The "Algorithms Studio" Project: Using Sketch-Based Visualization Technology to Construct and Discuss Visual Representations of Algorithms

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Abstract

The "Algorithms Studio" project explores a novel, studio-based approach to teaching an undergraduate course on computer algorithms. Inspired by the design studio commonly used in architecture education, the approach emphasizes conceptual design activities in which students use sketch-based algorithm visualization technology to create their own visual representations of the algorithms under study. They then discuss their representations with their peers and instructor within the context of regularly scheduled critique sessions. A diverse program of planned empirical studies will investigate the value and role of visualization technology in learning algorithms at the cognitive, social, and cultural levels.

1. Introduction

Algorithm visualization (AV) technology supports the construction and interactive exploration of visual representations of computer algorithms. As has been the case for so many other educational technologies, developers were initially enthusiastic about the potential for AV technology to benefit computer science education. Unfortunately AV technology has failed to deliver on its initial promise. A majority of computer science educators simply do not use the technology. Moreover, experimental studies designed to substantiate the pedagogical effectiveness of AV software have yielded unconvincing results [4].

I argue that the failure of AV technology to catch on in computer science education can be traced to its grounding in a learning theory that is fundamentally deficient. That theory ("Epistemic Fidelity"; see [6]) holds that AV technology is pedagogically effective because it transfers an expert's mental model to learners. An alternative theoretical position that I have found promising in prior research is Sociocultural Constructivism (see, e.g., [5]), which views learning in terms of participation in the practices of a community. On this alternative view, learning is seen not as acquiring target knowledge structures, but rather as participating more centrally in the practices of a community.

Rooted in this alternative view of visualization effectiveness, the "Algorithms Studio" project has two principle objectives:

1. To explore the potential for visualization technology to facilitate participation in the practices of a community; and
2. To investigate empirically the role and value of visualization technology in learning complex scientific phenomena at three different conceptual levels: cognitive, social, and cultural.

Below, I briefly review the prior work on which this project is based; I describe specific project activities designed to fulfill the above objectives; and I report on the project's current status.

2. Foundational Work

The "algorithm studio" project builds on two related lines of previous work I pursued as part of my dissertation research [1]: ethnographic studies, and prototype "low fidelity" visualization software.

Ethnographic studies. I conducted ethnographic studies of a standard, third-year undergraduate algorithms course in which algorithm visualization (AV) technology was used to provide students with access to more central forms of participation. Specifically, students were required to construct and present their own "low fidelity" (unpolished, sketched) visualizations of the algorithms under study. Thus, students participated in the course in ways that instructors typically participate. A key observation in these studies was that students benefited from constructing and presenting their own visualizations, not only because this exercise increased their motivation and level of interest in algorithms, but also because it stimulated meaningful discussions about algorithms. See ([1], ch. 4, App. A & B) for a comprehensive review of these studies.

"Low fidelity" visualization software. I developed a prototype system for creating and presenting "low fidelity" algorithm visualizations. The system's design is firmly rooted in the results of (a) my ethnographic studies, and (b) prior detailed studies of how humans create and execute visualizations made out of simple art supplies.

The prototype's back-end is SALSA (Spatial Algorithmic Language for StoryboArding), a high-level, interpreted language for programming visualizations in terms of *spatial relations*. The prototype's front-end is ALVIS (ALgorithm VIsualization Storyboarder), an interactive, direct-manipulation environment for programming in SALSA. In ALVIS, users create visualizations by using a graphics editor to cut out and sketch visualization objects, which they lay out by direct manipulation. They then specify, either by direct manipulation or by directly typing in SALSA commands, how the objects are to be animated. See [3] for a detailed presentation of ALVIS and SALSA.

3. Project Activities

The "Algorithms Studio" project encompasses two major activities: the development of a studio-based curriculum, and a program of empirical research.

"Algorithms Studio" curriculum. I will take the visualization construction and presentation assignments explored in my ethnographic studies even further by developing a *studio-based* algorithms course. Inspired by instructional model used in architecture, this studio-based course will revolve around conceptual design activities supported and mediated by "low fidelity" visualization technology.

Specifically, in an "algorithms studio" equipped with electronic whiteboards running the ALVIS software, students will construct their own visual solutions to algorithm design and analysis problems. At regularly-scheduled "desk crits," students will present their intermediate design solutions, efficiency analyses, and proofs to their instructor in one-on-one sessions. Four "pin-up sessions" per semester will give students the opportunity to present their work to, and receive feedback from, the entire studio. Finally, instead of exams, students will present an "algorithms portfolio"— their solutions, proofs, and efficiency analyses for an extra set of design problems—to a jury of instructors at a science fair-style event.

Empirical research. The second key component of the project is a comprehensive program of empirical research into the role and value of visualization in facilitating learning at three conceptual levels:

- *Cognitive*. At this level, learning occurs in the individual, in the form of changes in students' conceptual and procedural knowledge of algorithms. Past experimental studies of AV effectiveness [4] have focused squarely on learning at this level. I will build on these experiments by experimentally comparing the cognitive impact of the studio-based approach to that of a more conventional approach.
- *Social*. At the social level, learning takes place through the collaborative negotiation of shared understandings; visualizations serve as mediational resources [6]. To explore learning at this level, students will be videotaped as they discuss visualizations with an instructor. Detailed transcripts of these sessions will form the foundation for exploring two key questions: (1) Do visualizations focus conversational participants on relevant topics; and (2) In what ways do visualizations help students and instructors to build shared understandings of algorithms?
- *Cultural*. At this level, learning takes place as learners become fuller participants of a community by increasingly taking on the roles and responsibilities of community experts [5]. I will explore the cultural dimensions of visualization construction and presentation through two separate empirical studies. First, research assistants will conduct ethnographic studies of my pilot offerings of the studio-based algorithm course. Second, I will explore and develop a research methodology for gauging level of community membership based on performance in visualization construction and interpretation tasks. This methodology will form the foundation for a *consensus study* of learning [2].

4. Project Status

This project was recently funded by a five-year National Science Foundation CAREER award (# 0133212). I have hired a team of graduate research assistants to assist with this research. In addition, I would like to collaborate with colleagues interested in the above research activities. For a complete description of the project, and information on how to get involved, please see the project website:

http://lilt.ics.hawaii.edu/~hundhaus/algstudio/

5. References

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[6] Roschelle, J. Designing for cognitive communication: Epistemic fidelity or mediating collaborative inquiry? *The Arachnet Electronic Journal on Virtual Culture*, 2(2), 1994.