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Colloquium

On two collateral effects of using algorithm visualizations

Pilu Crescenzi, Alessio Malizia, M Cecilia Verri, Paloma Diaz and Ignacio Aedo

Address for correspondence: Pilu Crescenzi and M Cecilia Verri, Department of Systems and Computer Science, University of Florence, Italy. Email: pierluigi.crescenzi@unifi.it, mariacecilia.verri@unifi.it; or Alessio Malizia, Paloma Diaz and Ignacio Aedo, Computer Science Department, Universidad Carlos III de Madrid, Avenida de la Universidad 30, 28911, Leganes, Madrid, Spain. Email: amalizia@inf.uc3m.es, pdp@inf.uc3m.es, aedo@ia.uc3m.es

Introduction

Algorithm visualization (AV) is a computer science education technology introduced in order to facilitate teaching and learning of the design, the behavior, and the analysis of algorithms and data structures. In an effort to better understand the role of visualization and engagement in computer science education, an engagement taxonomy has been recently proposed (Naps *et al*., 2003), and several studies have been conducted in order to evaluate the efficacy of AVs from an educational point of view and to quantify the difference between the effects of using AVs at different levels of the taxonomy itself (see, for example, Grissom, McNally & Naps, 2003).

Along this line of research, some studies have been more recently conducted in order to evaluate the joint effects of collaborative learning and AVs at different levels of the engagement taxonomy (Mikko-Jussi, Myller & Korhonen, 2009). The results presented in this paper have been obtained while trying to continue this latter kind of analysis. In particular, the experiment described in this paper was performed to evaluate the difference in efficacy of using AVs in individual and collaborative learning situations. To this aim, some students of the first year of an undergraduate program in computer science were asked, at the end of a course on algorithms and data structures, to participate in an experiment oriented towards validating the following hypothesis: the efficacy of using AVs is greater in the case of an individual learning environment than in the case of a collaborative environment. The rational behind this hypothesis is that the usefulness of AVs might be somehow compensated by the collaboration between students, while this is not true in the case of individual learning. The results obtained indeed do not support this hypothesis (even though no statistically significant result was obtained concerning the hypothesis in its integrity). However, two unexpected results were observed, which are the main contributions of this paper.

The first result is that, independently of the learning environment, the students who had access to AVs performed worse than the other students while dealing with theoretical questions concerning the visualized algorithm. This result is statistically significant. Hence, this can be considered a first *collateral* effect of using AVs: by focusing their attention to the execution of the algorithm, the student might not give sufficiently importance to the theory behind the algorithm itself. A similar result was reported by Montero, Díaz & Aedo (2010), where visualization appeared useless to understand abstract concepts of object-oriented programming, such as classes or structural relationships, but was very positive to get a better comprehension of more concrete concepts such as objects and instances, methods and invocations.

The second result, instead, concerns with the way students answered one of the three questions included in the experiment test. Indeed, 21 students of the 24 that used AVs answered to the question by pictorially showing the final result of the algorithm execution, while only five students over 21 that did not use AV felt the necessity to show this graphical information. This can be considered a second collateral effect of using AVs: by getting used to "see" the execution of the algorithm, the student might feel the need to show the result of this execution while answering a question (even when this is not explicitly required by the question itself).

The experiment

Algoritmi e Strutture Dati is a first-year course of the computer science undergraduate program at the Science Faculty of the University of Florence, which covers standard topics in the field of algorithms and data structures.

At the end of the course, the teacher asked to all students that successfully passed the two intermediate exams whether they wanted to participate in an experiment on the efficacy of AVs: 45 students answered to the call for participation.

These students were subdivided into four groups. The first group included seven students (individual/AV in Table 1), which were supposed to study the algorithm individually by using the visualizations at a changing level of the involvement taxonomy, while the second group included eight students (individual/no AV), which were supposed to study the algorithm individually without using the visualizations. The third and the fourth groups included 14 students (pair/AV) and 16 students (pair/No AV) respectively, who were supposed to study in pairs.

The students were given 30 minutes to study a description of the Huffman algorithm implemented by means of two queues and 30 minutes to answer three questions concerning the algorithm: all students had to take the test individually, even the students that studied the algorithm in pairs. The first question was assigned a score equal to 0.4, while the remaining two questions were assigned a score equal to 0.8: the students were said that their total score would have been added to their course final grade (over 10).

Data analysis

Table 1 summarizes the results obtained at the end of the experiments: in the table, we denote by μ (respectively, μ_i) and by σ (respectively, σ_i) the average score and its standard deviation obtained on all three questions (respectively, on question *i*).

As it can be seen from the first four rows of Table 2, there is no statistically significant difference between the total students' performances neither because of the use of the AV nor because of the possibility of studying in pairs. From the total performance point of view, we can just note that, in the case of the students who studied individually, using the AV caused a slight lower total score, while the opposite behavior can be seen in the case of the students who studied in pairs: even if these results are not statistically significant, they seem to contradict our original hypothesis.

First answer analysis

If we focus our attention on the first question, which was a more theoretical question concerning prefix-free codes in general, the fifth row of Table 2 shows that there is a statistically significant (with respect to both the *t*-test and the Wilcoxon test) difference between the score obtained by the

Table 1: Results of the answers to the three questions

Group	Students	μ	σ	μ_1	σ_1	μ_2	σ_2	μ_3	σ_3
Individual/AV	8	1.4	0.64	0.2	0.21	0.7	0.28	0.5	0.41
Individual/no AV	7	1.43	0.76	0.4	0	0.57	0.39	0.46	0.43
Pair/AV	16	1.45	0.56	0.2	0.21	0.75	0.2	0.5	0.4
Pair/no AV	14	1.37	0.71	0.29	0.19	0.63	0.34	0.46	0.41

Table 2: The P*-values of the* t*-tests, the* F*-tests, and the Wilcoxon tests performed on several pairs of samples*

Samples	t*-test*	F*-test*	*Wilcoxon*
Individual/AV/total vs. individual/no AV/total	0.9391	0.6604	0.8540
Pair/AV/total vs. pair/no AV/total	0.7432	0.3772	0.9138
Individual/AV/total vs. pair/AV/total	0.8544	0.6335	0.8982
Individual/no AV/total vs. pair/no AV/total	0.8714	0.7906	0.7811
Individual/AV/Q1 vs. individual/no AV/Q1	0.0332	0.0000	0.0418
Pair/AV/Q1 vs. pair/no AV/Q1	0.2436	0.7335	0.2499

Table 3: Different ways of answering the third question

	Individual/no AV	*Individual/AV*	*Pair/no AV*	*Pair/AV*
Tree drawn	0	8	5	13
Tree not drawn	7	0	9	3

students who studied individually without using the AV and the score obtained by the students who studied individually and used the AV. A similar behavior can be noted even in the case of the students who studied in pairs: in this case, however, the difference between the two scores is not statistically significant (see the sixth row of Table 2). This phenomenon can be considered as a first (maybe negative) collateral effect of using AVs. Indeed, it seems that the visualization somehow distracts the students from more theoretical aspects of the algorithm explanation.

Third answer analysis

We noticed a different behavior in answering the third question, which asked the students to compute the Huffman code of a specific input instance. Indeed, even though it was not explicitly required by the question formulation, some students supported their answer by showing the final Huffman tree. In particular, Table 3 shows how many students drew the tree in each of the groups.

As it can be seen, the inclusion of the tree drawing has been mostly performed by students who studied the algorithm with the support of the AV. This phenomenon can be considered as the second (maybe positive) collateral effect of using AVs. Indeed, it seems that the students who studied the algorithm by using its visualization thought that a good way of justifying their answer was to show the final Huffman tree.

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