Cognitive Science and Student Learning in the Classroom

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How can the cognitive science community take what they have learned from decades of laboratory research and make it useful to shaping instruction as it occurs in school? This question has been of interest over the past thirty years (e.g., Carver & Klahr, 2001), but much of what has been learned by cognitive scientists continues to remain within the cognition community and is not widely applied to student learning in the classroom. The papers presented in this symposium provide cutting-edge examples of research that build on systematic cognitive science research, and are being tested with children in school settings. The talks describe how iterative laboratory and classroom research efforts move our understanding of learning and instruction forward. The symposium papers examine how to use what cognitive science has learned about meta-cognition, spacing, deep explanations, and interactive adaptive tutoring in order to support learning in school-aged students. The moderator and discussant for this symposium is *Elizabeth Albro*.

Do "Learning by Teaching Environments" with Metacognitive Support Help Students Develop Better Learning Behaviors?

Adolescent learners often lack both motivation and the self-regulation skills necessary to succeed in school. We (*Wagster, Tan, Wu, Biswas, & Schwartz*) have developed computer environments using the "learning by teaching" paradigm to help middle school students learn about complex processes. Theoretically, students are motivated to learn so they can help their Teachable Agent, and in turn, the feedback generated by the agent helps them improve their own learning. However, young students may not have the meta-cognitive wherewithal to develop and organize their own learning behaviors, and may not benefit as greatly from learning by teaching. We ran a study to examine how students' meta-cognitive decisions (with and without support) about their own learning activities correlated with broader learning outcomes. We compared three systems where: (i) students taught a teachable agent and received metacognitive support as they were learning and teaching, (ii) students taught the computer agent but received no metacognitive support, and (iii) students learned by being taught by an agent and did not teach themselves. We captured the students' activities in log files, and then coded them into behavior sequences using six primary learning activities. We analyzed behavior fragments derived from the behavior sequences and correlated them with student performance. Student performance is measured by the: (i) quality of the students' concept maps and (ii) post test scores. Our results identify behaviors that correlate well with good performance (and not bad performance). Our results also ask if students who teach and receive metacognitive support exhibit more "good" behaviors than the other two groups.

Applying the Principles of Testing and Spacing to Classroom Learning

There is increasing interest among psychologists in the powerful ways that memory can be enhanced by testing (i.e., retrieval practice) and spacing (i.e., distributed practice). However, there have been few efforts to apply these principles to improving students' learning in educational contexts. We (*Carpenter, Pashler, & Alvarez*) explored whether or not these principles can benefit students' memory for course material. We selected a number of facts that students were learning in their courses (e.g., Ulysses S. Grant became president of the U. S. in 1869), and gave students a review of these facts at different times. Half of the students reviewed the facts immediately after learning them (massed review), and the other half reviewed them after a delay (spaced review). For some of the facts, students were asked to provide a short answer to a question prompt (e.g., Who became president of the U. S. in 1869?), which was followed by feedback (Ulysses S. Grant). Other facts were reviewed by simply re-reading them. Later, all students received a final test covering the facts that they reviewed through testing vs. re-reading, as well as some facts that were learned but that never appeared on the review. Results hold implications concerning whether the principles of testing and spacing can benefit retention of declarative, factual information that students learn in their courses.

Training in Experimental Design (TED):
Developing Scalable and Adaptive Computer-based Science Instruction

We (*Strand Cary, Klahr, Siler, Magaro, & Li*) are developing an intelligent tutoring system to improve 4th-8th grade science instruction. The instructional approach – focused on the conceptual understanding and procedural skills of designing and interpreting scientific experiments – has been used in laboratory studies with one-on-one instruction and in a variety of schools. Its one-size-fits-all approach has proven largely successful, yet has not been effective for some individuals. Our goal is to transform full-class lesson plans into computer-based, adaptive instructional interfaces for use by individual students.

To accomplish this goal, we are specifying an "expert" model of the target cognitive skills (Anderson, et. al, 1995) and the alternative novice models held by the students, and then building diagnostic and remedial capabilities into the computer tutor. Our development process iterates through a series of increasingly computerized and adaptive modules that include simulations of experiments, diagnostic capabilities, and adaptive algorithms that match task and feedback to diagnostic information. The basic instruction has been differentially effective and efficient in low-SES and high-SES classrooms (e.g., Klahr & Li, 2005). For this reason, we are conducting classroom validation studies of the instructional module in both high- and low-SES schools. Expert human tutors provide remedial instruction for those students who are "left behind" following the use of the current module. The tutoring process combines diagnoses of students' misconceptions and difficulties during instruction with theoretically-guided instruction that matches task and feedback to students' state of knowledge. Researchers incorporate successful diagnostic and instructional strategies into the next iteration of the tutoring system. By the end of development, we hope to have a tutor that adapts to individual learners throughout the course of learning and helps achieve robust mastery.

Interactive Tutoring vs. Deep-Level Reasoning Questions among Eighth Graders through Eleventh Graders in Newtonian Physics and Computer Literacy

When learning a new concept, should a learner interact with a knowledgeable partner or simply be exposed to a dialogue including deep level reasoning questions? In our study *(Gholson, Morgan, Graesser, & Brittingham)*, middle and high school students were presented with interactive tutoring sessions or vicarious learning conditions. Eighth and tenth graders were asked to learn computer literacy, while ninth and eleventh graders were presented with Newtonian physics. Each study involved interactive sessions with an intelligent tutoring system called AutoTutor, vicarious-learning conditions involving monologue presentations of content sentences from the curriculum, and vicarious learning conditions involving dialogue presentations of deep-level reasoning questions preceding each content sentence from the curriculum.

Analysis of covariance was performed on the posttest scores, using pretest scores as covariates, in a design that assessed grade (young vs. older), condition (dialogue, interactive, vs. monologue), and content domain (computer literacy vs. Newtonian physics). The effect of grade, content domain, and experimental condition were significant, but there were no significant aptitude-treatment or other interactions. The critical finding was the main effect of condition: Those in the dialogue condition, which contained deep-level reasoning questions before each content sentence, significantly outperformed those in both the interactive condition and in the monologue condition. The deep-level reasoning questions may have activated relevant schemas, encouraged relationships among ideas, and promoted the construction of deep-level explanations. There were few deep-level questions in the interactive condition and none in the monologue condition. It is conceivable that exposure to these questions and answers may encourage learners to generally process materials at deeper levels of inquiry.

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