Using the Learning-by-Teaching Paradigm to Design Intelligent Learning Environments

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The idea that teaching others is a powerful way to learn is both intuitively compelling, and has garnered support in the research literature. We have developed an architecture for computer-based, domain-independent *Teachable Agents* that students teach using an explicit representational structure, an interactive concept map that models causal relationships. This structure becomes shared knowledge between students and the teachable agent. In addition, the concept map simplifies implementations of tools for monitoring and formative assessment, the query and quiz mechanism respectively.

The query mechanism lets students ask the teachable agent questions that are composed from concepts in their maps. Then, the teachable agent reasons with the concept map to find answers. These mechanisms allow students to explore qualitative interactions and static relationships between concepts. When students interact with the teachable agent via these two tools, they monitor the agent's learning progress, hence, reflecting on their own knowledge.

Realizing that fifth graders often are novices in teaching and in the domain of river ecosystems, we have also developed integrated domain resources and system tutorials as well as the software *Mentor Agent*. This agent provides formative assessment through a set of pre-defined, scaffolded quiz questions to help students assess their knowledge during the teaching process.

The present study investigates the contributions of three learning processes in enhancing learning outcomes for fifth-grade students—external-guided learning (ITS), self-guided learning (LBT), and self-guided learning with feedback supporting self-regulated learning (SRL)—in the domain of river ecosystems. The mentor agent directs the ITS group to learn materials to answer a set of pre-defined quiz questions, and provides tailored, local feedback on the structure of students' concept maps. The LBT group teaches the teachable agent using the same set of tools and receiving the same feedback as the ITS group, but can choose own learning goals and directions. The SRL group has access to the same tools as the other groups but receives feedback that suggests learning strategies of utilizing tools in the environment. This group also receives global instead of local domain feedback.

We have measured knowledge gains, the development of learning strategies, and the ability to transfer. Results from this study illustrate the importance of different tasks and feedback toward the design of intelligent learning environments for children learning complex, scientific domains.