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# Integrating Algorithm Visualization Video into a First-Year Algorithm and Data Structure Course

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**ABSTRACT**

In this paper we describe the results that we have obtained while integrating algorithm visualization (AV) movies (strongly tightened with the other teaching material), within a first-year undergraduate course on algorithms and data structures. Our experimental results seem to support the hypothesis that making these movies available significantly improved students' performances. Moreover, the movies were highly appreciated by the students (both from a comprehensibility point of view and from a usefulness point of view), even though with a low attitude towards the emerging video pod-cast technology. Finally, our results indicate the necessity of integrating the AV movies with audio comment, which seems to be one of the most interesting research question left open by our study.

**Keywords**

CS2 course, Algorithm and data structure visualization, experimental evaluation

## Introduction

Algorithm visualization (in short, AV) is one of the two main subareas (along with program visualization) of the software visualization research field. In order to distinguish between static and dynamic visualizations of algorithms, in the literature it is often used the term algorithm animation instead of algorithm visualization: in this paper, we will consider the two terms equivalent. By adapting the definition of this latter field given in (Price, Baecker, & Small, 1993), we could say that AV is “the use of the crafts of typography, graphic design, animation, and cinematography with modern human computer interaction and computer graphics technology to facilitate” the human teaching and learning of the design, the behavior, and the analysis of algorithms and data structures. Since its birth (that can be identified with the seminal video of Ron Baecker developed at the beginning of the eighties and successively described in (Baecker, 1998)), AV has been one of the most active research areas within the more general field of computer science education. The 30-minute video, entitled Sorting out sorting, was developed with the assistance of Dave Sherman within the Dynamic Graphics Project of the University of Toronto in 1981, and successively included in SIGGRAPH Video Review 7, 1983. In particular, researchers alternated between the proposal of new tools and languages for developing and distributing algorithm visualizations (such as the ones described in (Rössling & Freisleben, 2002; Naps, Eagan, & Norton, 2000; Shneerson & Tal, 1997; Crescenzi & Nocentini, 2007; Laakso, Myller, & Korhonen, 2009)), and the experimental evaluation of the efficacy of these tools from a pedagogical point of view. This latter line of research culminated in the meta-study described in (Hundhausen, Douglas, & Stasko, 2002), which examined from a more abstract point of view 24 experimental studies performed during the nineties. In a further effort to understand these experimental results and to explore the role of visualization and engagement in computer science education, a framework for experimental studies of AV effectiveness has been proposed in (Naps et al., 2003), based, beyond other things, on an engagement taxonomy including six different forms of student engagement with AV technology.

In this paper, we focus our attention on the full integration of AV movies within the teaching material distributed to the students of a first-year algorithm and data structure course. Our goal is to experimentally validate (we refer to experimental validation in general sense and not to controlled experiment) the hypothesis that making AV movies available can significantly improve students' performances, whenever the visualization is strongly tightened with the front lecture and with the lecture notes. To this aim, we have developed eight sorting AVs, which have been distributed (in MPEG-4 format) along with the lecture notes after the front lecture. We have successively analyzed the students' grades obtained while taking a written exam on topics related to the AV movies. Finally, we have asked the students to fill surveys concerning their opinion about the usefulness of the AV movies.

The rationale behind the video format choice is that we also wanted to somehow verify the students attitude towards the emerging video pod-cast technology. Indeed, in the last few years several papers (Campbell, 2005; Brittain, Glowacki, Van Ittersum, & Johnson, 2006) have depicted this technology in a quite enthusiastic way, by imagining a world in which students would listen "to a podcast on the drive to school, then reinforcing the day's learning by listening to another podcast, or perhaps the same podcast, on the drive back home" (Campbell, 2005). The second goal of this paper is, then, to quantitatively and qualitatively verify the attitude of our students towards this near future scenario.

The rest of the paper is organized as follows. In Section II we briefly describe the AV tool we have used in order to produce the AV movies. Sections III and IV reports the evaluation experiment carried out in order to evaluate the efficacy of AV movies from a pedagogical point of view. Finally, in Section V we summarize the related work and in Section VI we provide some conclusions and future work.

## AlViE

In order to develop the AV movies, we used an algorithm visualization system, called AlViE, which is a *post-mortem* tool (according to the post-mortem approach, visualization takes place after the algorithm execution and requires some sort of trace files which is recorded during the execution itself) based on the *interesting event* paradigm (see, for example, (Price et al., 1993)). In particular, AlViE includes (1) a visualization player that allows the user to navigate through a visualization, (2) a graphical input developer that allows the user to create new input and, hence, to change a visualization, and (3) a Java class library, which allows a programmer to create new visualizations on the ground of the following data structures: arrays, matrices, lists, binary trees, graphs, queues, and stacks.

The AlViE distribution we used (Crescenzi, Gambosi, Grossi, Nocentini, & Verdese, 2007) included 65 visualizations of algorithms and data structures. This collection of visualizations is physically included in the distribution and can, hence, be used off-line, that is, without the necessity of being connected to a world wide web server, as in the case of JHAVE, another AV environment which comes with several algorithm and data structure visualizations (Naps, 2005).

The user interface of AlViE can be fully localized: indeed, every graphical and textual component of the interface is associated with several properties whose value is specified within a language-dependent text file. Currently, the interface of AlViE is available in Italian and in English: creating a new localization is a matter of a few time translating task.

Almost all the visualizations included in the AlViE distribution provide the possibility of showing the pseudo-code of the algorithm, which is written in a pseudo-C language. Moreover, by specifying the value of several properties contained into language-dependent text files, all the visualizations can be easily customized from a graphical point of view, and they all support localization: currently, all the visualizations are available in Italian and in English.

The user can create new visualizations of any of the algorithms included in the AlViE distribution by creating new inputs by means of the graphical input developer, which is part of the AlViE framework. Moreover, the Java class library allows a programmer to quite easily construct new visualizations of new algorithms: in the last three years, this feature has been extensively used and more than forty new visualizations have been produced by almost eighty second year undergraduate students. Even in this case, as far as we know, this is one of the largest collection of visualizations constructed by students by means of the same AV tool.

AlViE is currently supported by an Italian text book on algorithms and data structures (Crescenzi, Gambosi, & Grossi, 2006), which is, as far as we know, the first book which fully integrates AV technology into the theoretical design and analysis of algorithms and data structures. Indeed, very few examples are printed within the book, while most of the time the explanation of an algorithm refers to the visualization of the algorithm itself. The text book has been adopted in the universities of Florence, Pisa, Siena, and Verona in Italy and it is suggested in almost twenty other Italian computer science undergraduate programs.

## Quantitative evaluation

In this section we present the results of the experimental study we have performed in order to determine whether the distribution of AV movies along with the lecture notes improves students' performances. In particular, we intended to demonstrate that viewing AV movies can improve students' grades by making use of a scenario-based design approach (Rosson & Carroll, 2002). To this aim, we have designed an experimental scenario among the students of a first-year algorithm and data structure course, which was made of two intermediate exams for the course. We have then performed a statistical analysis of the grades obtained by the students while taking these intermediate exams. At the same time, we asked the students to fill surveys in order to express their opinion about the usefulness of the movies and the technological aspects of the visualizations.

### *The course*

*Algoritmi e Strutture Dati* is a first-year course of the Computer Science undergraduate program at the Science Faculty of the University of Florence. The topics covered by the course are the following: algorithm complexity analysis, elementary data structures (arrays and lists), abstract data structures (stacks, queues, priority queues, trees), search algorithms (binary search, binary search trees, AVL and 2-3 trees, tries, random search), sorting algorithms (elementary algorithms, quicksort, mergesort, heap sort), graphs (representation, search algorithms, MST). The course corresponds to 12 ECTS credits (the European Credit Transfer and Accumulation System is a standard for comparing the study attainment and performance of students of higher education across the European Union, with 12 credits being approximately 100 front lecture hours). The individual student's grade is decided on the ground of four distinct exams: a first intermediate written exam is taken after the first part of the course (that is, up to the search algorithms), a second intermediate written exam is taken at the end of the sorting algorithm part, while an oral exam and a laboratory exam (to be arranged along with the *Programmazione* course) are taken at the end of the course. Programmazione is a programming course which also corresponds to 12 ECTS credits: even though the laboratory exam is arranged along with Algoritmi e Strutture Dati, the grades assigned to the students in the two courses are independent. The course (as almost any course of the undergraduate program) uses the Moodle platform (Cole & Foster, 2007) in order to distribute the learning material and to manage all the related web activities.

### *The students*

Almost 200 students signed to the course on the Moodle platform. However, only 91 students took the first intermediate exam: 54 of them also took the second intermediate exam. Our sample was formed by these latter 54 students. The 54 students represent one fourth of the registered students but this is a quite normal trend in Italy for this kind of first-year courses, in which there is a high abandoning rate.

### *The AV movies*

Eight movies were produced and distributed, related to the three more advanced sorting algorithms (that is, quicksort, mergesort, and heap sort). The movies were developed by making use of AlViE and of the ScreenFlow software (Telestream, Inc, 2009) (in order to capture the screen activity and to produce MPEG-4 movies). They were distributed along with the lecture notes just after the front lectures. All movies include the algorithm pseudo-code (taken from the lecture notes): moreover, as a consequence of the comment of one student, the last six movies also visualize the values of most of the auxiliary variables used by the pseudo-code. The movies can now be downloaded starting from the web page of AlViE (Crescenzi et al., 2007).

### *Independent variable*

There was only one independent Boolean variable, that is, whether the students viewed or not some of the movies that were distributed. By using the Moodle platform, we could trace the movies downloads: however, downloading a movie does not imply viewing it. Hence, since the students were not forced to download and to see the movies, in order to quantify this variable, we asked the students to fill a survey for each of four groups of videos, concerning the usefulness of the movies and their technological aspects (see Appendix A). The first group of two videos concerned the basic quicksort algorithm, the second group of two videos was related to two modified version of the quicksort algorithm, the third group contained only one video of the mergesort algorithm, and the last group of three videos concerned the heap sort algorithm.

Note that, since the experimental set-up is scenario-based and not a controlled experiment, we could only infer our conclusions about the independent variable values assuming it equal to true if and only if the student filled a sufficient number of surveys to guarantee that he/she viewed at least two movies. Note that a couple of students filled a survey without downloading any movie: this is not a contradiction, since it is reasonable to assume that movies were also passed among the students.

According to the above criterion, the 54 students have been divided into two groups: the first group contained the 26 students that watched at least two movies, while the second group contained the remaining 28 students that did not watch any movie at all (or, at least, did not fill any survey): interestingly, the sample is almost split into two halves. In the following, we will denote with $Y$ and $N$ the first and the second group, respectively.

***Dependent variable***

Even in this case, there was only one dependent variable, that is, the grade obtained by the student while taking the second intermediate exam. In particular, this exam contained the following five questions (the students were given up to two hours to complete the exam):

**Q1.** What is a stable sorting algorithm? Give at least three examples of stable sorting algorithms.

**Q2.** Find a permutation of the first 10 integer positive numbers on which the quicksort algorithm, with the pivot chosen as the median of three, executes the maximum number of comparison.

**Q3.** Sort the array 15, 5, 12, 10, 20, 23, 18, 13, 3, 6, 7, and 19 by using the insertion sort algorithm.

**Q4.** Sort the array of the third question by using the quicksort algorithm with the pivot chosen as the rightmost element.

**Q5.** Sort the array of the third question by using the heap sort algorithm.

Each question is evaluated by means of a grade between 0 and 6. Hence, the dependent variable is a number between 0 and 30.

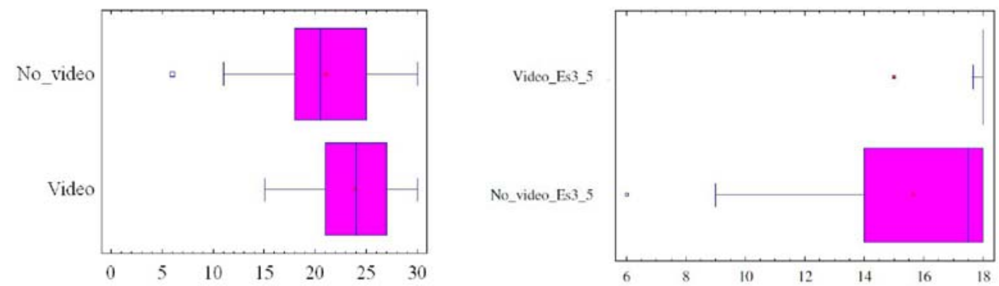
***Data analysis***

We denote by $\mu_Y$ (respectively, $\mu_N$) the mean of the grades of the students in $Y$ (respectively, $N$). Moreover, we denote by $\sigma^2_Y$ (respectively, $\sigma^2_N$) the variance of the grades of the students in $Y$ (respectively, $N$). Finally, we denote by $\mu^Y_{1/2}$ (respectively, $\mu^N_{1/2}$) the median of the grades of the students in $Y$ (respectively, $N$). The values of these measures are summarized in the following Table 1 (30 was the maximum grade).

*Table 1.* Students' grades: (Y) watched at least 2 videos, (N) did not watch any video

| **Measure** | $\mu_Y$ | $\mu_N$ | $\sigma^2_Y$ | $\sigma^2_N$ | $\mu^Y_{1/2}$ | $\mu^N_{1/2}$ |
|---|---|---|---|---|---|---|
| **Value** | 23.9 | 21.1 | 4.2 | 6.3 | 24.0 | 20.5 |

We could not assume that $\sigma^2_Y$ and $\sigma^2_N$ are equal, since the results of an F-test to compare the standard deviations suggests that there may be a significant difference between them. For this reason, we did not run a *Student's t-test* analysis to compare the means: instead, we ran a Mann-Whitney-Wilcoxon test (Dix, Finlay, Abowd, & Beale, 2003) to compare the medians. This test, which is one of the best-known non-parametric significance tests, is constructed by combining the two samples, sorting the data from smallest to largest, and comparing the average ranks of the two samples in the combined data. By applying the test to our data, we obtain a $P$-value equal to 0.043: since this value is less than 0.05, we can conclude that there is a statistically significant difference between the medians at the 95% confidence level. This implies that the difference of the means is significant (see also Figure 1(a)). Even if the statistical results are not strictly related to a controlled experiment, by considering the settings proposed at the beginning of this section we can conclude that the average grade was significantly higher in the case of students that watched the video material and, in particular, in the case of the last 3 questions where students scored better results distributed uniformly.




(a) (b)

*Figure 1.* (a) Students that did not watch any video (No_video) against students that did watch at least two videos (Video): *X*-axis presents grades, while *Y* axis has two values if videos have been watched or not. (b) Students using videos have more uniformed grades that tend to be higher than students that did not watch any video (whose grades are more scattered and seem to depend only on students' skills).

A flattening effect that uniforms results of students that watched videos clearly appears in Figure 1(b) (Exercise 3, 4, and 5), where the *X*-axis presents grades, and the *Y*-axis has two values if videos concerning questions 3, 4, and 5 have been watched or not. Thus students using videos have more uniformed grades that tend to be higher than students that did not watch any video (whose grades are more scattered and seem to depend only on students' skills).

### *Further results*

In order to be sure that the above result is not due to the fact that students in *Y* are consistently better than students in *N*, we performed the same data analysis by using as dependent variable the grade obtained by the students while taking the first intermediate exam, which consisted of questions not related to the topics explained in the videos. In this scenario such evaluation can be comparable to a control group in a controlled experiment even if in our case conclusions cannot be as strong because of the open scenario (i.e. no time on task has been measured). Referring to the previously introduced notation, the measure values are summarized in Table 2.

*Table 2.* Students' grades for the first intermediate exam: (Y) watched at least 2 videos; (N) did not watch any video.

| **Measure** | $\mu_Y$ | $\mu_N$ | $\sigma^2_Y$ | $\sigma^2_N$ | $\mu^Y_{1/2}$ | $\mu^N_{1/2}$ |
|---|---|---|---|---|---|---|
| **Value** | 23.7 | 22.0 | 4.3 | 5.1 | 23.0 | 23.0 |

By running the Mann-Whitney-Wilcoxon test on these data, we obtain a *P*-value equal to 0.31: since this value is greater than 0.05, we can conclude that there is no statistically significant difference between the medians at the 95% confidence level. This means that the difference of the means is not statistically significant. In other words, differently from what we could do in the case of the second intermediate exam, in this case we cannot reject the null hypothesis and hence we cannot draw conclusions about students' level of preparation.

As a further support to this statement, we have also compared the grades obtained by the students, while taking the second intermediate exam, relative to the first two questions (which were more theoretical) with the ones relative to the last three questions (which were more practical). Once again, referring to the same notation, the measure values are summarized in Table 3.

By running the Mann-Whitney-Wilcoxon test on the first two question data, we obtain a *P*-value equal to 0.369: since this value is greater than 0.05, we are not allowed to conclude that there is a statistically significant difference between the medians at the 95% confidence level. On the other hand, by running the Mann-Whitney-Wilcoxon test on the second three question data, we obtain a *P*-value equal to 0.002: since this value is less than 0.05, we can conclude that there is a statistically significant difference between the medians at the 95% confidence level. In other words, as we could expect, the students performance improvement by watching videos is mainly related to more practical questions, in which the simulation of an algorithm was required. Moreover if we observe the variance in the case of the first two questions and of the other three, then we can notice an interesting phenomenon: the variance decreases ($\sigma^2_Y$ = 3.7 in the case of the first two questions and $\sigma^2_Y$ = 1.0 in the case of the last three). This could be explained by the fact that, as already noticed, the use of videos has a sort of flattening effect on the learning curve.

*Table 3.* Students' grades for the first intermediate exam split in first part (two questions) and second part (3 questions): (Y) watched at least 2 videos, (N) did not watch any video.

| First two questions | | | | | | |
|---|---|---|---|---|---|---|
| **Measure** | $\mu_Y$ | $\mu_N$ | $\sigma^2_Y$ | $\sigma^2_N$ | $\mu^Y_{1/2}$ | $\mu^N_{1/2}$ |
| **Value** | 6.2 | 5.4 | 3.7 | 4.1 | 6.0 | 5.0 |
| **Last three questions** | | | | | | |
| **Measure** | $\mu_Y$ | $\mu_N$ | $\sigma^2_Y$ | $\sigma^2_N$ | $\mu^Y_{1/2}$ | $\mu^N_{1/2}$ |
| **Value** | 17.7 | 15.6 | 1.0 | 3.4 | 18.0 | 17.5 |

## Qualitative evaluation

As we have already said before, the students were asked (but not forced) to express their opinion about the AV movies by filling one or more surveys. Just before the second intermediate exam, we collected the data contained in the 55 surveys filled by 31 students (note that some students clearly filled more than one survey). The results are summarized as follows:

- Only 5 students (that is, 16%) viewed at least one movie on an iPod/iPhone or on another PDA device.
- Of the above 5 students, one judged the video resolution as very good, three judged it as good, and one judged it as bad.
- In 12 surveys (that is, 22%) the visualization was judged very comprehensible. In all the other surveys, it was judged comprehensible.
- In 21 surveys (that is, 38%) the visualization was judged very useful, in 33 it was judged useful, and only in 1 it was judged unuseful.
- In 40 surveys (that is, 73%) the integration of an audio comment was judged useful.
- In 19 surveys over 32 (that is, 59%) the visualization of the auxiliary variable was judged very useful, in 10 surveys (that is, 31%) it was judged somehow useful, in 2 surveys (that is, 6%) it was judged maybe confusing, and in the remaining survey (that is, 3%) it was judged completely unuseful and confusing.

From these results, it is clear that the students appreciated the AV movies, both from a comprehensibility point of view and from a usefulness point of view. Interestingly, it seems that the video pod-cast technology is not very spread, and that the students prefer to see the movies on their desktop/laptop displays. Indeed, it could also be that most of the students do not even own an iPod/iPhone or another PDA device.

## Related work

As we already said in the introduction, several experimental studies have been carried out concerning the pedagogical efficacy of the AV technology (most of these studies are surveyed in (Hundhausen et al., 2002)). As far as we know, however, our work is the first attempt to evaluate the strong integration of this technology within an algorithm and data structure course in a quite transparent way: as we already specified, the students were not forced to see the movies neither to fill the surveys. We also emphasize the fact that our integration of the movies was very tightened with the course contents: indeed, the movies show exactly the same pseudo-code that was explained by the teacher during the front lectures and that was included in the lecture notes. As far as we know, the only similar example of such a systematic integration within an undergraduate official course is described in (Crescenzi & Nocentini, 2007).

For what concerns the use of video pod-casts within a learning environment, apart from the two papers already cited in the introduction, it is worth mentioning (Lazzari, 2009): in this paper the author describes an academic experience of pod-casting, which involved a group of students of a course on multimedia communication and human-computer interaction. Finally, in (Hürst, Lauer, & Nold, 2007) the efficacy of algorithm visualization on mobile devices is studied by setting up an empirical experiment with 16 advanced students of computer science. In this experiment the independent variables were the kind of used device and the presence of an audio comment.

## Conclusions

In this paper we have described the results obtained while integrating AV movies within a first-year undergraduate course on algorithms and data structures. These results, which are promising both from a student performance point of view and from a student appreciation point of view, can be summarized as follows:

- AV movies seem to be a proficous way to get the students to invest their time while learning an algorithm. Indeed, after one month of front lectures, students who viewed and reviewed at least two movies performed in a statistically significant way (with respect to the Mann-Whitney-Wilcoxon test) better than the other students, while taking an intermediate exam fully devoted to the visualized sorting algorithms. Clearly, the same effect could have happened if one group of students would have read a text book, while the other group did nothing. However, we believe that AV movies have some motivating factor that we cannot forget: our results support the hypothesis that AV movies may be an effective way of helping students use time well (which is one of the seven principles of good practice in higher education indicated in (Chickering & Gamson, 1987)).
- The above performance difference is mainly concentrated on simulation exercises. Students who viewed the movies performed better on these exercises while answering on more theoretical questions did not result in any statistical significant difference. Observe that this result somehow supports the hypothesis that making AV movies available is the main justification for the better performances, since they get the students to invest more time in understanding the behavior of an algorithm.
- Students preferred to see the movies on their desktop/laptop display rather than on iPod or another PDA. Indeed, only a negligible percentage of students viewed the movies on these latter devices. It is worth noting, however, that we did not ask the students to specify whether they owned such a device: hence, this result could be simply due to the fact that these devices were not very popular among the analyzed cohort of students.
- Basically all students considered the AV movies a useful tool for reviewing and studying the material covered by the lecture notes. As a consequence of this result, the integration of AVs into a learning management system such as Moodle seems to be a very interesting line of future research. Indeed, this possibility has already been explored in (Röβling & Vellaramkalayil, 2009), where the authors present a Moodle activity that is able to incorporate animations created in the ANIMAL system (Rössling & Freisleben, 2002).
- Many students stated that the integration of an audio comment into the movies would have been useful. This result seems to be consistent with the experiment performed in (Hürst et al., 2007)) and suggests an interesting research direction. The main problem, in this case, is twofold. From a technical point of view, it is not easy to automatically add an audio comment to a movie, if we want to maintain the internationalization of our software. From a visualization efficacy point of view, instead, an automatically produced audio comment could turn out to be boring and, hence, not very effective. For this reason, we think that satisfying this students' request might turn out to be quite challenging.

As a consequence of the results described in this paper, the new version of AlViE is now capable of automatically recording visualizations and of saving them in different video formats: we hope that this feature will turn out to be a good tool for study strategy (as also suggested in (Yi-Chuan & Cifuentes, 2006)). Besides the experimental results we have described in this paper, there are at least two other main reasons that justify this extension. First of all, movies can help algorithm visualization producers while advertising and distributing new algorithm visualizations. By using movies, there is no need to download a specific software: the final user can see the visualization (even on a browser) and subsequently decide whether it is worth using it and changing it (for instance, by executing the algorithm with different inputs). In this latter case, of course, the necessary software has to be downloaded. Secondly, producing movies can turn out to be a motivating way for students to present their visualizations. On the ground of the first author's experience, it seems that students like to construct and to present their own algorithm visualizations: we think that if they can also distribute them by means, for example, of a video pod-cast directory, then they might even be more motivated in realizing an effective visualization (which should turn out in a better understanding of the algorithm).

From a more pedagogical point of view, finally, an interesting line of research would be to explore the effects of offering the possibility of interacting with the AVs (for instance, by producing new visualizations with different inputs). In particular, during the next academic year we plan to perform experiments similar to the ones described in this paper in order to evaluate the efficacy of fully integrating this possibility. Once again, our hypothesis will be that whenever the algorithm animations are strictly tightened to the other course material then the possibility of creating new visualizations with different inputs will further improve student performances.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## References


Baecker, M. (1998). Sorting out sorting: A case study of software visualization for teaching computer science. In T. Stasko, J. B. Domingue, M. Brown, & B. Price (Eds.), *Software Visualization*. Cambridge, MA: The MIT Press.

Brittain, S., Glowacki, P., Van Ittersum, J., & Johnson, L. (2006). Podcasting lectures. *EDUCAUSE Quarterly*, *29*(3), 24-31.

Campbell, G. (2005). There's something in the air: Podcasting in education. *EDUCAUSE Review*, *40*(6), 32-47.

Chickering, A. W., & Gamson, Z. F. (1987). Seven principles for good practice in undergraduate education. *AAHE Bulletin*, *39*(7), 3-7.

Cole, J., & Foster, H. (2007). *Using Moodle: Teaching with the Popular Open Source Course Management System*. Sebastopol, CA: O'Reilly Media, Inc.

Crescenzi, P., Gambosi, G., & Grossi, R. (2006). *Strutture di Dati e Algoritmi – Progettazione, Analisi e Visualizzazione*. Turin, Italy: Pearson Education.

Crescenzi, P., Gambosi, G., Grossi, R., Nocentini, C., & Verdese, W. (2007). AlViE [Computer software]. Available from http://www.algoritmica.org/software/

Crescenzi, P., & Nocentini, C. (2007). Fully integrating algorithm visualization into a CS2 course. In *Proceedings of the Twelfth Annual Conference on Innovation and Technology in Computer Science Education* (pp. 296-300). New York, NY: ACM

Dix, A., Finlay, J., Abowd, G., & Beale, R. (2003). *Human-Computer Interaction* (3rd ed.). Essex, England: Prentice Hall.

Hundhausen, C. D., Douglas, S. A., & Stasko, J. T. (2002). A meta-study of algorithm visualization effectiveness. *Journal of Visual Languages and Computing*, *13*(3), 259-290.

Hürst, W., Lauer, T., & Nold, E. (2007). A study of algorithm animations on mobile devices. In I., Ressell (Ed.), *Proceedings of the Thirty-eighth SIGCSE Technical Symposium on Computer Science Education* (pp. 160-164). NY, USA: ACM

Laakso, M.-J., Myller, N., & Korhonen, A. (2009). Comparing learning performance of students using algorithm visualizations collaboratively on different engagement levels. *Journal of Educational Technology & Society*, *12*(2), 267-282.

Lazzari, M. (2009). Creative use of podcasting in higher education and its effect on competitive agency. *Computers & Education*, *52*(1), 27-34.

Naps, L. (2005). JHAVÉ: Supporting algorithm visualization. *IEEE Computer Graphics and Applications*, *25*(5), 49-55.

Naps, L., Eagan, J. , & Norton, L. (2000). JHAVÉ – An Environment to actively engage students in Web-based algorithm visualizations. In S., Haller (Ed.), *Proceedings of the Thirty-first SIGCSE Technical Symposium on Computer Science Education* (pp. 109-113). NY, USA: ACM

Naps, L., Rössling, G., Almstrum, V., Dann, W., Fleischer, R., Hundhausen, C.,…Velázquez-Iturbide, J. Á.. (2003). Exploring the role of visualization and engagement in computer science education. *ACM SIGCSE Bulletin, 35*(2), 131-152.

Price, B., Baecker, R., & Small, I. (1993). A principled taxonomy of software visualization. *Journal of Visual Languages and Computing, 4*(3), 211-266.

Rössling, G., & Freisleben, B. (2002). Animal: A system for supporting multiple roles in algorithm animation. *Journal of Visual Languages and Computing, 13*(3), 341-354.

Röβling, G., & Vellaramkalayil, T. (2009). A visualization-based Computer science hypertextbook prototype. *ACM Transactions on Computing Education, 9*(2), 1-13.

Rosson, M., & Carroll, J. (2002). Scenario-based design. In A. Sears & J. Jacko (Eds.), *The human-computer interaction handbook: Fundamentals, evolving technologies and emerging applications* (pp. 1032-1050). CA, USA: Taylor & Francis Group.

Shneerson, M., & Tal, A. (1997). GASP-II – A geometric algorithm animation system for an electronic classroom. In *Proceedings of the Fourteenth ACM Annual Symposium on Computational Geometry* (pp. 379-381). NY, USA: ACM

Telestream, Inc. (2009). ScreenFlow (Version 3) [Computer software]. Available from http://www.telestream.net/screen-flow/

Yi-Chuan, J., & Cifuentes, L. (2006). Student-generated visualization as a study strategy for science concept learning. *Journal of Educational Technology & Society*, *9*(3), 137-148.

# Appendix A

**The survey questions**

In the Table A.1 we show the questions included in the four surveys (the last four questions had to be answered only if the student answered yes to the second question).

*Table A.1.* Questionnaire presented to the students.

| **Question** | **Answers** | | | |
|---|---|---|---|---|
| Have you downloaded the movies? | Yes | | No | |
| Have you seen the movies? | Yes | | No | |
| If you answered yes to the previous question, which device have you used? | Desktop or laptop screen | iPod or iPhone | Other PDA | Other |
| If you used iPod/iPhone or other PDA, how was the resolution? | Very good | Good | Bad | Very bad |
| How was the visualization from a comprehensibility point of view? | Very comprehensible | Comprehensible | Not comprehensi-ble | Completely incomprehensible |
| How was the visualization from a usefulness point of view? | Very useful | Useful | Not useful | Completely unuseful |
| How was the visualization of the auxiliary variables? (*Not in the first survey*) | Very useful | Somehow useful | Might be confusing | Completely unuseful and confusing |
| Would the integration of an audio comment have been useful? | Yes | | No | |