofit partners. Key to all of these endeavors is an emphasis on diversity, equity, and inclusion.

INTRODUCTION

AI holds significant transformative potential for improving K-12 education. Narrative-centered learning, which features story-based learning experiences, has long been recognized for the significant promise it holds for creating learning experiences that are both effective and engag-

ing for a broad range of student populations and subject matters (Mott et al. 1999; Saleh et al. 2022). The NSF AI Institute for Engaged Learning (EngageAI) conducts (1) use-inspired AI research on AI-driven narrative-centered learning environments, and (2) foundational AI research on natural language processing, computer vision, and machine learning. Inspired by a student-centered vision

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of AI-driven learning, the EngageAI Institute is creating AI-driven narrative-centered learning environments designed to promote student engagement. Advances in core AI technologies will enable new levels of interactivity and multimodal engagement, as well as support the creation of powerful predictive models of student learning.

The EngageAI Institute focuses on AI-driven narrative-centered learning environments that create engaging story-based problem-solving experiences to support collaborative inquiry learning (Saleh et al. 2022). The institute's AI-driven narrative-centered learning environments feature interactions with virtual characters capable of engaging in conversation while playing a variety of different roles. Generating interactive narratives dynamically tailored to the needs and interests of individual students in specific learning contexts requires a deep level of awareness of students' learning processes, as well as deep contextual understanding of what is happening in individual, small-group, and classroom (or museum) settings. Multimodal learning analytics utilizing new advances in natural language processing, computer vision, and machine learning will provide this awareness and understanding. By augmenting social interactions via embodied conversational agents that leverage multimodal data streams, AI-driven narrative-centered learning environments will deeply engage students in story-based learning experiences. These narrative-centered experiences will immerse students in storylines that drive their efforts, deepen their understanding of STEM concepts, facilitate their experience of STEM as a process of collective inquiry, and help them see STEM as addressing key societal challenges.

RESEARCH STRANDS

The institute's research has three complementary strands (Figure 1).

Narrative-centered learning

The institute is creating narrative-centered learning environments that generate engaging interactive story-based problem scenarios (Saleh et al. 2022). To support interest-driven learning explorations, the learning environments dynamically generate interactive narratives linked to authentic problem-solving scenarios, characters' behaviors and speech, curricular content, and support for learning. These capabilities are being created based on advances in generalizable and robust training of ML models with limited supervision, so as to enable tailored generation of interactive narratives that foster engaged student learning. With an emphasis on supporting narrative scenar-

ios that elicit rich communication, require coordination, and spark collaborative creativity, the narrative-centered learning technologies will be driven by advances in multimodal generative machine learning and reinforcement learning.

Embodied conversational agents

The institute is creating embodied conversational agent technologies (i.e., virtual agents) with multiple modalities for communication (speech, facial expression, gesture, gaze, and posture) to support engaging learning interactions (Johnson and Lester 2018). Embodied conversational agents are driven by advances in (1) natural language understanding (multiparty dialog structure, language models for long-form dialog, query-based video retrieval, low-resource automatic speech recognition for nonadults, multiple speakers, and noisy classrooms), (2) natural language generation (video and dialog summarization, question-answering, question-generation, explanation generation, paraphrasing for stylistic alignment, and controllable text-to-speech synthesis), (3) computer vision (gaze estimation, joint attention, attention and motion tracking, gesture, and action recognition), and (4) student modeling (predictive models of students' goals, plans, problem-solving strategies, cognitive states, and learning outcomes). The agents will support a broad range of roles including (1) providing students with cognitive, motivational, and affective support, (2) serving as virtual learning companions in collaborative learning, and (3) serving as cognitive assistants to teachers.

Multimodal learning analytics

The institute is creating an innovative framework for multimodal learning analytics to support students, researchers, teachers, and informal STEM educators (Hutchins and Biswas 2023). It seeks to greatly expand teacher awareness and support with innovations in natural language processing, computer vision, and machine learning methods. Rich streams of multimodal data derived from students' conversations, gaze, facial expressions, gesture, and posture as they interact with each other, with teachers, and with embodied conversational agents, will support comprehensive student modeling. The institute is developing multimodal interfaces with visualization, summarization, and query-based retrieval capabilities for students and teachers with a special focus on multimodal learning analytics for narrative-centered learning. Explanatory features of multimodal interfaces will significantly enhance teachers' capacity to

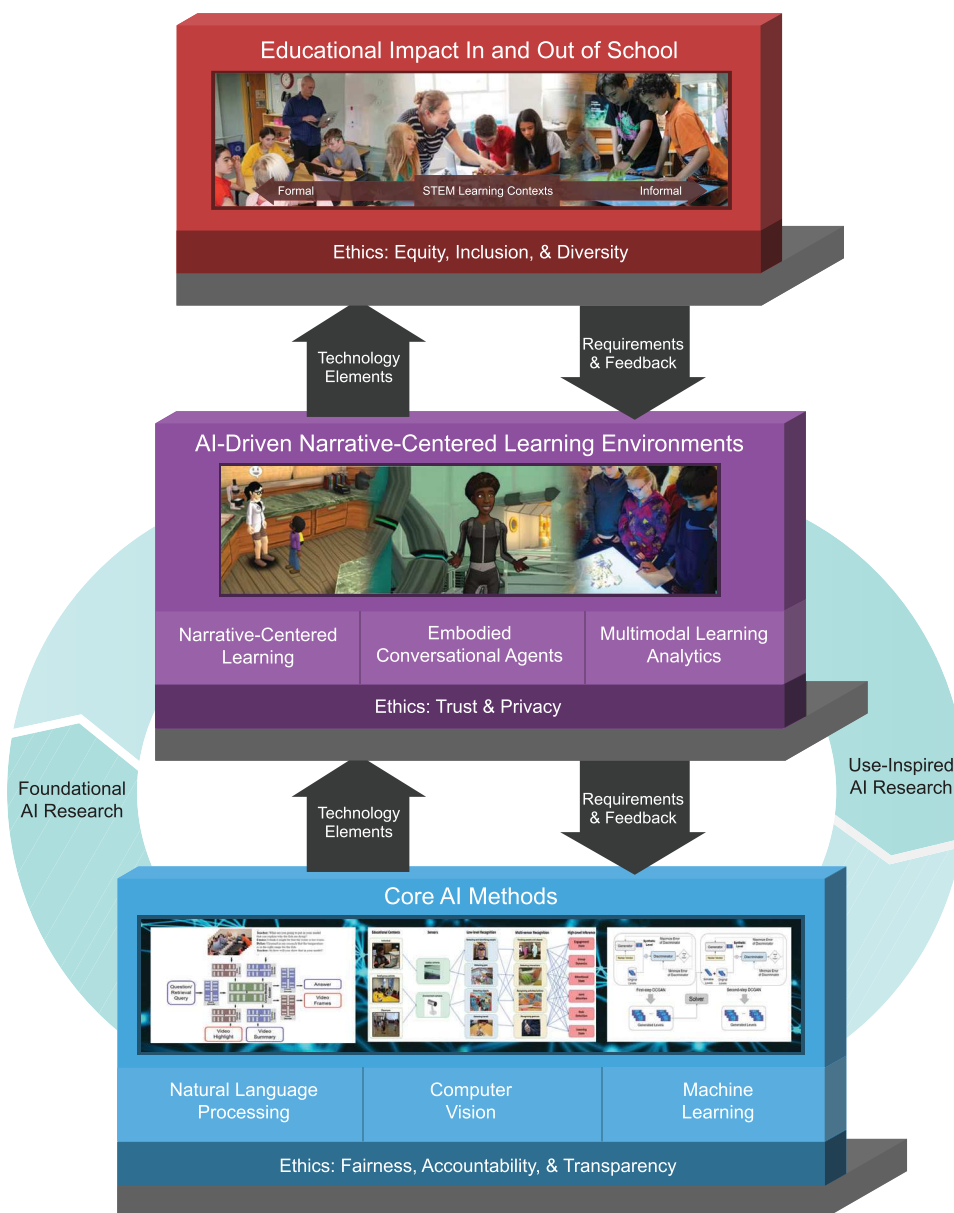


FIGURE 1 EngageAI Institute Research.

dynamically analyze and support the orchestration of rich student learning activities.

The institute's design of AI-driven narrative-centered learning environments is guided by educators' needs and students' interests and competencies. For example, middle school science teachers provide high-level guidance on narrative scenario generation to teach particular science concepts. By analyzing prior student performance inferred from student models, which are being driven by advances in machine learning, narrative-centered learning environments should anticipate student difficulties and need to adaptively support problem solving. For example, they should provide collaborative problem-solving advice delivered by conversational agents to

a group of middle school students solving a science problem.

Illustrative scenario

To illustrate how AI-driven narrative-centered learning environments developed by the institute leverage advances in natural language processing, computer vision, and machine learning, consider a hypothetical middle school science class that is using an AI-enhanced version of a narrative-centered learning environment, EcoJourneys. When using EcoJourneys in the classroom, students work in small, co-located groups where they can



easily converse and interact using a shared instance of the learning environment. Early in the EcoJourneys storyline, students travel to a fictional island in the Philippines where they encounter a dilemma: a local fish farm is reporting that tilapia are falling sick at an alarming rate. This science inquiry-based problem-solving scenario centers on ecosystems, moving from understanding relevant components, processes and mechanisms in a system, before advancing to more complex ecosystem interactions. To support students through the collaborative inquiry process, each student can be assigned a unique path in EcoJourneys to explore the virtual environment and progress through the problem scenario.

Leveraging advances in foundational and use-inspired AI research by the institute, problems such as the sick fish scenario can be generated and dynamically tailored to foster engaged learning experiences that are meaningful and adapted to local relevance, students' interests, collaboration requirements, and STEM knowledge. Narrative-centered learning environments can feature interactive storylines linked to authentic science problems that shape how the scenarios unfold as students solve them. The primary elements of interactive narratives such as sequences of plot events and character behaviors can be synthesized by generative models and reinforcement learning. Virtual environments can be generated procedurally based upon several factors, including socio-cultural factors to prioritize inclusion and relevance across a diverse range of learners. To create learning experiences that are both effective and engaging, dynamically generated adaptive support (e.g., hints, prompts, and feedback) can be discreetly embedded within the narrative scenarios to support learners in articulating how the data they collect can support claims about the algal bloom and its impact on the aquatic ecosystem.

Adaptive scaffolding can be delivered by virtual characters deeply infused with next-generation conversational agent technologies that combine dynamically generated dialog, facial expression, gaze, gesture, and body movement for each character. The characters can engage with students in dialogs by serving as (1) virtual mentors, (2) teachable agents, (3) virtual learning companions, (4) virtual collaborators, and (5) virtual facilitators. Students can engage in rich multiparty dialogs with virtual characters; engage in exchanges involving multimodal question generation, answering, and summarization; and communicate naturally through verbal and nonverbal behavior.

As students work together on EcoJourneys in the classroom, multimodal learning analytics can track students' learning and the difficulties they face, as well as students' eye gaze, facial expression, posture, and verbal and nonverbal interactions, with each other, and with their teacher. This data can be analyzed using natural language processing and computer vision to drive run-time narrative

generation and pedagogical decisions. Multimodal learning analytics can also track students' contributions to the collaborative learning process, and adaptive scaffolding functionalities delivered through embodied conversational agents can support student collaboration and reasoning about the problem scenario.

Throughout students' collaborative learning experiences, the teacher can be informed of students' progress and difficulties, and they can use this information to engage each group through conversations, providing resources, and further facilitating dialog among the students to reinforce ideas and perspectives from within the student's assigned roles in supporting the inquiry process.

INSTITUTE TEAM

The Institute brings together a deeply interdisciplinary team spanning five organizations with expertise in AI and education: four universities (North Carolina State University, University of North Carolina at Chapel Hill, Vanderbilt University, and Indiana University) and Digital Promise, a nonprofit intermediary organization, which serves as a "nexus" role for the institute. Headquartered in the Research Triangle of North Carolina and with a multi-state network of school and museum partners, the Institute is led by PI James Lester (North Carolina State University) and Managing Director Jonathan Rowe (North Carolina State University) and co-PIs Mohit Bansal (University of North Carolina at Chapel Hill), Gautam Biswas (Vanderbilt University), Cindy Hmelo-Silver (Indiana University), and Jeremy Roschelle (Digital Promise). They are joined by colleagues in natural language processing, computer vision, machine learning, AI in education, learning analytics, the learning sciences, STEM education, and teacher education.

ETHICAL AI IN EDUCATION

The transformative potential of AI comes with significant responsibility to look beyond its prospective benefits and recognize the challenges and potential risks inherent in AI-augmented engaged learning. The institute thus identifies strategies for addressing challenges, managing the risks, and assessing the areas where caution is necessary to ensure that AI's impacts are beneficial for learning and fairly distributed. Equally important to the careful design and execution of the Institute's ethical AI is transparent communication among all partners in AI-augmented engaged learning: researchers, educators, learners, their families, and the public. **Promoting equity, inclusion, and diversity in AI-augmented**

engaged learning: The institute engages with a diverse range of learners and educators throughout the design and development of its AI-driven narrative-centered learning environments, and it is advancing computational models of narrative toward producing story-centric problem scenarios and virtual worlds that embody socio-culturally relevant settings and contexts, cultivating feelings of personal identification and relevance across a broad range of learners. **Maintaining privacy and trust:** The institute's research, development, and dissemination efforts are infused with an emphasis on the use of privacy-aware techniques throughout the design and implementation of the AI-driven narrative-centered learning environments. Additionally, the institute is focused on designing, developing, and investigating AI models that are *trustworthy*, particularly among key stakeholders: students, educators, researchers, administrators, parents, and policy makers (Tam et al. 2023). **Fairness, accountability, and transparency in AI-empowered education:** Recent years have seen growing recognition of the important role of algorithmic bias in AI systems. The institute is formulating principles and methods to detect and mitigate the potential for codifying implicit bias into the AI models that drive its AI-driven narrative-centered learning environments.

ENGAGEAI R&D MODEL

The institute's research is driven by progression through (1) fundamental breakthroughs in narrative-centered learning environment technologies, (2) integrated narrative-centered learning environments, and (3) scalable narrative-centered learning environments. First, the institute targets fundamental breakthroughs in narrative-centered learning environment technologies, which span foundational AI and use-inspired AI technologies. Second, the institute's research on narrative-centered learning environments includes the design and development of integrated narrative-centered learning environments that integrate all of the functionalities required for narrative-centered learning. Third, the institute's research on narrative-centered learning environments will include the design and development of scalable narrative-centered learning environments that can be implemented "in the wild" at scale. The outcome of this work will be narrative-centered learning environments that can be used by students and educators at scale.

The institute has established a hybrid top-down/bottom-up research and development model that supports interconnections between the institute's use-inspired AI research and foundational AI-research activities and enables advances toward the institute's targeted research outcomes (Figure 2). The R&D model maps out a set

of critical shared resources that are continuously created, refined, and used by the institute in service to the accomplishment of its strategic and tactical objectives. The institute employs a system-integration approach to bring together the key enabling technologies—narrative-centered learning environments, embodied conversational agents, and multimodal learning analytics—into a single interoperable system that functions as a whole. The institute's AI-driven narrative-centered learning environments utilize a layered system architecture. The top layer, a dynamic narrative environment with multiple embodied conversational agents, is being designed to support teachers and students as they participate in interactive story-based problem-solving scenarios. Supporting the top layer is a lower layer consisting of a set of analytic and interpretation engines powered by multimodal analytics.

BROADER IMPACTS

The EngageAI Institute emphasizes broad participation and diverse perspectives to ensure that advances in AI-augmented learning address inequities in STEM and computer science education. The institute brings together a multistate network of universities, diverse K-12 school systems, science museums, and nonprofit partners. Digital Promise, a nonprofit intermediary organization, serves a nexus role for the institute. Digital Promise leads the League of Innovative Schools, a network of 114 districts nationwide, serving over three million students. Through Digital Promise, the institute engages educators, related research and development communities, industry and start-ups, and philanthropy to solve broad-ranging problems in education and STEM workforce development. The institute provides a robust infrastructure to support at-scale implementations of AI-driven narrative-centered learning environments. A key emphasis in all of these endeavors is on diversity, equity, and inclusion. In addition to workforce development for undergraduates, graduate students, and postdocs, as well as Institute Convergence Workshops and partnerships with Boys & Girls Clubs, the institute partners with organizations committed to broadening participation in computer science, including STARS Computing Corps, Code.org, the Computer Science Teachers Association, and CSforAll.

HIGHLIGHTS OF ACCOMPLISHMENTS

During its first 2 years, the EngageAI Institute has seen the launch of more than 25 active research projects, including 12 multi-institutional multidisciplinary projects, spanning use-inspired AI research and foundational AI research that

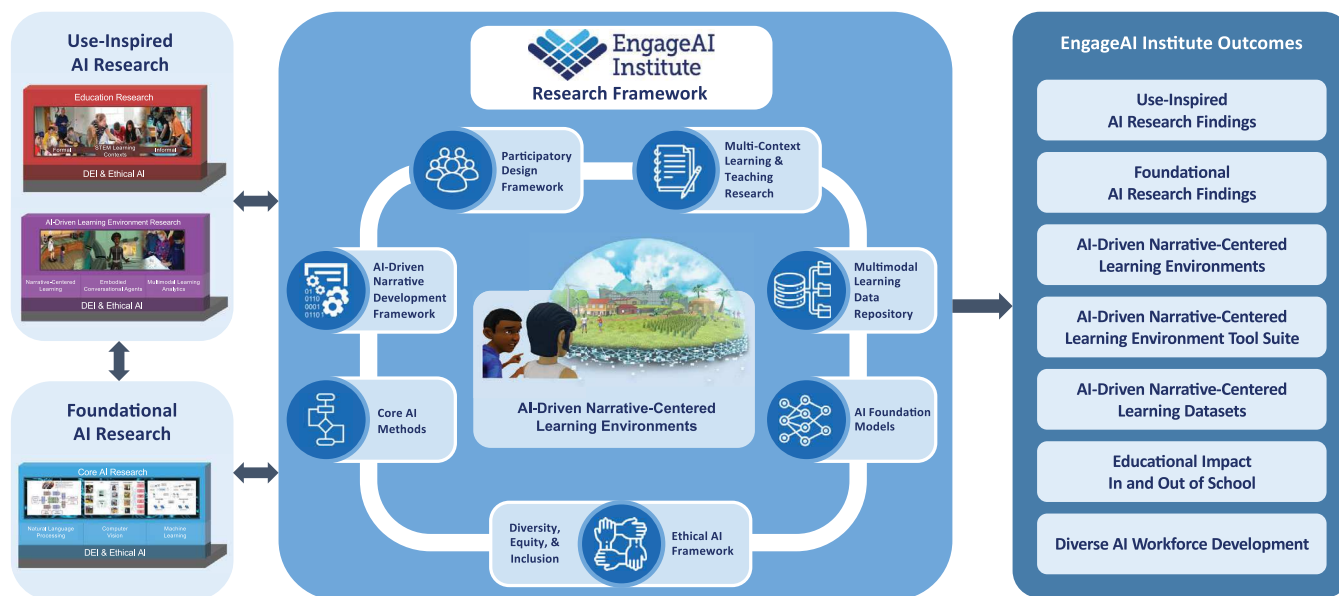


FIGURE 2 EngageAI R&D Model.

support the design, development, and investigation of AI-driven narrative-centered learning environments. Selected accomplishments include the following:

1. The institute designed and developed its first prototype AI-driven narrative-centered learning environment that serves as an AI system integration demonstration for AI-driven narrative planning, embodied conversational agents, and multimodal learning analytics functionalities integrated into a single system. The prototype features a run-time AI-driven narrative planner that can dynamically redirect the flow of interactive narrative events unfolding in real-time in a narrative-centered learning environment (Wang et al. 2018). The prototype's narrative planning capabilities are guided by a set of decision-making policies induced using deep reinforcement learning techniques. The prototype AI-driven embodied conversational agent provides a text-based natural language interface, which utilizes pretrained language models (e.g., T5, S-BERT) to drive natural language understanding functionalities in support of question-answer dialogs between the student and agent relevant to the learning environment's science problem-solving scenario. The prototype was also integrated with a multimodal sensor-based data capture module that provides functionalities for capturing student facial expression, posture tracking, and interaction trace logs that record problem-solving actions in the narrative-centered learning environment.
2. A joint team from NC State University and Indiana University investigated deep learning-based multiparty dialog act recognition using text chat data from student

collaborative learning interactions in the EcoJourneys narrative-centered learning environment (Saleh et al. 2022). The analysis utilized text utterances from student collaborative problem-solving chat, which were manually annotated using a theoretically grounded coding scheme. Using this dataset, the team examined the efficacy of transfer learning techniques with pretrained LLMs (i.e., BERT, T5) on dialog analysis of student and facilitator chat messages. Results showed LLM-based methods outperformed baseline models on automated classification of topic- and epistemic-based labels for the utterances. The results of this analysis show significant promise for informing AI-driven models for adaptively scaffolding student collaborative problem-solving by embodied conversational agents.

3. A team at the University of North Carolina investigated the performance of state-of-the-art video-and-language retrieval and summarization models on publicly available classroom video datasets. Specifically, the team focused on text-to-video retrieval, video-moment retrieval, video-moment segmentation, and video-moment captioning models, which retrieve the most relevant video from a set of candidate videos according to an input text query and caption the small step/moment-based contents of the video. For text-to-video retrieval, the team evaluated CLIP ViTB/32 (zero-shot/fine-tuned) and the HiREST joint model (zero-shot/fine-tuned) that was developed in Co-PI Bansal's lab (Zala et al. 2023). For moment retrieval, moment segmentation, and moment captioning, the team focused on evaluating the HiREST joint model. Results from experiments indicated that

current models, such as CLIP and the HiREST joint model, are able to perform reasonably well on all four of the tasks (text-to-video retrieval and moment retrieval/segmentation/captioning) in this domain, but there is still significant room for improvement, especially for text-to-video retrieval and moment captioning.

4. A team led by Co-PI Biswas at Vanderbilt University designed and developed a prototype multimodal learning analytics pipeline that implements a modular, component-based, distributed data collection networking architecture that supports the collection, alignment, and archiving of data from multiple sensing modalities as well as a flexible multiprocessor computational architecture that supports the use of compute-intensive machine learning algorithms for multimodal data analysis (Hutchins and Biswas 2023). While still in its infancy, the implementation supports high-throughput communication in a distributed environment, where the artifacts from sensors (different modalities) can be collected, aligned, and archived in a centralized fashion.
5. The institute's Nexus team, led by Digital Promise, convened a pair of EngageAI Institute Forums at the Computer History Museum in Mountain View, California to engage researchers, practitioners, and developers in reflective discussion about artificial intelligence in education. A national group of 150 attendees have participated in the Forums' highly interactive programs, including panels, poster sessions, and roundtable discussions encouraging conversation about the present and future of AI-augmented learning. A series of blogs summarizing key findings from the forums, as well as other pieces on AI-augmented learning, has been published on the EngageAI Institute website and disseminated through social media.

CONCLUSION AND FUTURE PLANS

Driven by a vision in which AI supports and extends the intelligence of teachers and learners, the EngageAI Institute is designing, developing, and investigating AI-driven narrative-centered learning environments that create engaging story-based, collaborative problem-solving experiences. The EngageAI Institute will continue to pursue an ambitious research agenda consisting of foundational AI research in natural language processing, computer vision, and machine learning, as well as use-inspired AI research on narrative-centered learning environments with rich AI-driven virtual agents and powerful multimodal learning analytics to understand how students learn and collaborate in story-based problem scenarios. The

institute will develop a robust infrastructure to support at-scale implementations of AI-driven narrative-centered learning environments. It will serve as a nexus for distinctive innovations in in-school and out-of-school STEM education, and empower diverse learners to become the next-generation STEM workforce by creating generative, collaborative AI-driven narrative-centered learning environments that deeply engage learners in schools, at museums, and within their own communities. This vision is being informed by connections with diverse stakeholders to ensure that the institute's learning environments are ethically designed and promote diversity, equity, and inclusion. The EngageAI Institute stands at the forefront of innovation in STEM education, combining the power of AI-augmented learning with immersive storytelling to foster engaged and effective STEM learning experiences for all learners.

ACKNOWLEDGMENTS

The material is based upon work supported by the National Science Foundation under Grant No. DRL-2112635. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict.

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How to cite this article: Lester, J., M. Bansal, G. Biswas, C. Hmelo-Silver, J. Roschelle, and J. Rowe. 2024. “The AI Institute for Engaged Learning.” *AI Magazine* 45: 69–76.
<https://doi.org/10.1002/aaai.12161>

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