Exploring Cognitive, Social, and Cultural Dimensions of Visualization in Computer Science Education

Computer-based visualization technology graphically represents scientific processes and concepts. A key application area of the technology is science education, where it has been used to show students how abstract processes and physical systems work. While science educators were initially enthusiastic about the potential of computer-based visualization to enhance learning, experimental studies of its educational effectiveness have yielded widely mixed results, and it has failed to see the kind of widespread use in science education that its developers envisioned.

It is possible that the failure of computer-based visualization to realize its potential in science education can be traced to its grounding in a learning theory that is fundamentally deficient. Focusing on knowledge at the level of the individual, that theory holds that visualization technology is pedagogically effective because it provides a faithful account of an expert's mental model of a process or concept to be learned, thus enabling the robust and efficient transfer of that mental model to the learner. In contrast, a promising alternative, Sociocultural Constructivism, views learning at the level of the community. On this alternative view, visualization is seen to be pedagogically effective insofar as it enables learners to participate more centrally in the practices of a community.

How might visualization technology facilitate such participation? Within the context of a third-year, undergraduate computer science course on computer algorithms, I have been exploring an approach in which students become teachers by using algorithm visualization technology not only to construct their own visualizations, but also to present those visualizations to their instructor and peers for feedback and discussion. Inspired by the instructional model used in architecture, I propose to take this approach further by developing a *studio-based* algorithms course in which the construction and discussion of visualizations are the central activities of the course. Specifically, students will use algorithm visualization technology to construct their own visual solutions to algorithm design and analysis problems. In a variety of regularly scheduled review sessions, they will present their solutions to instructors and peers for feedback, discussion, and evaluation.

This research will yield several products and results from which science educators, educational researchers, visualization technologists, and even cognitive anthropologists stand to benefit. Specific outcomes and benefits of the proposed research include the following:

- *Technology delivery*. I shall develop and publicly disseminate novel software, specifically designed for electronic whiteboards, that supports the interactive construction and discussion of visualizations in a studio environment. By employing a sound, user-centered design process, and by collaborating with a community of partners within an open source environment, I will produce a robust, easy-to-use, well-documented software system that other educators can adapt for use in their own courses.

- *Curriculum development*. I shall develop and disseminate a detailed syllabus and curricular materials to support a studio-based algorithms course. These materials will be iteratively tested and refined through actual pilot courses. The studio-based curriculum will make a notoriously difficult course more accessible to students, thus enabling more students to learn the material and ultimately complete their computer science degrees.

- *Empirical results*. I shall publish the results of a diverse program of experimental, observational, and ethnographic studies that explore the value and role of visualization and communication in learning complex scientific processes at the cognitive, social, and cultural levels. These studies will build on a rich tradition of empirical work into both computer-based instructional visualization, and the use of representations in computer-supported collaborative learning.

- *Novel research methodology*. I shall develop a novel methodology for using visualization construction and interpretation tasks to gauge one's level of membership in a community of practice. This methodology, which builds on Cultural Consensus Theory (a product of cognitive anthropology), will be used as the basis for "consensus studies" that evaluate learning with respect to the Sociocultural Constructivist definition of increasingly central community membership.

- *Graduate and undergraduate apprenticeship*. I shall apprentice two graduate students and at least one undergraduate student per year in the methods of human-computer interaction, including user-centered software design, video analysis, ethnographic field techniques, and experimental methods. Dozens of other students will benefit through their participation in the proposed studio-based algorithms courses and empirical studies. In providing such training and experience, I will be furthering the educational mission of my department.