Learning and Retention in Data Structures: A Comparison of Visualization, Text, and Combined Methods

Vikrant Colaso, Aejaaz Kamal, Purvi Saraiya, Chris North, Scott McCrickard, and Clifford A. Shaffer
Department of Computer Science
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061 USA
http://infovis.cs.vt.edu/

Abstract: Numerous studies have been conducted to evaluate the effect of animated visualizations on students learning data structures, but few have attempted to evaluate the retention of information gained from visualizations. Our work focuses on comparing different media used for teaching data structures, particularly as they affect the learning process over time. Results from our empirical studies suggest that a combination of text and visualization helps students retain knowledge better than either approach alone.

Introduction

In computer science education, algorithms and data structures are complex topics and difficult for students to learn. Animated visualizations that graphically depict the processing steps of data structure operations are frequently developed as instructional media to help students learn. Many studies have been conducted to evaluate the effectiveness of these visualizations for learning (see Hundhausen 2002 or Wilson 1996 for a review). However, results have generally been negative, typically showing no significant difference between visualizations and traditional teaching methods. Minor design features seem to have major impact on effectiveness. Furthermore, few studies have attempted to evaluate students' long-term retention of information gained from data structure visualizations, the ultimate goal of education. A related study (Palmiter 1991) found that animated demonstrations to teach software user interfaces improved student performance over a textual manual in the short term, but did not maintain performance in the long term. It is possible that students merely mimicked the steps of the animations at first without actually understanding the steps as required for long term retention. We present a series of studies aimed to examine these issues.

Results

The goal of the first study was to compare different interaction strategies of data structure visualizations. 60 undergraduate CS students studied the AVL Tree data structure for 15 minutes using one of 3 methods: (1) a textual material derived from Shaffer's textbook (2001), (2) the Arsen visualization (Gogeshvili 2001) which simply animates the tree operations initiated by users, or (3) the BinaryTreesome visualization (Gustafson 1998) which quizzes students to perform the operation steps themselves while providing hints. Students then answered a 15-minute closed-book test containing 3 procedural questions about the 'insert', 'delete', and 'find' tree operations, and 2 conceptual questions about higher-level concepts.

The data (table 1) indicate that all 3 methods resulted in similar student performance on the test questions, except for the 'delete' operation question which had significantly better scores from the students who used the text material ($p<0.05$). This may be due to the open-ended nature of the visualization tools, which required users to discover and explore their full functionality to learn all the AVL tree operations. Many students simply may have forgotten to explore the 'delete' operation in the visualizations or ran out of time, whereas the text ensured coverage of the material and helped students to pace themselves. This indicates that open-ended visualizations should be accompanied by guidance material, and led to our examination of a combined text and visualization approach in the next study. The Arsen visualization received significantly better subjective satisfaction ratings from students than the other two methods ($p<0.05$) and a weak effect over BinaryTreesome on the 'delete' question ($p<0.1$), indicating some advantage of the simple animated visualization method.

	(1) Text	(2) Arsen	(3) BT
Test	73%	66%	57%
'delete'	40%	15%	0%
Subj. Sat.	66%	87%	77%

Table 1: Mean scores and ratings, 1st study.

The goal of the second study was to examine the effect of data structure visualization on longer-term knowledge retention. 49 undergraduate CS students studied the Depth-First and Breadth-First Search graph traversals for 20 minutes using one of 3 methods: (1) a textual material from Shaffer's textbook, (2) Saraiya's visualization (Saraiya 2001) which lets users step through the operations, or (3) the combination of (1) and (2). Students then answered a 10-minute closed-book test containing 3 procedural and 2 conceptual questions. After a period of 15 days, students again answered a second, similar test without reviewing the study material.

Overall, students scored similarly on the first test across all methods (table 2). Significant effects between methods were not found on either test. However, on average, students' scores decreased on the second test by 21% with the text method, by 11% with the visualization method, and by only 7% with the combined method. The 15-day waiting period had a significant effect on test scores ($p<0.05$). It had a significant detrimental effect on the text users ($p<0.01$) and a weak effect on the visualization users ($p<0.1$). No effect was detected for the combined method users. This data indicates a non-significant trend towards the combined method providing better retention. In future work, student tests should contain many more questions to enable higher resolution scores and more conclusive statistics. Strangely, on one conceptual analysis question, students' scores actually increased remarkably by 25% on average for the visualization and combined methods, while the text method scores remained constant. In subjective satisfaction ratings, the text method was the clear loser ($p<0.01$). On average, students most preferred the combined method.

	(1) Text	(2) Vis.	(3) Comb.
Test 1	74%	73%	75%
Test 2	53%	62%	68%
Subj. Sat.	62%	80%	87%

Table 2: Mean scores and ratings, 2nd study.

Conclusions and Future Work

For teaching data structures, we recommend a learning method that combines visualization and text. Students are clearly dissatisfied with usual text materials, but visualization alone can lead to gaps in knowledge. Since subjects perceive that visualizations are very helpful, visualizations will stimulate and motivate them to learn new topics. Visualizations can help to drive concepts into long-term memory. Accompanying text will ensure adequate coverage of the concepts. This approach simultaneously enables focus as well as open-ended exploration by students. Even in time pressure learning periods, students were able to juggle both learning methods to produce good performance, including taking time to learn the visualization tool itself.

Current research in algorithm visualizations suggests that actively engaging students while they are watching visualizations can increase their effectiveness (Hundhausen, et al. 2002). This would support our hypothesis that the visualizations in the first experiment failed because students were not guided to study the 'delete' operation. One approach to active engagement is to supply guide questions to be answered while the visualization is being studied. In addition to active engagement, we believe that there is an identifiable set of key features that are incorporated into nearly all successful visualizations. We currently hypothesize that this feature set includes: User control of the pace of the visualization animation; the ability to test hypotheses by allowing users to enter input; display of both logical and physical views of a data structure; the ability to backup the animation to replay critical steps; and a pseudocode display of the algorithm, keyed to the steps being visualized. We are presently conducting studies to measure the magnitude of the contribution of each of these features using a controlled visualization toolset.

References

Gogeshvili, A. (2001). AVL Tree visualization applet. http://www.seanet.com/users/arsen/avltree.html.

Gustafson, B., Kjenoli, J. (1998). BinaryTreesome. http://www.binarytreesome.com/.

Hundhausen, C., Douglas, S.A., and Stasko, J.T. (2002). A meta-study of algorithm visualization effectiveness. To appear in the *Journal of Visual Languages and Computing*.

Palmiter, S., & Elkerton, J. (1991). An evaluation of animated demonstrations for learning computer-based tasks. *Proceedings of the ACM Conference on Human Factors in Computing Systems,* (pg. 257-263).

Saraiya, P., Shaffer, C. (2001). DFS and BFS visualization. http://infovis.cs.vt.edu/.

Shaffer, C. (2001). *A Practical Introduction to Data Structures and Algorithm Analysis*, Prentice Hall.

Wilson, J., Aiken, R., and Katz, I. (1996). Review of animation systems for algorithm understanding. *Proceedings of the conference on integrating technology into computer science education*, (pg. 75–77).