

Embedding Effective Teaching Strategies in Intelligent Tutoring Systems

Keith T. Shubeck, Ying Fang, Andrew J. Hampton, Brent Morgan, Xiangen Hu and Arthur C. Graesser

Corresponding author: kshubeck@memphis.edu

Abstract

Technological advancements have facilitated the implementation of the core components of intelligent tutoring systems (ITS) that adapt to individual students. Some of these ITSs attempt to simulate the discourse and pedagogical strategies of human tutors. Natural language processing tools and agent-based software are increasingly working alongside hardware platforms that range from smartphones to desktops. To create an effective ITS, pedagogical considerations are needed from both a system-design perspective and a content-authoring perspective. ITS developers should also understand the most effective ways to provide pedagogically sound feedback and guidance to the learner. Feedback and guidance should take into account both the learner and domain models. For example, students with high domain knowledge interact differently with ITSs compared to those with low domain knowledge, and different domains afford distinct pedagogical techniques. Examples will be drawn from recent and ongoing efficacy studies using AutoTutor, a conversation-based ITSs with one or more animated pedagogical agents.

Keywords: AutoTutor, conversational agents, domain modeling, intelligent tutoring systems

[Back to Table of Contents](#)

[Link to Book](#)

APA citation information

Shubeck, K. T., Fang, Y., Hampton, A. J., Morgan, B., Hu, X., & Graesser, A. C. (2018). Embedding effective teaching strategies in intelligent tutoring systems. In S. D. Craig (Ed.). *Tutoring and Intelligent Tutoring Systems* (pp. 129- 156). New York, NY: Nova Science Publishers.

References

Albert, D., Nussbaumer, A, Kuo, B. C., Foltz, P. W., & Hu, X. (2017). Competence-based Knowledge Structures and Current Challenges for E-Assessment. In R. A. Sottolare, A. Graesser, X. Hu, & G. Goodwin (Eds.). *Design Recommendations for Intelligent Tutoring Systems: Volume 5 – Assessment* (pp. 129- 156). Orlando, FL: U.S. Army Research Laboratory. ISBN 978-0-9893923-9-6.

Aleven, V. A., & Koedinger, K. R. (2002). An effective metacognitive strategy: Learning by doing and explaining with a computer-based Cognitive Tutor. *Cognitive Science*, 26(2), 147-179.

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.

Anderson, J. R., Matessa, M., & Lebiere, C. (1997). ACT-R: A theory of higher level cognition and its relation to visual attention. *Human-Computer Interaction*, 12(4), 439-462.

Azevedo, R., Witherspoon, A., Chauncey, A., Burkett, C., & Fike, A. (2009). MetaTutor: A MetaCognitive tool for enhancing self-regulated learning. In R. Pirrone, R. Azevedo, & G. Biswas (Eds.), *Proceedings of the AAAI Fall Symposium on Cognitive and Metacognitive Educational Systems* (pp. 14-19). Menlo Park, CA: Association for the Advancement of Artificial Intelligence (AAAI) Press.

Baddeley, A. (2003). Working memory: looking back and looking forward. *Nature Reviews Neuroscience*, 4(10), 829-839.

Bandura, A. (1962). Social learning through imitation. In M. R. Jones (Ed.), *Nebraska Symposium of Motivation* (pp. 211–269). Lincoln: University of Nebraska Press.

Bloom, B. S. (1984). The 2 sigma problem: The search for methods of group instruction as effective as one-to-one tutoring. *Educational Researcher*, 13(6), 4–16.

Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., & Krathwohl, D. R. (1956). *Taxonomy of educational goals. Handbook I: Cognitive Domain*. New York, NY: McKay.

Britton, B. K., & Gülgöz, S. (1991). Using Kintsch's computational model to improve instructional text: Effects of repairing inference calls on recall and cognitive structures. *Journal of educational Psychology*, 83(3), 329-345.

Cai, Z., Graesser, A. C., & Hu, X. (2015). ASAT: AutoTutor script authoring tool. In R. Sottolare, A. C. Graesser, X. Hu, & K. Brawner (Eds.), *Design Recommendations for Intelligent Tutoring Systems: Authoring Tools* (Vol. 3) (pp. 199-210). Orlando, FL: Army Research Laboratory

Chi, M. T. (2009). Active-constructive-interactive: A conceptual framework for differentiating learning activities. *Topics in Cognitive Science*, 1(1), 73–105.

Chi, M. T. H. (2013). Two kinds and four sub-types of misconceived knowledge, ways to change it and the learning outcomes. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (2nd ed., pp. 49–70). New York, NY: Routledge Press.

Chi, M. T., De Leeuw, N., Chiu, M. H., & LaVancher, C. (1994). Eliciting self-explanations improves understanding. *Cognitive science*, 18(3), 439-477.

Chi, M. T., Roy, M., & Hausmann, R. G. (2008). Observing tutorial dialogues collaboratively: Insights about human tutoring effectiveness from vicarious learning. *Cognitive science*, 32(2), 301-341.

Chi, M. T., Siler, S. A., Jeong, H., Yamauchi, T., & Hausmann, R. G. (2001). Learning from human tutoring. *Cognitive Science*, 25(4), 471-533.

Cohen, P. A., Kulik, J. A., & Kulik, C. C. (1982). Educational outcomes of tutoring: A meta-analysis of findings. *American Educational Research Journal*, 19, 237–248.

Corbett, A. T., & Anderson, J. R. (1995). Knowledge tracing: Modeling the acquisition of procedural knowledge. *User Modeling and User-Adapted Interaction*, 4(4), 253-278.

Cox, R., McKendree, J., Tobin, R., Lee, J., & Mayes, T. (1999). Vicarious learning from dialogue and discourse. *Instructional Science*, 27, 431–458.

Craig, S. D., Driscoll, D. M., & Gholson, B. (2004). Constructing knowledge from dialog in an intelligent tutoring system: Interactive learning, vicarious learning, and pedagogical agents. *Journal of Educational Multimedia and Hypermedia*, 13(2), 163.

Craig, S. D., Gholson, B., Brittingham, J. K., Williams, J. L., & Shubeck, K. T. (2012). Promoting vicarious learning of physics using deep questions with explanations. *Computers & Education*, 58(4), 1042-1048.

Craig, S. D., Gholson, B., Ventura, M., Graesser, A. C., & the Tutoring Research Group. (2000). Overhearing dialogues and monologues in virtual tutoring sessions: Effects on

questioning and vicarious learning. *International Journal of Artificial Intelligence in Education*, 11, 242–253.

Craig, S. D., Hu, X., Graesser, A. C., Bargagliotti, A. E., Sterbinsky, A., Cheney, K. R., & Okwumabua, T. (2013). The impact of a technology-based mathematics after-school program using ALEKS on student's knowledge and behaviors. *Computers & Education*, 68, 495-504.

Craig, S. D., Sullins, J., Witherspoon, A., & Gholson, B. (2006). The deep-level-reasoning-question effect: The role of dialogue and deep-level-reasoning questions during vicarious learning. *Cognition and Instruction*, 24(4), 565-591.

Craig, S. D., Graesser, A. C., Brittingham, J., Williams, J., Martindale, T., Williams, G., et al., (2008). An implementation of vicarious learning environments in middle school classrooms. In K. McFerrin, R. Weber, R. Weber, R. Carlsen, & D. A. Willis (Eds.), *Proceedings of the 19th International Conference for the Society for Information Technology and Teacher Education* (pp. 1060-1064). Chesapeake, VA: AACE.

Dillon, J. T. (2004). *Questioning and teaching: A manual of practice*. New York: Teachers College Press.

Driscoll, D. M., Craig, S. D., Gholson, B., Ventura, M., Hu, X., & Graesser, A. C. (2003). Vicarious learning: Effects of overhearing dialog and monologue-like discourse in a virtual tutoring session. *Journal of Educational Computing Research*, 29(4), 431-450.

Falmagne, J. C., Albert, D., Doble, C., Eppstein, D., & Hu, X. (Eds.). (2013). *Knowledge spaces: Applications in education*. Berlin-Heidelberg: Springer.

Foronda, C. L., Shubeck, K., Swoboda, S. M., Hudson, K. W., Budhathoki, C., Sullivan, N., & Hu, X. (2016). Impact of virtual simulation to teach concepts of disaster triage. *Clinical Simulation in Nursing*, 12(4), 137-144.

Forsyth, C. M., Pavlik, P., Graesser, A. C., Cai, Z., Germany, M., Millis, K., Butler, H., Halpern, D., and Dolan, R. (2012). Learning gains for core concepts in a serious game on scientific reasoning. In K. Yacef, O. Zaiane, H. Hershkovitz, M. Yudelson, and J. Stamper (Eds.) *Proceedings of the 5th International Conference on Educational Data Mining* (pp 172-175). Chania, Greece: International Educational Data Mining Society.

Fox, B. (1991). Cognitive and interactional aspects of correction in tutoring. In P. Goodyear (Ed.), *Teaching Knowledge and Intelligent Tutoring* (pp. 149-172). Norwood, NJ: Ablex Publishing Corp.

Gholson, B., & Craig, S. D. (2006). Promoting constructive activities that support vicarious learning during computer-based instruction. *Educational Psychology Review, 18*(2), 119-139.

Gholson, B., Witherspoon, A., Morgan, B., Brittingham, J. K., Coles, R., Graesser, A. C., ... & Craig, S. D. (2009). Exploring the deep-level reasoning questions effect during vicarious learning among eighth to eleventh graders in the domains of computer literacy and Newtonian physics. *Instructional Science, 37*(5), 487-493.

Gonzalez, C., Burguillo, J. C., & Llamas, M. (2006). A qualitative comparison of techniques for student modeling in intelligent tutoring systems. In *Proceedings of the 36th frontiers in education conference* (pp. 13–18). IEEE.

Graesser, A. C. (2016). Conversations with AutoTutor help students learn. *International Journal of Artificial Intelligence in Education, (26)* 124-132.

Graesser, A. C., Cai, Z., Baer, W. O., Olney, A. M., Hu, X., Reed, M., & Greenberg, D. (2016). Reading comprehension lessons in AutoTutor for the Center for the Study of Adult Literacy. In S. A. Crossley and D. S. McNamara (Eds.), *Adaptive Educational Technologies for Literacy Instruction* (pp. 288-293). New York: Taylor & Francis Routledge.

Graesser, A. C., Chipman, P., Haynes, B. C., & Olney, A. (2005). AutoTutor: An intelligent tutoring system with mixed-initiative dialogue. *IEEE Transactions on Education, 48*(4), 612-618.

Graesser, A. C., D'Mello, S. K., Hu, X., Cai, Z., Olney, A., & Morgan, B. (2012). AutoTutor. In P. M. McCarthy, & C. Boonthum (Eds.), *Applied natural language processing and content analysis: Identification, investigation and resolution* (pp. 169-187). Hershey, PA: IGI Global.

Graesser, A. C., Forsyth, C., & Lehman, B. (2017). Two heads are better than one: Learning from computer agents in conversational dialogues. *Teachers College Record, 119*, 1-20.

Graesser, A. C., Hu, X., Nye, B. D., VanLehn, K., Kumar, R., Heffernan, C., ... & Baer, W. (2018). ElectronixTutor: an intelligent tutoring system with multiple learning resources for electronics. *International Journal of STEM Education, 5*, 1-21.
<https://doi.org/10.1186/s40594-018-0110-y>.

Graesser, A. C., Hu, X., Person, N. K., Jackson, G. T., & Toth, J. A. (2004). Modules and information retrieval facilities of the human use regulatory affairs advisor (HURAA). *International Journal on E-Learning*, 3(4), 29-39.

Graesser, A. C., Langston, M. C., & Baggett, W. B. (1993). Exploring information about concepts by asking questions. In G. V. Nakamura, R. M. Taraban, & D. Medin (Eds.), *The psychology of learning and motivation: Vol. 29. Categorization by humans and machines* (pp. 411-436). Orlando, FL: Academic Press.

Graesser, A. C., Lu, S., Jackson, G. T., Mitchell, H., Ventura, M., Olney, A., & Louwerse, M. M. (2004). AutoTutor: A tutor with dialogue in natural language. *Behavior Research Methods, Instruments, and Computers*, 36, 180–193.

Graesser, A. C., Moreno, K., Marineau, J., Adcock, A., Olney, A., & Person, N. (2003). AutoTutor improves deep learning of computer literacy: Is it the dialog or the talking head? In U. Hoppe, F. Verdejo, & J. Kay (Eds.), *Proceedings of Artificial Intelligence in Education* (pp. 47-54). Amsterdam: IOS Press.

Graesser, A. C., Ozuru, Y., & Sullins, J. (2009). What is a good question? In M. G. McKeown & L. Kucan (Eds.), *Threads of coherence in research on the development of reading ability* (pp. 112-141). New York: Guilford.

Graesser, A. C., & Person, N. K. (1994). Question asking during tutoring. *American Educational Research Journal*, 31(1), 104-137.

Graesser, A. C., Person, N. K., & Magliano, J. P. (1995). Collaborative dialogue patterns in naturalistic one-to-one tutoring. *Applied Cognitive Psychology*, 9(6), 495-522.

Graesser, A. C., Rus, V., Hu, X. (2017). Instruction based on tutoring. In R. E. Mayer and P. A. Alexander (Eds.), *Handbook of Research on Learning and Instruction* (pp. 460-482). New York: Routledge Press.

Harsley, R., Green, N., Barbara, D. E., Aditya, S., Fossati, D., & Al Zoubi O. (2016). Collab-ChiQat: A Collaborative Remaking of a Computer Science Intelligent Tutoring System. In *Proceedings of the 19th ACM Conference on Computer Supported Cooperative Work and Social Computing Companion* (CSCW '16 Companion) (pp. 281-284). New York, NY: ACM.

Holden, H. K. (2013). Understanding current learner modeling approaches. In Sottolare, R. A., Graesser, A. C., Hu, X., Holden, H (Eds.). *Design Recommendations for Intelligent Tutoring Systems* (pp.71-74). Orlando, FL: US Army Research Laboratory.

Hu, X., Nye, B. D., Gao, C., Huang, X., Xie, J., & Shubeck, K. (2014, June). Semantic representation analysis: A general framework for individualized, domain-specific and context-sensitive semantic processing. In *International Conference on Augmented Cognition* (pp. 35-46). Cham: Springer.

Jackson, G. T., Boonthum, C., & McNamara, D. S. (2010, June). The efficacy of iSTART extended practice: Low ability students catch up. In *International Conference on Intelligent Tutoring Systems* (pp. 349-351). Berlin, Germany: Springer.

Jonassen, D., Peck, K., & Wilson, B. (1999). *Learning with Technology: A Constructivist Perspective*. Upper Saddle River, NJ: Prentice Hall, Inc.

Koedinger, K. R., Corbett, A. C., & Perfetti, C. (2012). The Knowledge-Learning-Instruction (KLI) framework: Bridging the science-practice chasm to enhance robust student learning. *Cognitive Science*, 36 (5), 757-798.

Kulik, J. A., & Fletcher, J. D. (2016). Effectiveness of intelligent tutoring systems: a meta-analytic review. *Review of Educational Research*, 86(1), 42-78.

Landauer, T. K., Foltz, P. W., & Laham, D. (1998). An introduction to latent semantic analysis. *Discourse processes*, 25(2-3), 259-284.

Leelawong, K., & Biswas, G. (2008). Designing learning by teaching agents: The Betty's Brain system. *International Journal of Artificial Intelligence in Education*, 18(3), 181-208.

Lenhart, A. (2015). A Majority of American teens report access to a computer, game console, smartphone and a tablet. *Pew Research Center: Internet and Technology*. Retrieved from: <http://www.pewinternet.org/2015/04/09/a-majority-of-american-teens-report-access-to-a-computer-game-console-smartphone-and-a-tablet/>.

Mayer, R. E. (1997). Multimedia learning: Are we asking the right questions? *Educational Psychologist*, 32, 1-19.

Mayer, R. E. (2014a). 14 principles based on social cues in multimedia learning: Personalization voice image and embodiment principles. In R. E. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning* (pp. 345-368). New York: Springer.

Mayer, R. E. (2014b). Multimedia instruction. In Spector J., Merrill M., Elen J., Bishop M. (eds.), *Handbook of research on educational communications and technology* (pp. 385-399). New York: Springer.

Mayer, R. E. (Ed.). (2014c). *The Cambridge handbook of multimedia learning (2nd ed.)*. Cambridge university press. Cambridge, United Kingdom: Cambridge University Press.

McCarthy, K. S., Jacovina, M. E., Snow, E. L. Guerrero, T. A., & McNamara, D. S. (2017). iSTART therefore I understand: But metacognitive supports did not enhance comprehension gains. In B. Boulay, R. Baker, & E. Andre (Eds.), *Proceedings of the 18th International Conference on Artificial Intelligence in Education (AIED)*, (pp. 201-211). Wuhan, China: Springer.

McNamara, D. S., & Healy, A. F. (2000). A procedural explanation of the generation effect for simple and difficult multiplication problems and answers. *Journal of Memory and Language*, *43*, 652–679.

McNamara, D. S., Kintsch, E., Songer, N. B., & Kintsch, W. (1996). Are good texts always better? Interactions of text coherence, background knowledge, and levels of understanding in learning from text. *Cognition and instruction*, *14*(1), 1-43.

McNamara, D. S., Levinstein, I. B., & Boonthum, C. (2004). iSTART: Interactive strategy trainer for active reading and thinking. *Behavioral Research Methods, Instruments, & Computers*, *36*, 222-233.

McNamara, D. S., O'Reilly, T., Rowe, M., Boonthum, C., & Levinstein, I. B. (2007). iSTART: A web-based tutor that teaches self-explanation and metacognitive reading strategies. In D. S. McNamara (ed.), *Reading Comprehension Strategies: Theories, Interventions, and Technologies* (pp. 397-421). New York, NY: Lawrence Erlbaum Associates.

Millis, K., Forsyth, C., Butler, H., Wallace, P., Graesser, A. C., & Halpern, D. (2011). Operation ARIES! A Serious game for teaching scientific inquiry. In M. Ma, A. Oikonomou, & J. Lakhmi (Eds.), *Serious Games and Edutainment Applications* (pp. 169-196). London: Springer-Verlag.

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*, 1-22.

Mitrovic, A., Martin, B., & Suraweera, P. (2007). Intelligent tutors for all: Constraint-based modeling methodology, systems and authoring. *IEEE Intelligent Systems*, *22*(4), 38–45.

Moos, D. C., & Azevedo, R. (2008). Self-regulated learning with hypermedia: The role of prior domain knowledge. *Contemporary Educational Psychology, 33*(2), 270-298.

Moreno, R., & Flowerday, T. (2006). Students' choice of animated pedagogical agents in science learning: A test of the similarity-attraction hypothesis on gender and ethnicity. *Contemporary educational psychology, 31*(2), 186-207.

Nokes, T. J., Hausmann, R. G., VanLehn, K., & Gershman, S. (2011). Testing the instructional fit hypothesis: the case of self-explanation prompts. *Instructional Science, 39*(5), 645-666.

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.

Olney, A., D'Mello, S., Person, N., Cade, W., Hayes, P., Williams, C., Lehman, B., & Graesser, A. C. (2012). Guru: A computer tutor that models expert human tutors. In S. A. Cerri & B. Clancey (Eds.), *Proceedings of Intelligent Tutoring Systems (ITS) 2012* (pp. 256–261). Berlin: Springer.

O'Reilly, T., Best, R., & McNamara, D. S. (2004). Self-explanation reading training: Effects for low-knowledge readers. In *Proceedings of the Cognitive Science Society, 26*, 1053-1058.

Ozogul, G., Johnson, A. M., Atkinson, R. K., & Reisslein, M. (2013). Investigating the impact of pedagogical agent gender matching and learner choice on learning outcomes and perceptions. *Computers & Education, 67*, 36-50.

Pavlik, P. I., Brawner, K., Olney, A., & Mitrovic, A. (2013). A review of student model used in intelligent tutoring systems. In Sottolare, R. A., Graesser, A. C., Hu, X., Holden, H (Eds.). *Design Recommendations for Intelligent Tutoring Systems* (pp.39-67). Orlando, FL: US Army Research Laboratory.

Pew Research Center. (2017). *Mobile fact sheet*. Retrieved from: <http://www.pewinternet.org/fact-sheet/mobile/>.

Reeves, B., & Nass, C. I. (1996). *The media equation: How people treat computers, television, and new media like real people and places*. Cambridge, UK: Cambridge university press.

Rohrbeck, C. A., Ginsburg-Block, M. D., Fantuzzo, J. W., & Miller, T. R. (2003). Peer-assisted learning interventions with elementary school students: A meta-analytic review. *Journal of Educational Psychology, 95*(2), 240-257.

Roscoe, R. D., & Chi, M. T. (2008). Tutor learning: The role of explaining and responding to questions. *Instructional Science, 36*(4), 321-350.

Rosenshine, B., Meister, C., & Chapman, S. (1996). Teaching students to generate questions: A review of the intervention studies. *Review of educational research, 66*(2), 181-221.

Rowe, J. P., Shores, L. R., Mott, B. W., & Lester, J. C. (2011). Integrating learning, problem solving, and engagement in narrative-centered learning environments. *International Journal of Artificial Intelligence in Education, 21*(1-2), 115-133.

Schneider, W., Körkel, J., & Weinert, F. E. (1989). Domain-specific knowledge and memory performance: A comparison of high-and low-aptitude children. *Journal of Educational Psychology, 81*(3), 306-312.

Schroeder, N. L., Adesope, O. O., & Gilbert, R. B. (2013). How effective are pedagogical agents for learning? A meta-analytic review. *Journal of Educational Computing Research, 49*(1), 1-39.

Shubeck, K. T., Craig, S. D., & Hu, X. (2016). Live-action mass-casualty training and virtual world training: A Comparison. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (pp. 2103-2107). Los Angeles, CA: SAGE Publications.

Snaider, J., Olney, A., & Person, N. (2011). Nonverbal action selection for explanations using an enhanced behavior net. In Vilhjálmsón H.H., Kopp S., Marsella S., Thórisson K.R. (eds.), *Intelligent Virtual Agents* (pp. 141-147). Berlin, Germany: Springer.

Sottolare, R. A., Graesser, A., Hu, X., & Goldberg, B. (Eds.) (2014). *Design Recommendations for Intelligent Tutoring Systems: Instructional Management* (Vol. 2). Orlando, FL.: US Army Research Laboratory.

Sottolare, R., Graesser, A., Hu, X., Holden, H. (Eds.) (2013). *Design Recommendations for Intelligent Tutoring Systems: Learner Modeling* (Vol. 1). Orlando, FL: Army Research Laboratory.

Steenbergen-Hu, S., & Cooper, H. (2014). A meta-analysis of the effectiveness of Intelligent Tutoring Systems (ITS) on college students' academic learning. *Journal of Educational Psychology, 106*, 331–347.

Sullins, J., McNamara, D., Acuff, S., Neely, D., Hildebrand, E., Stewart, G., & Hu, X. (2015). Are you asking the right questions: The use of animated agents to teach learners to become better question askers. In I. Russell & W Eberle (Eds.). *Proceedings of the 28th International Florida Artificial Intelligence Research Society (FLAIRS) Conference* (pp. 479-481). Hollywood, FL: AAAI Press.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12*, 257– 285.

Sweller, J. (1999). *Instructional Design in Technical Areas*. Melbourne, Australia: Australian Council for Educational Research.

Sweller, J., Ayres, P., & Kalyuga, S. (2011). *Cognitive load theory* (Vol. 1). Berlin: Springer Science & Business Media.

Taub, M., Mudrick, N. V., Azevedo, R., Millar, G. C., Rowe, J., & Lester, J. (2017). Using multi-channel data with multi-level modeling to assess in-game performance during gameplay with Crystal Island. *Computers in Human Behavior, 76*, 641-655.

Twyford, J., & Craig, S. D. (2017). Modeling goal setting within a multimedia environment on complex physics content. *Journal of Educational Computing Research, 55*(3), 374-394.

VanLehn, K. (2011). The relative effectiveness of human tutoring, intelligent tutoring systems, and other tutoring systems. *Educational Psychologist, 46*(4), 197-221.

Vidal-Abarca, E., Martínez, G., & Gilabert, R. (2000). Two procedures to improve instructional text: Effects on memory and learning. *Journal of Educational Psychology, 92*(1), 107.

Wagster, J., Tan, J., Wu, Y., Biswas, G., & Schwartz, D. L. (2007). Do learning by teaching environments with metacognitive support help students develop better learning behaviors? In D. S. McNamara & J. G. Trafton (Eds.), *Proceedings of the 29th annual meeting of the cognitive science society* (pp. 695-700). Austin, TX: Cognitive Science Society.

Walker, C. H. (1987). Relative importance of domain knowledge and overall aptitude on acquisition of domain-related information. *Cognition and Instruction*, 4(1), 25-42.

Webb, N. M., & Mastergeorge, A. M. (2003). The development of students' helping behavior and learning in peer-directed small groups. *Cognition and instruction*, 21(4), 361-428.

Webb, N. M., & Palincsar, A. S. (1996). Group processes in the classroom. In D. Berliner & R. Calfee (Eds.), *Handbook of educational psychology* (pp. 841–873). New York, NY:

Wisher, R. A., & Graesser, A. C. (2007). Question asking in advanced distributed learning environments. In S. M. Fiore, & E. Salas (Eds.), *Toward a science of distributed learning and training* (pp. 209-234). Washington, DC: American Psychological Association.

Woolf, B. P. (2009). *Building intelligent interactive tutors*. Burlington, MA: Morgan Kaufmann Publishers.