

Educational Visualizations of Sorting Algorithms in Virtual Reality

Daniel Novák ¹, Gregor Rozinaj ², Marek Vančo ²

¹ Faculty of Informatics and Information Technologies, Institute of Informatics, Information Systems and Software Engineering, Ilkovicova 2, 841 04, Bratislava, Slovakia

² Faculty of Electrical Engineering and Information Technologies, Institute of Multimedia Information and Communication Technologies, Ilkovicova 3, 812 19 Bratislava, Slovakia
daniel.novakeyp@gmail.com

Abstract – Education is one of the few areas where little to no progress has been done in terms of innovation in the past decades. However, with the recent boom of virtual reality, experiments in the field of education have been carried out and have proved its usefulness. According to research conducted on the Tampere University of Technology (TUT), visualization is a very effective tool when used correctly in teaching computer science. Students often struggle learning algorithms and data structures in their respective introductory programming courses. In this article, I propose an application, a virtual laboratory, in which students can improve their understanding of the algorithms. Visualizations are being done with the Bloom’s revised taxonomy in mind, as suggested by Lahtinen et al. To enhance one’s experience in such virtual environment, and to keep such person motivated, gamification elements are added.

Keywords – virtual reality; education; visualization; computer science; Bloom’s revised taxonomy

I. INTRODUCTION

In spite of slow progress in improving education in the past century, we can observe an effort to refine and improve the way students are taught at schools and universities alike. Programming is a fundamental skill for anyone in the field of computer science. Hence, teaching and learning programming is tremendously important and poses one of the biggest challenges in the Computer Science Education [1].

There are years of conducted research showing that students have several difficulties while undertaking the journey to learn how to program. The lack of understanding how to properly use and combine the basic data structures, was identified as the key problem to successfully building a program. One factor which greatly contributes to person’s ability to learn programming is his/her knowledge of mathematics and problem solving. Students studying mathematics or having mathematical abilities achieve better grades in their introductory courses [1] [2].

I therefore believe that proper understanding of abstract structures and algorithms associated with them is crucial for any aspiring programmer.

II. BLOOM’S REVISED TAXONOMY

Bloom’s taxonomy was created in 1956. Behind its creation was a team led by educational psychologist Dr. Benjamin

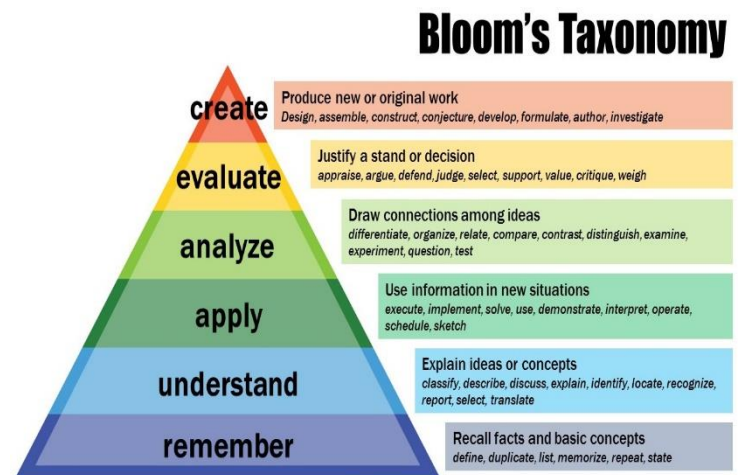


Figure 1. Bloom's Revised Taxonomy

Bloom. The idea was to promote higher forms of thinking in education. Most often, it can be found used when creating educational and learning processes [3]. There are three domains of learning.

1) Three Domains of Learning

- Cognitive: mental skills (knowledge).
- Affective: growth in feelings or emotional areas (attitude or self).
- Psychomotor: manual or physical skills (skills).

In this article, I am only concerned with the first domain – the Cognitive domain. The cognitive domain involves knowledge and the development of intellectual skills. That includes the ability to recall or recognize certain facts, patterns and principles and how they tie together. There are six major categories in the Bloom’s Taxonomy. However, they were changed in Bloom’s Revised Taxonomy by the Bloom’s very students Lorin Anderson and David Krathwohl. In the original taxonomy, the categories were nouns. In the revised taxonomy, they are verbs. The new taxonomy is better, because it is more accurate and reflects a more active approach to thinking and learning [3].

Why use or even mention Bloom’s taxonomy in this paper? The authors of the revised taxonomy outline few points along with clarifications:

2) *Few Outlined Points with Clarifications*

- Learning goals are important to be established in a dialogue between teachers and students, so that both groups clearly understand what objectives they are trying to achieve.
- Teachers benefit from using frameworks or guidelines because organizing objectives helps them in a structured way to both students and teachers.
- Having an organized set of objectives helps teachers with:
 - Planning and delivering clear and appropriate instructions;
 - Designing valid assessment tasks and strategies;
 - Ensuring that instructions and assessments are aligned with objectives.

To conclude, the Revised Bloom’s Taxonomy draws attention away from the static notion of learning and achieving learning goals. It introduces dynamic concepts of classification. My virtual laboratory is going to be designed with this taxonomy in mind.

A. *Prepare Your Paper Before Styling*

The ideas for developing visualizations are divided into different levels according to Bloom’s Taxonomy levels of cognitive development [4]. Only illustrative visualizations are not enough in learning programming. The use of illustrative visualizations has its justification when introducing new concepts, but after that the students’ learning process must be supported with other types and categories of visualizations. The aim of developing such categorization of different visualizations is to help the developers and teachers recognize the variety of skills needed to be included in learning programming. The end result would be a visualization tool that is useful throughout the whole course and is easier to integrate [4]. The categories are presented in Tab. 1. Please do note that the table is not updated to match the Bloom’s Revised Taxonomy.

Table 1. Bloom’s Taxonomy Applied to visualizations

Level of the taxonomy	Visualization category	Characteristics and examples
1.Knowledge & 2.Comprehension	Illustrative visualizations	Presenting concepts, demonstrative, used to introduce a new subject
3.Application	Utilizing visualizations	Modify some parts of the program code to make certain changes to the functionality of the program, use visualization to better understand the program and the said changes
4.Analysis	Problem-solving visualizations	Debug broken program code, analyse program behaviour, use visualization to help understand
5.Synthesis	Productive visualizations	Use the visualization tool as a visual debugger when the student independently writes program code, or visualize the assignment description
6.Evaluation	Discerning visualizations	Visualizing solutions to a problem and comparing or evaluating them

B. *Course Integration and Usage of Visualization Tool*

The visualization tool must be integrated in a course in such a way that students actually use it. Students do not develop the habit of using such tool unless it is integrated well. To achieve this, the teacher must plan its use with great care and actively guide the students in using it. If the visualization tool is in a separate learning environment, for example on a web page that is not connected to the course material, students either do not find it or do not realize the right time to use it [4].

Now I am going to sum up the results of a study consisting of a group of students in TUT (Tampere University of Technology) in an introductory course for programming. There were 308 students enrolled in the course. In Fig. 3 we can see the number of exercises turned in by the students who always used the visualization tool and those who always used pen and paper. We can see more than 50% decrease in activity in both groups, but still noticeably higher in the latter group. In Fig. 4 we can see how the students assessed the visualization tool. To conclude, the students were guided so that using the visualizations was easy while being reminded that it was in fact optional. Another thing to note is that students using the tool continued to take more active approach in the course. I would also like to highlight the fact that only 2% of students who tried the visualization tool never used it again.

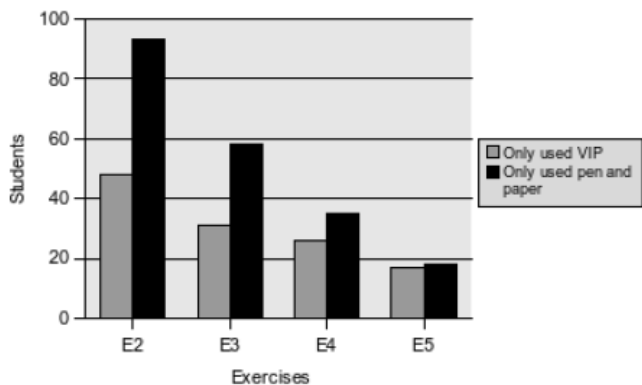


Figure 2. Number of exercises turned in by the students who only used pen and paper and those who only used the visualization tool

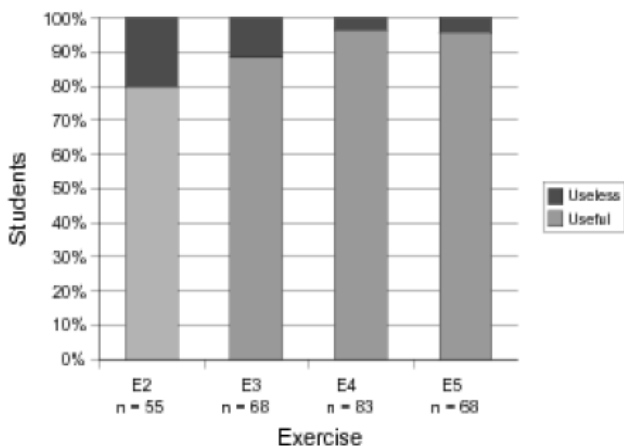


Figure 3. How useful students who used visualization tool found it in the assignments

III. GAMIFICATION

Understanding the role of gamification in education means understanding under what circumstances game elements can drive a student's learning behaviour so that he or she may achieve better results in the learning process. Engagement is the main objective in applying gamification.

Gamification isn't about turning the classes into a game; although the gamification technique is not truly an academic methodology, it may improve the performance of students in the learning process. Gamification is about applying game mechanics to any project, idea or situation [5].

In my case, I want to implement some game mechanics to make learning algorithms more fun; consequently, this will allow longer retention of the material among the students.

IV. VIRTUAL REALITY

Virtual reality (VR) is a simulated reality presented to our senses in such a way, that we perceive it as if it was real, and we were really there. We could also say that it is a realistic and immersive simulation of a three-dimensional environment, created using interactive software and hardware, and experienced or controlled by movement of the body [6]. It uses

a host of technologies to achieve this goal and is a technically complex feat that must account for our perception and cognition. It can be used in many areas other than entertainment, e.g. medicine, architecture or education. The technology has become much more widespread with the recent official releases of VR headsets, also known as head-mounted displays (HMD).

We can expect to see many innovative uses for the technology [7]. I believe that virtual reality is going to be a big game changer in visualization and therefore in learning and teaching data structures and programming as such.

A. Virtual Reality in Education

In the past decades, the virtual reality and augmented reality (AR) interfaces have both shown great promise in enhancing teaching and learning, by combining the best of both worlds [8]. Educators from different countries have been carrying out experiments in their respective education systems. In 2007, Hougang Elementary school in Singapore applied an AR prototype into a typical primary class to facilitate the learning of seed germination and plant growth. There was a significant boost in engagement and the students felt much more motivated to learn, thanks to the technology [9].

More recently, the rapid advancement of the VR devices made VR an affordable and suitable technology for education. Just last year in 2016 - Sony, HTC, and Oculus made commercial releases of their respective VR HDMs. VR can be applied anywhere in education, from primary and secondary schools to colleges and universities. In particular, virtual sandbox environment allows its users to move freely through a virtual world. They can choose when and how they go about approaching objectives, and create domain specific mods. It serves as a good VR candidate for teachers to design VR-based learning environments [10].

V. PROPOSED VIRTUAL LABORATORY

The goal of my work is to create a virtual laboratory, in which the students will be able to increase their knowledge of algorithms and how they work, and their comprehension of data structures. My vision is to make learning programming for students not only easier, but also much more of an enjoyable process and experience. Teachers will also benefit from this, as virtual reality helps keeping students motivated.

A. Summary of Technologies and Strategies to be Used

The I am drawing inspiration mainly from the Finnish and their visualization tool. In their research, they identified various kinds of visualizations to match with the corresponding levels of the Bloom's taxonomy. I am adapting this method as well, but I will map visualization types with levels of the Revised Bloom's taxonomy. There is not enough time to implement all the different types of visualizations defined by the Lahtinen and others. However, in my solution there are already illustrative and utilizing visualizations covering the first three steps of Bloom's revised taxonomy.

My VR application is being built for Gear VR using the Unity game engine. For scripting, I use Visual Studio Community Edition and I write the scripts in C#.

I am adding gamification in a form of competition between students, e.g. who can complete a routine of sorting algorithm faster. The way it is going to work is as follows: students pick algorithm and according to that algorithm's rules they try to sort the array as fast as possible. There is going to be a leaderboard with people's names and their respective times. With this feature, I hope to encourage the students to try out the different sorting algorithms I have to offer and while competing with their fellow colleagues, they will figure out how they work.

VI. CONCLUSION AND DISCUSSION

Currently, my VR laboratory is capable of visualizing two algorithm sorts: bubble sort and quick sort. Both sorts are equipped with audio files that guide you throughout the visualizations. Should the students feel ready, they can turn on interactions with the sort, e.g. they can be manually choosing the pivot elements in the quick sort recursive calls. With this concrete option, they can see for themselves the difference in always choosing the worst pivot element possible versus the best element possible.

There are many possible extensions for this application. At first, I also wanted to create many more visualizations. The two next candidates would be insertion sort and shell sort. I still hope to finish those two before the end of June 2017. After that, more gamification elements would follow. For example, students could be the sort's guide and decide when and what action happens. This interactive mode would allow some level of competition, as there would be a leaderboard with the best times and students' names who achieved them. There is also room for some audio. Currently, there is no music playing in the background or when some event is triggered within the sort. All in all, there is a lot of room for improvement, not even mentioning special effects.

It is fair to note that a lot of time was spent learning how to program in a new language, new environment and with virtual reality as such.

There are no statistics between students who use this tool and those who do not, since the laboratory is still being developed and has not been previously tested.

However, as discussed in previous sections, visualizations have proven to be effective, as well as attempts at integrating VR solutions to educational processes. Therefore, I have decided that my application should merge both – visualizations and the VR technology.

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