



Towards the Future of AI-Augmented Human Tutoring in Math Learning

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Abstract. One of the primary obstacles to improving middle school math achievement is lack of equitable access to high-quality learning opportunities. Human delivery of high-dosage tutoring can bring significant learning gains, but students, particularly economically disadvantaged students, have limited access to well-trained tutors. Augmenting human tutor abilities through the use of artificial intelligence (AI) technology is one way to scale up access to tutors without compromising learning quality. This workshop aims to highlight the challenges and opportunities of AI-in-the-loop math tutoring and encourage discourse in the AIED community to develop human-AI hybrid tutoring and teaching systems. We invite papers that provide clearer understanding and support the progress of human and AI-assisted personalized learning technologies. The structure of this full-day hybrid workshop will include presentations of accepted papers, small or whole group discussion, and a panel discussion focusing on common themes related to research and application, key takeaways, and findings imperative to increasing middle school math learning.

Keywords: Tutoring · Personalized learning · AI-assisted tutoring

1 Leveraging AI and Human Tutoring

The primary challenge to improving middle school math achievement is providing all students equitable access to the existing high-quality learning opportunities that we know to be effective. Students from economically disadvantaged and historically underserved backgrounds can learn just as well as their peers when given the same opportunities, but they are more likely to experience learning gaps due to a lack of access to these learning

opportunities [2]. High-dosage human tutoring can produce dramatic learning gains, particularly if tutors are well-trained in providing students social-motivational support [4]. However, low-income students lack access to well-trained tutors, evidenced by the 16 million low-income children on the waitlist for high-quality afterschool programs [1]. In addition, the estimated costs of \$2500+ per student for individualized tutoring prohibits student access [3]. Human tutoring alone cannot meet present students need. Sustainable and scalable tutoring infrastructures are possible through the combined synergy of artificial intelligence (AI)-assisted and human technologies that can be achieved through novel and well-engineered AI-supported tutoring models.

AI-assisted tutoring shows promise and can potentially double learning outcomes [5], but analytics show that many students, especially from low-income backgrounds, are not getting sufficient learning opportunities. Student inaccessibility can be attributed to a variety of factors, including: not having sufficient access to the medium of using AI, such as digital devices and internet; issues facing inclusion with inadequate support of diverse student needs, such as English language learners and students with disabilities; and a lack of understanding of AI capabilities and limitations [7]. The challenges facing math learning related to access, equity, fairness, and inclusion have fostered collaborative and focused efforts on AI-assisted human-technology ecosystems that increase learning opportunities for all students.

This workshop aims to facilitate discussion and engagement among the Artificial Intelligence in Education (AIED) community regarding AI-assisted individualized learning tools to improve middle school teaching and tutoring. In particular, the workshop hosts updates on progress, findings, and challenges to AI-supported, personalized instruction. We invite empirical and theoretical papers aligned with the theme particularly (but not exclusively) within the following areas of research and application:

- **AI-assisted and Human Tutoring Systems:** Insight into better understanding and supporting human, AI-assisted, and interactive learning technologies related to individualized instruction
- **Delivery and Scale:** Efficacy of different human tutoring delivery systems (e.g., video, audio, chat) and the corresponding needed differentiated support; Different models for scaling including peer tutoring, computer tutoring, etc.
- **Training Development:** Tutor/teacher training development that recognizes diverse experiences and backgrounds, in relation to AI-assisted tutoring support structures
- **Equity and Inclusion:** Issues facing equity and inclusion, with focus on intelligent techniques to support students from under resourced communities
- **Ethics:** Privacy and transparency of intelligent techniques, such as using federated machine learning and explainable AI to examine data ownership and human-AI collaboration; Transferability and fairness of predictive models across contexts
- **Evaluation:** Program evaluation, such as applications using large-language models or dataset development for reinforcement learning of models; Methods of measuring student growth, with possible insights into dosage; Evidence of learning outcomes
- **Key Challenges:** Barriers, considerations, and challenges to providing human and AI-based tutoring and individualized instruction at scale
- **Interoperability:** How do AI and human tutoring systems interact with existing technological and social systems?

2 Relevance and Call for Papers from the AIED Community

There is a concerted effort within the AIED community to increase learning opportunities among economically disadvantaged and historically underrepresented students. The COVID-19 pandemic had a severe impact on education globally. The U.S. has lost nearly twenty years of math progress among middle school students [6], with racial and economic learning gaps preventing millions of students from realizing their potential. By leveraging the power of AI, the AIED community is working to provide equitable learning opportunities and helping bridge the persistent opportunity gap in action.

The workshop will include presentations of accepted papers and facilitated discussion sessions. We will solicit papers relevant to the themes using the short- or long-paper format described in the conference proceedings guidelines. Papers will go through a single-blind review process, with reviewers anonymous and authors known. Reviewers will be required to make a recommendation of either acceptance or rejection of the paper and explain their reasoning behind their decision. They will assess the paper based on three criteria, using a scoring system of -1 , 0 , or 1 ; alignment with the workshop's theme, level of interest to AIED, and overall quality. Authors of accepted papers will provide presentations at the conference. The paper submission deadline is May 26, 2023, with schedule details on the workshop website: <https://sites.google.com/andrew.cmu.edu/aied2023workshop/>.

3 Target Audience and Participation

The target audience consists of researchers, educational practitioners, businesses, policy-makers, and anyone among the AIED community interested in enriching their knowledge of AI-assisted and human tutoring working in synergy to provide individualized learning experiences. The workshop intends to set a wider agenda related to AI and human tutoring to grasp novel research ideas, interesting findings, and key insights to meet the practical needs of those involved in the research and development of AI-assisted and human tutoring ecosystems. This workshop is hybrid with no limit on the number of remote participants.

4 Workshop Format

We propose a full-day hybrid workshop with following activities: 1) presentations of accepted papers with Q&A, 2) small-group discussions on the conference themes, 3) reports of small-group discussions, 4) a moderated panel with audience participation focused on next steps, and 5) a closing summary and discussion. These activities will be oriented toward the workshop goals to develop shared understanding of the current state of AI-augmented human math tutoring and to pose key research questions and challenges for future research. The length of presentations will be determined by the organizing committee based on the maturity of the work, level of interest among AIED, and significance to the themes. Small group discussions will follow, and these will be aligned with the eight research areas described. A subsequent whole-group discussion will contain a question-and-answer period with in-person panelists. A summary of the

key issues and responses from the panel discussion, along with commonalities among accepted papers, will be published in the workshop proceedings.

5 Organizing Committee (Alphabetical Order)

Vincent Aleven, Ph.D., Carnegie Mellon University, aleven@cs.cmu.edu

Vincent is a Professor of Human-Computer Interaction at Carnegie Mellon University, with 30 years of experience in research of AI-based learning. His lab created Mathtutor, an AI-based tutoring software for middle school math and the tools for AI-based software, CTAT and Tutorshop. Vincent has written over 250 publications, with he and his team winning 11 best paper awards at international conferences and has acted as PI or co-PI on 20 major research grants. Currently, Vincent is co-editor-in-chief of the *International Journal of Artificial Intelligence in Education* (IJAIED).

Richard Baraniuk, Ph.D., OpenStax, Rice University, richb@rice.edu

Richard is the C. Sidney Burrus Professor of Electrical and Computer Engineering at Rice University and the Founding Director of OpenStax. He is a Member of the National Academy of Engineering and American Academy of Arts and Sciences and a Fellow of the National Academy of Inventors, American Association for the Advancement of Science, and IEEE. For his work in open education, he has received the C. Holmes MacDonald National Outstanding Teaching Award, the Tech Museum of Innovation Laureate Award, the Internet Pioneer Award from the Berkman Center for Internet and Society at Harvard Law School, and many other prestigious awards.

Emma Brunskill, Ph.D., Stanford University, ebun@cs.stanford.edu

Emma is an Associate Professor in the Computer Science Department at Stanford University where she aims to create AI systems that learn from a few samples to robustly make good decisions. Her work is inspired by the positive impact AI may have in education and healthcare, with interests in large language models to advance AI-assisted human tutoring. Emma is part of the Stanford AI Lab, the Stanford Statistical ML group, and AI Safety @Stanford. She has received an NSF CAREER award, Office of Naval Research Young Investigator Award, and many other awards. Emma and her lab have received multiple best paper nominations for their AI and machine learning work.

Scott Crossley, Ph.D., Vanderbilt University, scott.crossley@vanderbilt.edu

Scott is a Professor of Special Education at Vanderbilt University. His primary research focus is on natural language processing and the application of computational tools and machine learning algorithms in language learning, writing, and text comprehensibility. His main interest area is the development and use of natural language processing tools in assessing writing quality and text difficulty. He is also interested in the development of second language learner lexicons and the potential to examine lexical growth and lexical proficiency using computational algorithms.

Dora Demszky, Ph.D., Stanford University, ddemszky@stanford.edu

Dora is an Assistant Professor in Education Data Science at Stanford University. Her research focuses on measuring equity, representation, and student-centeredness in educational texts, with the goal of providing insights to educators to improve instruction. She develops measures based on natural language processing that work well for high-dimensional, unstructured data, and she applies these measures to provide feedback to educators. Dr. Demszky has received her PhD in Linguistics at Stanford.

Stephen Fancsali, Ph.D., Carnegie Learning, sfancsali@carnegielearning.com

Stephen is Director of Advanced Analytics at Carnegie Learning. With over a decade of experience in educational data science, he specializes in statistical and causal modeling of data produced by learners as they interact with AI-driven instructional software. He works on innovative learning analytics and models of student learning underlying MATHia, LiveLab, MATHstream, and other products. Stephen has published in the *Journal of Learning Analytics* and many conference proceedings. He received a Ph.D. in Logic, Computation, and Methodology from Carnegie Mellon University.

Shivang Gupta, Carnegie Mellon University, shivangg@andrew.cmu.edu

Shiv is the Head of Product at PLUS - Personalized Learning Squared at Carnegie Mellon University. A graduate of the Masters in Educational Technology and Applied Learning Science (METALS) program at CMU, Shiv was the lead curriculum developer at First Code Academy in Hong Kong and previously worked on corporate training in the metaverse.

Kenneth Koedinger, Ph.D., Carnegie Mellon University, koedinger@cmu.edu

Ken is the Hillman professor of Computer Science and Psychology at Carnegie Mellon University and founder of PLUS tutoring. He is a co-founder of Carnegie Learning, Inc. that has brought Cognitive Tutor based courses to millions of students since it was formed in 1998, and leads LearnLab, the scientific arm of CMU's Simon Initiative. Through extensive research and development in human-computer tutoring, Ken has demonstrated a doubling of math learning among middle school students, with future aims at bringing similar high-quality tutoring at scale. He has authored over 300 research papers and over 60 grant proposals.

Chris Piech, Ph.D., Stanford University, piech@cs.stanford.edu

Chris is an Assistant Professor in Computer Science at Stanford University. His research is in AI (and other computational methods) for education. He teaches introduction to Computer Science, CS106A and the online offering, Code in Place. The secret ingredient to both courses is high-quality human tutoring at scale.

Steve Ritter, Ph.D., Carnegie Learning, sritter@carnegielearning.com

Steve Ritter is Founder and Chief Scientist at Carnegie Learning. Dr. Ritter earned a doctorate in cognitive psychology at Carnegie Mellon University. He was instrumental in the development of the Cognitive Tutors for math, which led to Carnegie Learning, where it forms the basis of the MATHia intelligent tutoring system. Dr. Ritter is the author of many papers on the design and evaluation of adaptive instructional systems

and is recognized as an expert in the field. Dr. Ritter leads a research team devoted to using learning engineering to improve the efficacy of the company's products.

Danielle R. Thomas, Ed.D., Carnegie Mellon University, drthomas@cmu.edu

Danielle is a systems scientist at Carnegie Mellon University and research lead on the PLUS - Personalized Learning Squared tutoring project. She is a former middle school math teacher and school administrator, founding several mentoring programs supporting young women and youth in STEM. Danielle leverages her past experiences to advance research and development of tutor training and the creation of AI-assisted tutor feedback. She has first-authored over a dozen peer-reviewed papers since 2021.

Simon Woodhead, Ph.D., Eedi, simon.woodhead@eedi.co.uk

Simon is a co-founder of Eedi and also host of the Data Science in Education meetup. He coordinates Eedi's machine learning research, which has been conducted in collaboration with Microsoft Research, and turns this into new product features. With experience leading both product development and research, he has created award-winning edtech solutions with strong data science foundations.

Wanli Xing, Ph.D., University of Florida, wanli.xing@coe.ufl.edu

Wanli is an assistant professor of educational technology at the College of Education. His research themes are: (1) explore and leverage educational big data in various forms and modalities to advance the understanding of learning processes; (2) design and develop fair, accountable and transparent learning analytics, and AI-powered learning environments; (3) create innovative strategies, frameworks, and technologies for AI, Data Science, and STEM education.

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