EDUC 5183: Adaptive Learning Systems
Professor Ryan Baker

SYLLABUS

Instructor Info
Email: rybaker@upenn.edu
Course time: Thursday 515p
Course location: Online https://upenn.zoom.us/j/94463987501
Office hours: Online, Mondays 5p-6p and Wednesdays 905a-10a https://upenn.zoom.us/j/93923377036
Class discussion forum: https://educ5183-a24.jeepyta.net/

Required Texts:
- None

Course Goals: More and more education takes place asynchronously and online, but relatively little asynchronous instruction takes advantage of the technological advancements that have taken place in recent decades, replicating traditional models for instruction online.

In this class, you will learn about the pedagogy and technology of adaptive learning systems, individualized and personalized technology that helps students construct understanding and develop skill. We will review multiple generations of these technologies, including computer-aided instruction, intelligent tutoring systems, dialogue tutors, and tutors based on large language models, as well as related learning technologies that incorporate adaptive features.

We will read and reflect on both classic and recent papers on this technology, and study many of the successful examples of adaptive learning systems, both systems that have scaled and systems that have failed to scale. We will investigate key methods this type of learning leverages, and key pedagogies it affords.

Course Pre-requisites: None.

Assignments:

This course will be graded on the basis of three assignments, participation in synchronous discussions, and other forms of participation:
1. System Review (25% of grade)
2. Semester Paper Prospectus (14% of grade)
3. Semester Paper (25% of grade)
4. Synchronous Discussions in Vivi-SD (16% of grade)
5. Other Participation (20% of grade)

No examinations will be given in this class.

You will have the opportunity to discuss the materials you are learning and the assignments in weekly discussion groups, TA hours, instructor “ask me anything” (AMA) sessions, and the course discussion forum.

TA hours and AMA sessions will be offered at multiple times each week, in order to accommodate different student schedules. Participation can consist of engagement in each of these activities, and you

can receive a full participation grade from active participation in any of these activities. However, please note that simply attending synchronous sessions (but never speaking or typing) is *not considered participation*. Also please note that your participation grade does not include participation in Vivi-SD, which is graded separately.

If you do not want to use the JeepyTA forum at all, or you do not want to participate in VIVI-SD activities at all, you can contact me by email for alternate options.

Foundation model policy: Within this class, you are welcome to use foundation models (ChatGPT, GPT, Claude, Bing Chat, DALL-E, Stable Diffusion, Midjourney, GitHub Copilot, and anything after) in a totally unrestricted fashion, for any purpose, at no penalty. However, you should note that all large language models still have a tendency to make up incorrect facts and fake and image generation models can occasionally come up with highly offensive products. You will be responsible for any inaccurate, biased, offensive, or otherwise unethical content you submit regardless of whether it originally comes from you or a foundation model. If you use a foundation model, its contribution must be acknowledged in the handin; you will be penalized for using a foundation model without acknowledgement. Having said all these disclaimers, the use of foundation models is encouraged, as it may make it possible for you to submit assignments with higher quality, in less time.

Plagiarism policy: The university's policy on plagiarism still applies to any uncited or improperly cited use of work by other human beings, or submission of work by other human beings as your own. If you are not sure whether some action counts as plagiarism, ask before doing it. The university’s policy on plagiarism will be strictly followed.

Course Schedule

Week 1: May 30, 2024
Knowledge Communication, Knowledge Construction, or Procedural Skill Development: What's the Point?

Readings

- Complete the interactives and watch the videos on the Materials page
- VanLehn, K. (2011). The relative effectiveness of human tutoring, intelligent tutoring systems, and other tutoring systems. *Educational Psychologist*, *46*(4), 197-221.

Secondary Readings

- Anderson, J. R., Corbett, A. T., Koedinger, K. R., & Pelletier, R. (1995). Cognitive tutors: Lessons learned. *The journal of the learning sciences*, *4*(2), 167-207.
- Graesser, A. C., VanLehn, K., Rosé, C. P., Jordan, P. W., & Harter, D. (2001). Intelligent tutoring systems with conversational dialogue. *AI magazine*, *22*(4), 39-39.
- Wenger, E. (1987). *Artificial intelligence and tutoring systems: computational and cognitive approaches to the communication of knowledge*. Morgan Kaufmann. Chapter 1: Knowledge Communication

Week 2: June 6, 2024
Knowledge Tracing and Mastery Learning

Core Readings

- Complete the tutorial on the Materials page
    - Make sure to start at page 0
- Watch the video on the Materials page
- Baker, R.S. (2023) *Big Data and Education: 7th Edition.* Chapter 4, Videos 1 and 2. https://learninganalytics.upenn.edu/MOOT/bigdataeducation.html
- San Pedro, M. O. Z., & Baker, R. S. (2021). Knowledge Inference Models Used in Adaptive Learning. In *Computational Psychometrics: New Methodologies for a New Generation of Digital Learning and Assessment* (pp. 61-77).
- Ritter, S., Yudelson, M., Fancsali, S. E., & Berman, S. R. (2016). How mastery learning works at scale. In *Proceedings of the Third (2016) ACM Conference on Learning@ Scale* (pp. 71-79).

Secondary Readings

- Pelánek, R., & Řihák, J. (2018). Analysis and design of mastery learning criteria. *New Review of Hypermedia and Multimedia*, *24*(3), 133-159.
- Emery, A., Sanders, M., Anderman, L. H., & Yu, S. L. (2018). When mastery goals meet mastery learning: Administrator, teacher, and student perceptions. *The Journal of Experimental Education*, *86*(3), 419-441.
- Lee, J. I., & Brunskill, E. (2012). The Impact on Individualizing Student Models on Necessary Practice Opportunities. *Proceedings of the International Conference on Educational Data Mining Society*.
- Guskey, T. R., & Gates, S. L. (1986). Synthesis of research on the effects of mastery learning in elementary and secondary classrooms. *Educational leadership*, *43*(8), 73.

- Sales, A. C., & Pane, J. F. (2019). The role of mastery learning in an intelligent tutoring system: Principal stratification on a latent variable. *The Annals of Applied Statistics*, *13*(1), 420-443.

Week 3: June 13, 2024
Knowledge Graphs and Prerequisite Tracing

Core Readings

- Watch the video on the Materials page
- Essa, A. (2016). A possible future for next generation adaptive learning systems. *Smart Learning Environments*, *3*(1), 16.
- Zou, X., Ma, W., Ma, Z., Baker, R. (2019) Towards Helping Teachers Select Optimal Content for Students. *Proceedings of the 20th International Conference on Artificial Intelligence in Education*, 413-417.

Secondary Readings

- Desmarais, M. C., Meshkinfam, P., & Gagnon, M. (2006). Learned student models with item to item knowledge structures. *User Modeling and User-Adapted Interaction*, *16*(5), 403-434.
- Chen, P., Lu, Y., Zheng, V. W., Chen, X., & Yang, B. (2018). KnowEdu: a system to construct knowledge graph for education. *IEEE Access*, *6*, 31553-31563.
- Krauss, C., Salzmann, A., & Merceron, A. (2018). Branched Learning Paths for the Recommendation of Personalized Sequences of Course Items. In *DeLFI Workshops*.
- Brunskill, E. (2011). Estimating Prerequisite Structure From Noisy Data. *Proceedings of the International Conference on Educational Data Mining* (pp. 217-222).
- Chen, Y., González-Brenes, J. P., & Tian, J. (2016). Joint Discovery of Skill Prerequisite Graphs and Student Models. *Proceedings of the International Conference on Educational Data Mining*

Week 4: June 20, 2024
Memory Optimization and Spiraling Review

Core Readings

- Watch the video on the Materials page
- Wang, Y., & Heffernan, N. T. (2014). The effect of automatic reassessment and relearning on assessing student long-term knowledge in mathematics. In *International Conference on Intelligent Tutoring Systems* (pp. 490-495). Springer, Cham.
- Seibert Hanson, A. E., & Brown, C. M. (2020). Enhancing L2 learning through a mobile assisted spaced-repetition tool: an effective but bitter pill?. *Computer Assisted Language Learning*, *33*(1-2), 133-155.
- Wozniak, P. (2018) The true history of spaced repetition. https://www.supermemo.com/en/articles/history

Secondary Readings

- Pavlik, P., Bolster, T., Wu, S. M., Koedinger, K., & Macwhinney, B. (2008). Using optimally selected drill practice to train basic facts. In *International conference on intelligent tutoring systems* (pp. 593-602). Springer, Berlin, Heidelberg.
- Settles, B., & Meeder, B. (2016). A trainable spaced repetition model for language learning. In *Proceedings of the 54th annual meeting of the association for computational linguistics (volume 1: long papers)* (pp. 1848-1858).

- Khajah, M. M., Lindsey, R. V., & Mozer, M. C. (2014). Maximizing students' retention via spaced review: Practical guidance from computational models of memory. *Topics in cognitive science*, *6*(1), 157-169.

Week 5: June 27, 2024
Hints and Feedback

Core Readings

- Watch the video on the Materials page
- Hattie, J., & Timperley, H. (2007). The power of feedback. *Review of educational research*, *77*(1), 81-112.
- Aleven, V., Mclaren, B., Roll, I., & Koedinger, K. (2006). Toward meta-cognitive tutoring: A model of help seeking with a Cognitive Tutor. *International Journal of Artificial Intelligence in Education*, *16*(2), 101-128.

Secondary Readings

- Wisniewski, B., Zierer, K., & Hattie, J. (2020). The power of feedback revisited: A meta-analysis of educational feedback research. *Frontiers in Psychology*, *10*, 3087.
- McKendree, J. (1990). Effective feedback content for tutoring complex skills. *Human-computer interaction*, *5*(4), 381-413.
- Keuning, H., Jeuring, J., & Heeren, B. (2018). A systematic literature review of automated feedback generation for programming exercises. *ACM Transactions on Computing Education (TOCE)*, *19*(1), 1-43.
- Heiner, C., Beck, J., & Mostow, J. (2004). Improving the help selection policy in a Reading Tutor that listens. In *InSTIL/ICALL Symposium 2004*.
- Hume, G., Michael, J., Rovick, A., & Evens, M. (1996). Hinting as a tactic in one-on-one tutoring. *The Journal of the Learning Sciences*, *5*(1), 23-47.
- Razzaq, L., & Heffernan, N. T. (2010). Hints: is it better to give or wait to be asked?. In *International Conference on Intelligent Tutoring Systems* (pp. 349-358). Springer, Berlin, Heidelberg.
- Almeda, V., Baker, R., Corbett, A. (2017) Help Avoidance: When Students Should Seek Help, and the Consequences of Failing to Do So. *Teachers College Record*, 117 (3).
- Pardos, Z.A., Bhandari, S. (2023) Learning gain differences between ChatGPT and human tutor generated algebra hints. arXiv:2302.06871
- Pankiewicz, M., Baker, R.S. (2023) Large Language Models (GPT) for automating feedback on programming assignments. *Proceedings of the International Conference on Computers in Education.*
- Nguyen, H.A., Stec, H., Hou, X., Di, S., McLaren, B.M. (2023) Evaluating ChatGPT's Decimal Skills and Feedback Generation in a Digital Learning Game. *Proceedings of the European Conference on Technology-Enhanced Learning*.

July 4 NO CLASS

Week 6: July 11, 2024
Student Input Recognition and Classification

Core Readings

- Watch the video on the Materials page
- Anderson, J. R., Boyle, C. F., Corbett, A. T., & Lewis, M. W. (1990). Cognitive modeling and intelligent tutoring. *Artificial intelligence*, *42*(1), 7-49.

- Mitrovic, A., Koedinger, K. R., & Martin, B. (2003). A comparative analysis of cognitive tutoring and constraint-based modeling. In *International Conference on User Modeling* (pp. 313-322). Springer, Berlin, Heidelberg.

Secondary Readings

- Roll, I., Aleven, V., & Koedinger, K. R. (2010). The invention lab: Using a hybrid of model tracing and constraint-based modeling to offer intelligent support in inquiry environments. In *International Conference on Intelligent Tutoring Systems* (pp. 115-124). Springer, Berlin, Heidelberg.
- Mitrovic, A. (2012). Fifteen years of constraint-based tutors: what we have achieved and where we are going. *User modeling and user-adapted interaction*, *22*(1-2), 39-72.
- Paquette, L., Lebeau, J. F., & Mayers, A. (2010). Authoring problem-solving tutors: A comparison between ASTUS and CTAT. In *Advances in intelligent tutoring systems* (pp. 377-405). Springer, Berlin, Heidelberg.
- Aleven, V., McLaren, B. M., Sewall, J., Van Velsen, M., Popescu, O., Demi, S., ... & Koedinger, K. R. (2016). Example-tracing tutors: Intelligent tutor development for non-programmers. *International Journal of Artificial Intelligence in Education*, *26*(1), 224-269.
- McNichols, H., Zhang, M., & Lan, A. (2023). Algebra Error Classification with Large Language Models. In *International Conference on Artificial Intelligence in Education* (pp. 365-376).

Week 7: July 18, 2024
Assessing and Tutoring Complex Behavior

Core Readings

- Watch the video on the Materials page
- Li, H., Gobert, J., Dickler, R., & Moussavi, R. (2018). The impact of multiple real-time scaffolding experiences on science inquiry practices. In *International Conference on Intelligent Tutoring Systems* (pp. 99-109). Springer, Cham.
- Rus, V., Olney, A. M., Foltz, P. W., & Hu, X. (2017). Automated Assessment of Learner-Generated Natural Language Responses. *Design Recommendations for Intelligent Tutoring Systems: Assessment Methods*, *5*, 155-170.

Secondary Readings

- Kim, Y. J., Almond, R. G., & Shute, V. J. (2016). Applying evidence-centered design for the development of game-based assessments in physics playground. *International Journal of Testing*, *16*(2), 142-163.
- Rowe, E., Asbell-Clarke, J., Baker, R.S., Eagle, M., Hicks, A.G., Barnes, T.M., Brown, R.A., Edwards, T. (2017) Assessing Implict Science Learning in Digital Games. *Computers in Human Behavior*, 76C, 617-630.
- Sao Pedro, M.A., Baker, R.S.J.d., Gobert, J., Montalvo, O. Nakama, A. (2013) Leveraging Machine-Learned Detectors of Systematic Inquiry Behavior to Estimate and Predict Transfer of Inquiry Skill. *User Modeling and User-Adapted Interaction, 23* (1), 1-39.
- Roscoe, R. D., & McNamara, D. S. (2013). Writing Pal: Feasibility of an intelligent writing strategy tutor in the high school classroom. *Journal of Educational Psychology*, *105*(4), 1010.
- Crossley, S., Roscoe, R., & McNamara, D. (2013). Using automatic scoring models to detect changes in student writing in an intelligent tutoring system. In *The Twenty-Sixth International FLAIRS Conference*.
- McCarthy, K. S., Roscoe, R. D., Allen, L. K., Likens, A. D., & McNamara, D. S. (2022). Automated writing evaluation: Does spelling and grammar feedback support high-quality writing and revision?. *Assessing Writing*, *52*, 100608.

- Foltz, P. W. (2016). Advances in automated scoring of writing for performance assessment. In *Handbook of Research on Technology Tools for Real-World Skill Development* (pp. 659-678). IGI Global.
- Foltz, P. W., & Rosenstein, M. (2015). Analysis of a large-scale formative writing assessment system with automated feedback. In *Proceedings of the Second (2015) ACM Conference on Learning@ Scale* (pp. 339-342).

Week 8: July 25, 2024
Self-Regulated Learning and Engagement

Core Readings

- Watch the video on the Materials page
- Aleven, V., Roll, I., McLaren, B. M., & Koedinger, K. R. (2016). Help helps, but only so much: Research on help seeking with intelligent tutoring systems. *International Journal of Artificial Intelligence in Education*, *26*(1), 205-223.
- Bouchet, F., Harley, J. M., & Azevedo, R. (2016). Can adaptive pedagogical agents' prompting strategies improve students' learning and self-regulation?. In *International conference on intelligent tutoring systems* (pp. 368-374).
- Arroyo, I., Woolf, B. P., Cooper, D. G., Burleson, W., & Muldner, K. (2011). The impact of animated pedagogical agents on girls' and boys' emotions, attitudes, behaviors and learning. In *2011 IEEE 11th International Conference on Advanced Learning Technologies* (pp. 506-510). IEEE.

Secondary Readings

- Biswas, G., Roscoe, R., Jeong, H., & Sulcer, B. (2009). Promoting self-regulated learning skills in agent-based learning environments. In *Proceedings of the 17th international conference on computers in education* (pp. 67-74).
- Azevedo, R., & Hadwin, A. F. (2005). Scaffolding self-regulated learning and metacognition–Implications for the design of computer-based scaffolds. *Instructional Science*.
- DeFalco, J.A., Rowe, J.P., Paquette, L., Georgoulas-Sherry, V., Brawner, K., Mott, B.W., Baker, R.S., Lester, J.C. (2018) Detecting and Addressing Frustration in a Serious Game for Military Training. *International Journal of Artificial Intelligence and Education, 28* (2), 152-193.
- D'Mello, S., Lehman, B., Sullins, J., Daigle, R., Combs, R., Vogt, K., ... & Graesser, A. (2010). A time for emoting: When affect-sensitivity is and isn't effective at promoting deep learning. In *International conference on intelligent tutoring systems* (pp. 245-254). Springer, Berlin, Heidelberg.
- Baker, R.S.J.d., Corbett, A.T., Koedinger, K.R., Evenson, S.E., Roll, I., Wagner, A.Z., Naim, M., Raspat, J., Baker, D.J., Beck, J. (2006) Adapting to When Students Game an Intelligent Tutoring System. *Proceedings of the 8th International Conference on Intelligent Tutoring Systems*, 392-401.
- Vanacore, K., Gurung, A., Mcreynolds, A., Liu, A., Shaw, S., & Heffernan, N. (2023). Impact of Non-Cognitive Interventions on Student Learning Behaviors and Outcomes: An analysis of seven large-scale experimental inventions. In *LAK23: 13th International Learning Analytics and Knowledge Conference* (pp. 165-174).
- Vanacore, K., Gurung, A., Sales, A., & Heffernan, N. T. (2024). The Effect of Assistance on Gamers: Assessing The Impact of On-Demand Hints & Feedback Availability on Learning for Students Who Game the System. In *Proceedings of the 14th Learning Analytics and Knowledge Conference* (pp. 462-472).
- Leon, A., Nie, A., Chandak, Y., & Brunskill, E. (2024). Estimating the Causal Treatment Effect of Unproductive Persistence. In *Proceedings of the 14th Learning Analytics and Knowledge Conference* (pp. 843-849).

Week 9: August 1, 2024
Dialogue Tutors

Core Readings

- Watch the video on the Materials page
- Nye, B. D., Graesser, A. C., & Hu, X. (2014). AutoTutor and family: A review of 17 years of natural language tutoring. *International Journal of Artificial Intelligence in Education*, *24*(4), 427-469.
- Singer, N. (2023) Not Just Math Quizzes: Khan Academy's Tutoring Bot Offers Playful Features. *New York Times.* https://www.nytimes.com/2023/06/08/business/khanmigo-tutor-chat.html
- Singer, N. (2023) In Classrooms, Teachers Put A.I. Tutoring Bots to the Test. https://www.nytimes.com/2023/06/26/technology/newark-schools-khan-tutoring-bot.html

Secondary Readings

- Litman, D. J., Rosé, C. P., Forbes-Riley, K., VanLehn, K., Bhembe, D., & Silliman, S. (2006). Spoken versus typed human and computer dialogue tutoring. *International Journal of Artificial Intelligence in Education*, *16*(2), 145-170.
- Boyer, K. E., Phillips, R., Wallis, M., Vouk, M., & Lester, J. (2008). Balancing cognitive and motivational scaffolding in tutorial dialogue. In *International conference on intelligent tutoring systems* (pp. 239-249). Springer, Berlin, Heidelberg.
- Graesser, A. C., Moreno, K., Marineau, J., Adcock, A., Olney, A., Person, N., & Tutoring Research Group. (2003). AutoTutor improves deep learning of computer literacy: Is it the dialog or the talking head? In *Proceedings of artificial intelligence in education* (pp. 47-54).
- Baylor, A. L. (2009). Promoting motivation with virtual agents and avatars: role of visual presence and appearance. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1535), 3559-3565.
- Kim, Y., & Baylor, A. L. (2016). Research-based design of pedagogical agent roles: A review, progress, and recommendations. *International Journal of Artificial Intelligence in Education*, *26*(1), 160-169.
- Walton, D. (2023) Personalized Cognitive Tutoring using Davinci-003 API for Adaptive Question Generation and Assessment. arXiv:2304.02772
- Jiao, Y., Shridhar, K., Cui, P., Zhou, W., & Sachan, M. (2023). Automatic Educational Question Generation with Difficulty Level Controls. In *International Conference on Artificial Intelligence in Education* (pp. 476-488).

Week 10: August 8, 2024
Games and Gamification

Core Readings

- Watch the video on the Materials page
- Jackson, G. T., & McNamara, D. S. (2013). Motivation and performance in a game-based intelligent tutoring system. *Journal of Educational Psychology*, *105*(4), 1036.
- Johnson, W. L., Vilhjálmsson, H. H., & Marsella, S. (2005). Serious games for language learning: How much game, how much AI?. In *AIED* (Vol. 125, No. 1, pp. 306-313).
- Mayer, R. E. (2019). Computer games in education. *Annual review of psychology*, *70*, 531-549.

Secondary Readings

- Lomas, J. D., Koedinger, K., Patel, N., Shodhan, S., Poonwala, N., & Forlizzi, J. L. (2017). Is difficulty overrated? The effects of choice, novelty and suspense on intrinsic motivation in educational games. In *Proceedings of the 2017 CHI conference on human factors in computing systems* (pp. 1028-1039).
- Lomas, D., Patel, K., Forlizzi, J. L., & Koedinger, K. R. (2013). Optimizing challenge in an educational game using large-scale design experiments. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 89-98).
- Shute, V. J. (2011). Stealth assessment in computer-based games to support learning. *Computer games and instruction*, *55*(2), 503-524.
- Kim, Y. J., & Shute, V. J. (2015). The interplay of game elements with psychometric qualities, learning, and enjoyment in game-based assessment. *Computers & Education*, *87*, 340-356.
- Hamari, J., Shernoff, D. J., Rowe, E., Coller, B., Asbell-Clarke, J., & Edwards, T. (2016). Challenging games help students learn: An empirical study on engagement, flow and immersion in game-based learning. *Computers in human behavior*, *54*, 170-179.
- Ketelhut, D. J., Nelson, B. C., Clarke, J., & Dede, C. (2010). A multi-user virtual environment for building and assessing higher order inquiry skills in science. *British Journal of Educational Technology*, *41*(1), 56-68.
- Millis, K., Forsyth, C., Wallace, P., Graesser, A. C., & Timmins, G. (2017). The impact of game-like features on learning from an intelligent tutoring system. *Technology, Knowledge and Learning*, *22*(1), 1-22.
- Long, Y., & Aleven, V. (2017). Educational game and intelligent tutoring system: A classroom study and comparative design analysis. *ACM Transactions on Computer-Human Interaction (TOCHI)*, *24*(3), 1-27.
- Long, Y., & Aleven, V. (2014). Gamification of joint student/system control over problem selection in a linear equation tutor. In *International Conference on Intelligent Tutoring Systems* (pp. 378-387). Springer, Cham.

Week 11: August 22, 2024 OPTIONAL BONUS SESSION
Intelligent Tutoring Systems in the Classroom

Core Readings

- ASSISTments.org (2019) ASSISTments in my Classroom. Video at https://www.youtube.com/watch?v=kGxQsN0DBUU
- Miller, W.L., Baker, R., Labrum, M., Petsche, K., Liu, Y-H., Wagner, A. (2015) Automated Detection of Proactive Remediation by Teachers in Reasoning Mind Classrooms. *Proceedings of the 5th International Learning Analytics and Knowledge Conference*, 290-294.
- Xhakaj, F., Aleven, V., & McLaren, B. M. (2017). Effects of a teacher dashboard for an intelligent tutoring system on teacher knowledge, lesson planning, lessons and student learning. In *European conference on technology enhanced learning* (pp. 315-329). Springer, Cham.

Secondary Readings

- Holstein, K., McLaren, B. M., & Aleven, V. (2019). Co-Designing a Real-Time Classroom Orchestration Tool to Support Teacher-AI Complementarity. Journal of Learning Analytics, 6(2), 27-52
- Feng, M., & Heffernan, N. T. (2006). Informing teachers live about student learning: Reporting in the assistment system. Technology Instruction Cognition and Learning, 3(1/2), 63
- Sales, A. C., Wilks, A., & Pane, J. F. (2016). Student Usage Predicts Treatment Effect Heterogeneity in the Cognitive Tutor Algebra I Program. *Proceedings of the International Conference on Educational Data Mining*.

- Rockoff, J. E. (2015). Evaluation report on the School of One i3 expansion. *Unpublished manuscript. New York, NY: Columbia University*.
- Karumbaiah, S., Borchers, C., Shou, T., Falhs, A. C., Liu, P., Nagashima, T., Rummel, N., Aleven, V. (2023,). A Spatiotemporal Analysis of Teacher Practices in Supporting Student Learning and Engagement in an AI-Enabled Classroom. In *International Conference on Artificial Intelligence in Education* (pp. 450-462).