

Guest Editorial: Special Section on Learning Systems for Science and Technology Education

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MANY successful computer-based educational systems have been developed and empirically tested in science and technology domains. A number of these systems are designed to be intelligent in analyzing and understanding learner input and adapting to the students' level of knowledge. Science and technology domains are well defined and can be described using formal representation. However, deeper understanding of the concepts and principles, and developing problem solving skills such as inquiry and discovery skills in science and technology domains, make the design and implementation of learning environments quite challenging. Students often have difficulties learning these skills; thus, scaffolding mechanisms become an important component of these systems. Furthermore, science knowledge and achievement is a core prerequisite for careers in engineering and technology. Hence, these skills are vital to the well being and continued advancement of society.

However, in spite of the central role that science and technology plays in sustaining and advancing our societies, college enrollment in science and technology has been declining in many European and American countries [1], [2]. Fewer students take science and technology courses and many drop out after initially enrolling in these programs. Research and reviews identify a lack of engagement and motivation in science, starting from the middle school and continuing through post-secondary education [3], [4]. These reviews also point out that computer-based tools are most often used for very basic instruction, such as manipulating data and applying mechanical or algorithmic procedures, and not to teach conceptual understanding of key scientific ideas. Moreover, many assessment tools focus on multiple-choice question answering and short answers, which are not very amenable to gaining a deep understanding of domain concepts and to developing problem solving skills.

Yet computer-based technology can significantly enhance science education and training, as well as shape both what and how people learn. With this special issue of the *IEEE Transactions on Learning Technologies (TLT)*, we present

contributions that address education and training in science and technology disciplines using computer-based technology innovations, with a particular emphasis on the development and application of intelligent software that supports conceptual understanding and high-order learning approaches.

This special section includes six contributions. The first four papers focus on specific systems for learning topics in science and technology. Each contribution highlights a unique educational need and describes and argues for technology that has been developed to enable that learning. The systems have all been used and tested in real-world educational settings.

Dragon et al. present Metafora, a software platform to support students in self-regulating their group learning of science and mathematics topics. The authors argue that learning subject matter relies upon the acquisition of critical skills for learning together. To illustrate and emphasize this point, the authors discuss the critical skills underlying learning "how to collaboratively learn"—for instance, distributed leadership and mutual engagement—and refer to this collection of higher-order skills as "Learning to Learn Together" (L2L2). Next, the authors explain how technology can enable and support L2L2. The Metafora system brings together technology for planning, experimentation and exploration (using microworld software), and reflection (using collaborative discussion and argumentation software). The authors describe Metafora as both a pedagogy and platform to promote L2L2. Their approach is illustrated using a scenario built from empirical observation and data logged in a real educational setting.

Bollen and van Joolingen present SimSketch, a system targeted at learning science through sketching and simulating the resulting sketches. The authors advocate a self-guided discovery approach to learning, focusing on having learners acquire subject matter through freely building models and running simulations. They argue for the motivational benefits of this approach. A big challenge in their work is bridging the gap between formal modeling tools and the more conceptual and informal approaches of constructing, evaluating, and revising models. SimSketch allows learners to draw a model by hand, through digitized sketches, and, thus, work in an informal way. Components appearing in the drawings are associated with predefined behavioral features of formal models, allowing learners to then simulate the behavior of a system without having to be skilled in the semantics and syntax of formal modeling approaches.

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Zitek et al. present DynaLearn, a learning environment to help learners develop and deepen their conceptual understanding of systems. The system focuses on notions such as cause-effect analysis, distinguishing structure from behavior, and discovering system states. DynaLearn features a number of software instruments to achieve this, notably a progression of self-contained learning spaces and a recommendation system fed by a repository of community created models. The authors report on an evaluation study, which took place over the course of multiple days, in which two learners worked with DynaLearn. The results illustrate key changes occurring in knowledge structure and content for both students.

Myneni et al. present ViPS, a simulation-based learning environment focused on identifying and remediating misconceptions learners may have in understanding basic physics concepts. ViPS has a tutoring capability that oversees the problem solving on behalf of the student, and interacts by generating focused feedback and appropriate follow-up exercises for the learner to work on. The authors discuss and emphasize the added value of solving physics problems while interacting with virtual systems, such as provided with ViPS, compared to working with real physical systems. The paper reports evaluation results that support the authors' approach.

The final two papers focus on a specific learning method, and less on a system that enables that learning.

Dyke et al. focus on the conversation style deployed by software agents while scaffolding discussion among participants in a collaborative learning setting, referred to as Academically Productive Talk (APT). Traditionally, the approach would be to elevate the conceptual depth of the discussion. In contrast, Dyke et al. present work in which the agents promote productive practices such as explanation of reasoning and refinement of ideas. Two conversation styles are compared to one another, referred to as "revoicing support" and "feedback support." Evaluation studies are presented that led the authors to conclude that significantly more learning happens with revoicing support.

Chin et al. focus on the pedagogical approach of Teachable Agents (TAs), a specific version of "learning by teaching." In this case, learners teach a virtual agent by creating a concept map that represents the agent's knowledge. In their contribution, the authors first emphasize three design principles to encourage learning with TAs. Next, the authors present results from evaluation studies addressing a number of different aspects of TAs. One notable finding is the possibility to help younger children learn scientific modes of reasoning, such as hierarchical reasoning, by means of creating a formal visual representation to teach their agent. This paper also demonstrates that TA technology can be used in classroom environments to support teachers in their instruction and assessment activities with little assistance from the researchers and system developers.

The variety of systems and approaches presented in this special section illustrates the extensiveness and potential effectiveness of educational technology in support of science and technology education. This technology holds the potential to better support student learning of science and technology and, perhaps more importantly, to increase

interest and sustain motivation in these topics. While we see all of this work as an excellent step toward better supporting and motivating students in learning science and technology, there is still much work to do in the area of computer-supported science and technology learning. We, the guest editors, look forward to an exciting future of research and contributions in this area!

ACKNOWLEDGMENTS

The guest editors would like to thank the authors for supporting this special section by submitting their contributions and then diligently working through the review process. We believe the papers published in this special section demonstrate the wide variety and scope of opportunities for designing effective learning environments for science and technology. We would also like to thank the reviewers for their important role in providing critical but constructive and objective reviews, which were extremely important in making this a quality special section. In thanking the reviewers, we would like to note that special care was taken in reviewing the papers for which the special section guest editors are coauthors. In particular, the reviews and accept/reject decisions for these papers were handled by Associate Editors who did not have direct connections to the special section. We also want to thank Editor-in-Chief Peter Brusilovsky for his support and effort in bringing this special section to fruition. Finally, we are grateful to the *IEEE TLT* staff for prodding and poking three very busy researchers in keeping this special section on schedule.

REFERENCES

- [1] The Organisation for Economic Co-operation and Development (OECD), "Declining Student Enrolment in Science & Technology: Is It Real? What Are The Causes? What Can Be Done?" <http://www.oecd.org/science/sci-tech/conferenceondecliningstudentenrolmentinscienceandtechnology.htm>, 2005.
- [2] A. Ali and C. Shubra, "Efforts to Reverse the Trend of Enrollment Decline in Computer Science Programs," *Issues in Informing Science & Information Technology*, vol. 7, pp. 209-224, 2010.
- [3] Tapping America's Potential, "Gaining Momentum, Losing Ground," http://www.education.rec.ri.cmu.edu/roboticscurriculum/research/TappingAmericasPotential_2008.pdf, 2008.
- [4] M. Sanfeliz and M. Stalzer, "Science Motivation in the Multi-cultural Classroom," *The Science Teacher*, vol. 70, no. 3, pp. 64-66, 2003.



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