

## **Preface - Emerging Technologies and Landmark Systems for Learning Mathematics and Science: Dedicated to the Memory of Erica Melis - Part 1**

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It is our distinct pleasure, as co-editors, to introduce this special edition of the International Journal of Artificial Intelligence in Education. Not only do we have four very interesting and high quality papers about emerging educational technologies in mathematics and science to present, but we also have the opportunity to dedicate this volume to our colleague and friend, Erica Melis, who passed away in February 2011 at the age of 61. We all knew Erica well and two of us (McLaren, Sosnovsky) worked closely with her for several years and personally witnessed the bravery with which she fought her illness and faced her mortality.

Erica was an important figure in AI in Education (AIED) research, tirelessly working on both new ideas and more established, landmark research in the area of education and technology. This volume focuses on one aspect of Erica's research life – new ideas. A soon-to-be released companion issue of the International Journal of Artificial Intelligence in Education will focus on the second passion of Erica's research life – landmark instructional systems for supporting learners and learning.

Erica was a dedicated and rigorous researcher, and led a full life. She was born in Cuba in 1949 to a German Jewish family in exile, eventually returning to Germany to live and lead her academic life. In East Germany, where she first lived upon returning to Germany, she studied Kripke Logic. When she moved to the west, her academic interests shifted to a study of analogy and case-based reasoning, subfields of artificial intelligence. She also did seminal proof planning work with Joerg Siekmann, who eventually became her husband. She was always keenly interested in international collaborations, spending time

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at Edinburgh University in Scotland, collaborating with Alan Bundy, at the University of Texas at Austin, U.S.A., collaborating with Woodrow Bledsoe, and at Carnegie Mellon University, Pittsburgh U.S.A., collaborating with Dana Scott, Manuela Veloso, and Kurt van Lehn. During some of her academic visits to Pittsburgh, she stayed with one of us (Aleven) and enjoyed discussing and debating common research interests and important life questions. In addition to her research, and perhaps as an escape from her technical work life, Erica was an artist. Some of her artwork is available to see at her post-mortem website (<<http://www-ags.dfkf.uni-sb.de/~melis/>>).

Erica recognized the difficulty that many students have in understanding and constructing mathematical proofs and took an interest in tutoring and assisting students in this task. This inspired her to research, design, and develop her own seminal contribution to the AI in education community: ActiveMath (Melis et al. 2001) (<http://www.activemath.org/>). In 2000, she began the development of the ActiveMath system, which is a web-based system aimed at tutoring students in a variety of mathematical topics, from basic mathematics, such as fractions, to more advanced topics, such as calculus. ActiveMath employs a variety of AI techniques to model students and support their learning by providing feedback during problem solving, planning personalized curricula and generating navigational cues to help students find the best topics to study. It uses various open standards to semantically represent mathematical content and annotate it with rich metadata. Erica worked tirelessly on ActiveMath, as well as related projects, such as MathBridge (Sosnovsky et al. 2014), from its inception until the time of her death. One of us (Sosnovsky) continues Erica's work on ActiveMath within the Deutsche Forschungszentrum für Künstliche Intelligenz (DFKI) in Germany, where Erica worked for many years. Erica's paper on ActiveMath, published in this journal in 2001 (Melis et al. 2001), is the journal's tenth highest cited paper of all time.

Erica's intellect and interests in AIED were wide ranging, including collaborations with a variety of educational psychologists and visiting researchers. One of her special interests was on the use of erroneous examples to assist learning. She and one of us (McLaren, as a visiting researcher in Germany) formed a close collaboration on this area of research (e.g., (Tsovaltzi et al. 2012)), launching an important line of inquiry that continues today (e.g., (Adams et al. 2014)). Erica recognized around 2004 or 2005 that this type of instructional material, in which students are presented with one or more errors in worked solutions and are prompted to find and fix the errors, could be an important instructional technique that could be integrated with interactive software.

It is Erica's interest in new ideas and challenges that is highlighted in this special issue of the International Journal of AI in Education. She was always searching for new and better ways to support students in their learning and was not afraid to embark on new research pathways. We honor Erica's memory in this volume by presenting four papers that follow her passion for novel approaches to helping students learn with technology.

The four papers of this special issue present novel and interesting approaches to helping students learn with technology, the type of new work that would have excited Erica. The first two papers in this special issue, one by Lenat and Durlach, the other by Pareto, present similar instructional methods. Both papers describe a learning-by-teaching approach for helping students study basic mathematics. In both papers, students take the role of a tutor helping a teachable virtual agent to acquire mathematics knowledge. In both, the learning system is implemented as a serious game environment. An interesting connection between these two articles and Erica's work is that

learning by teaching provides an opportunity for students to study incorrect examples, namely, the incorrect solutions generated by the teachable agent. A student playing the role of a tutor has to analyze the solutions given by the agent, recognizing potential errors and correcting them – much like a student interacting with erroneous examples.

An interesting aspect of the Lenat and Durlach paper: the knowledge representation mechanism employed by their tutoring system is based on a large common-purpose ontology: CYC. The erroneous and/or incomplete understanding of the domain by the teachable agent is represented as dedicated micro-theories within the global ontology with explicitly modeled incorrect or missing knowledge. The system uses the conflicts that such erroneous representations introduce to CYC to control the behavior of the agent and guide the learning process. Such an architectural solution is also very characteristic of Erica's research. ActiveMath was one of the first ITSs to heavily rely on ontologies and semantic web technologies for representing domain knowledge, modeling instructional content, and communicating between the components of the system (Melis et al. 2006).

The third paper, by Dzikovska et al., presents a tutorial dialogue system that helps students learn about electricity and electronics. BEETLE II tries to stimulate student meta-cognitive learning activities, such as self-evaluation and self-reflection, thus helping students achieve a deeper understanding of the basic underlying concepts and principles. The instructional approach implemented in BEETLE II combines experimentation with a circuit simulator where students can examine their (incorrect) hypotheses. Once confronted with an error, a student engages in a tutorial dialog with the system, trying to explain the reason for the incorrect simulator behavior. BEETLE II then generates adaptive feedback by using symbolic Natural Language Processing techniques. Besides the clear connection to the aforementioned research on erroneous examples, there are several other aspects of this research that are relevant to Erica's work. She actively studied technologies for feedback in ITS; dynamic strategies for feedback generation (Gogvadze & Melis 2008), adaptive informative feedback (Narciss et al. 2014) and strategic feedback supporting deeper meta-cognitive processes (Melis & Andres 2005) are among them. Another technology employed in BEETLE II is curricula planning. Erica contributed to this field as well (Ullrich & Melis 2009).

The final paper of this issue, by Khachatryan et al., presents an educational system that implements a cross-cultural approach to teaching mathematics. At the core of the Genie 2 system described in this paper are the mathematical curricular and the instructional methods adopted in Russian middle school education. The paper presents a detailed analysis of the Russian tradition of teaching mathematics and makes a compelling case for its efficiency and effectiveness. The authors designed Genie 2 to play the role of a bridge between the two educational traditions by teaching U.S. middle school math students according to the Russian curriculum. The system has been deployed in a wide range of schools in the U.S. resulting in higher test results, improved motivation and wide adoption by both students and teachers. There is a strong connection between this research and one of the fields in which Erica was active. The cross-cultural aspects of teaching mathematics were always an interest of hers. She recognized that in order to be effective for students from various countries, an educational system must be aware of the teaching tradition accepted within the target population, both on the level of instructional design and on a more basic level of properly presented notations. As a result, the ActiveMath system implemented a set of technologies for delivering culturally-adaptive educational material (Melis et al. 2009). The other fascinating connection of this paper to Erica is a more personal one: As someone who deeply

experienced life in different cultures (Cuba, East Germany, West Germany, U.S.A.) it is not hard to imagine Erica appreciating the importance of instruction rooted in culture.

In summary, we see Erica's spirit in all four of the papers of this special issue. Her restlessness in research, constantly searching for new ideas, is clearly visible in all of the papers. We would like to think that Erica is smiling somewhere about how her legacy of new ideas continues.

Erica with her parents, in Cuba, sometime in the 1950s.



Erica circa 2010.



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