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Software systems for simulation and visualization of abstract theoretical concepts

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Abstract

Abstract theory presented in a traditional way often causes apathy in students, while connecting it to something real and physical usually leads to greater interest and enthusiasm. This paper discusses the importance of using educational software systems in the teaching process, which are effective auxiliary tools for mastering complex theoretical constructions in engineering education. The introduction and adoption of new information technologies in learning and teaching has evolved rapidly in recent years. The role of technology in higher education is to encourage students to think about the problem of study and to enhance the educational process, not to reduce it to a set of procedures for the delivery of content. Therefore, this paper lists the essential aspects of software systems that are necessary for the system to be characterized as educational, that is, as a learning support system.
Keywords: *software systems, education software, learning support*

1. Interactive aspect of education

In order to achieve more effective pedagogical results, it is necessary to abandon certain stereotypes of traditional teaching, which implies verbal and one-way transmission of knowledge - the teacher teaches, the student listens. Modern teaching methods imply innovative approaches. Interactivity is the key to an effective and efficient teaching and learning process where the teacher can attract the student's attention and the students can learn more compared to the traditional method. Interactivity plays a crucial role in the acquisition of knowledge and the development of cognitive skills and that interaction is inherent in effective teaching practice and individual discovery. The term "interactive" appears in two different sets of educational research discourse, one related to pedagogy and the other related to new technologies in education (Beauchamp and Kennewell, 2010). Pedagogical interactivity refers to the interaction between teachers and students. The use of technology in education implies the effective integration of information and communication technologies (ICT) into the teaching process.

In his research, Wang (2008) proposes a generic model for the effective integration of ICT in the teaching and learning process. According to this model, pedagogy, social interaction and technology are key components of a technologically enhanced learning environment. Interactivity in such an environment can be represented graphically as in Figure 1.

In the digital era, students want more activity in class that is not limited to sitting, holding a pen and a book (Pradono, Astriani, and Moniaga, 2013). The introduction of interactive ICT-based tools can encourage students to self-motivate and direct their own learning (Evans and Gibbons, 2007). Also, these tools can improve learning because they allow users to control the learning process themselves and provide them with the ability to review content, skip and repeat as needed (Wang, Vaughn and Liu, 2011).

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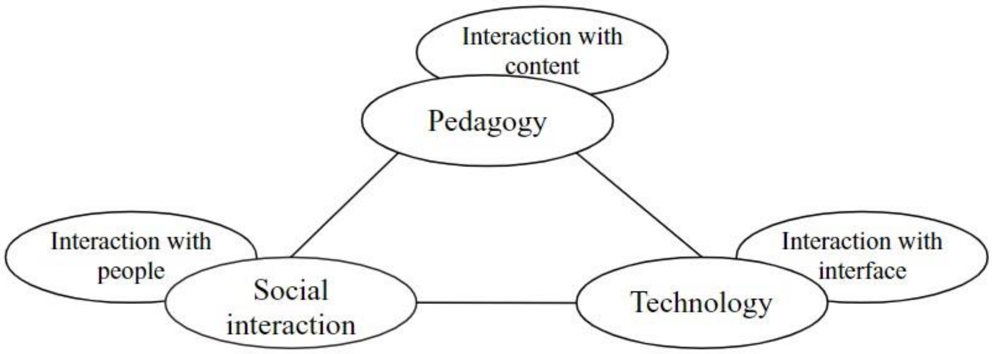
Figure 1. Interactivty based on Wang (2008) model



If the concept of interactivity on ICT is made concrete, then it can be said that the most important element of the interactive process is appropriate educational software. Today, educational software cannot be imagined without interaction. In addition to interactivity, the software used in education should have another important feature that can contribute to more effective transfer of knowledge, which is the ability to visualize the subject of study. Visualization and interactivity are necessary and expected components when talking about software applied in education.

2. Application of visualization in teaching

In the literature, a number of explicit definitions of visualization can be found, and mostly this term is used to describe the cognitive activity of imagination of visual representation. When defining the term visualization, Phillips, Norris and Macnab (2010) distinguish three different concepts:

- Objects of visualization are physical objects that a person observes and interprets in order to understand something other than the given object. Other sensory data such as sound can be integral parts of these objects and objects can appear on many media, such as paper, computer screen, slides;
- Introspective visualization is "the imaginative construction of some possible visual experience" in the absence of the object of visualization. Introspective visualization focuses on "mental objects projected in man's consciousness";
- Interpretive visualization refers to the interpretation of the meaning of objects of visualization or introspective visualization in relation to "existing beliefs, experiences and understandings".

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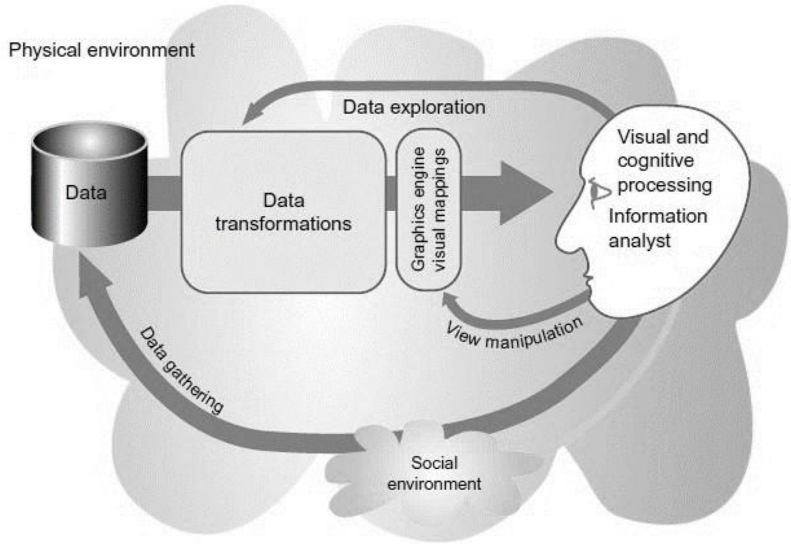
deas in the scientific and engineering world most often arise from visual and specific situations. The perception of reality is basically visual and in many cases man uses symbolic processing, visual diagrams and other forms of imaginative processes in order to gain an intuition of what in its formal aspect has an abstract structure (Díaz, Dormido and Rivera, 2015).

Kostić (2017) states in his dissertation that the cognitive-visual approach represents a modern didactic-methodical conception that promotes the visualization of the learning process in a multi-representative environment. Also, he states that for the optimal use of the potential of students' visual thinking, a stimulating visual environment for learning is needed, as well as that in the realization of the cognitive-visual approach, visualized tasks play a particularly important role.

In the last decade, with the accelerated progression of computing capacity and the advancement of graphic design technologies, multimedia learning environments have evolved from a sequential static framework for text and images to highly sophisticated visualization (Bétrancourt, 2005). Information technologies and specially designed software products open up new opportunities in developing the necessary skills and abilities of students (perceptual, mental, verbal, practical...) (Makarova, 2016). Therefore, it can be said that visualization triggers the imagination of students and deepens their understanding of certain contents.

A good visualization is not just a static image or a three-dimensional virtual environment. Ware (2019) believes that a good visualization is something that allows the viewer to drill down and find more data about anything that seems important. Ideally, every data object on the screen will be active, not just a blob of color. It will be able to display more information as needed, disappear when not needed, and accept user commands to aid in thought processes. Interactive visualization is a process consisting of a large number of interconnected feedback loops. A graphic representation of the data visualization process (Ware, 2019) includes four basic phases, combined in a large number of feedback loops (Figure 2).

Figure 2. Visualisation process according by Ware (2019)



3. Application of visualization in teaching educational software

Association for educational communications and technology (aect), the largest professional society focused exclusively on educational technology, the term "educational technology" means the study and ethical practice related to the creation and use of technological processes and resources in order to improving performance and facilitating the learning process (Rasmussen and Salkind, 2008). In practice, educational technology refers to several areas. One is the planning and installation of technology for education which, since the mid-1970s, has been mainly about computers for teaching and learning management. Another area of focus is educational software, while the third is focused on the processes and products used to design instruction. This actually refers to the process of planning, constructing and developing instruction, organizing and controlling learning, and applying cognitive psychology to instructional design, rather than physical hardware or a type of software. These activities are known as instructional design.

Educational software can generally be called any software that can be used in the educational process for teaching and learning. A more precise definition of educational software can be found in (Nadrjanski, 2000), where it is presented as software that includes programming languages and auxiliary tools, a specific organization of teaching and learning, and which is based on logic and pedagogy. This kind of software should be didactically designed to enable students to progress gradually according to their abilities (Odadžić, v., 2016). Today, educational software cannot be imagined without interactive capabilities that provide immediate correction of errors, the ability to return, repeat or retain certain elements of the teaching material, as well as determining the acquired knowledge.

The design of educational software involves the imagination, idea, elaboration and description of a computer system in relation to some pedagogical goals and various educational constraints that should be taken into account in relation to the environment in which the software will be used (Tchounikine, 2011). This technical programming phase can be performed from scratch or built upon existing software components.

If educational software is well designed, maximum individualization of teaching work is ensured (Popov and Jukić, 2006). Radosav (2005) believes that the design of educational software should take into account the following stages:

- Selection of content to be realized on the computer;
- Collecting the necessary literature and materials in written and electronic form;
- Material processing and designing;
- The programming process;
- Educational software verification – testing;
- Development of program documentation;
- Program evaluation.

There are different types of educational software, and classification can be done based on different criteria. Classification based on didactic-methodical criteria can be found in (Nadrjanski, Nadrjanski and Soleša, 2008). The authors distinguish several types of educational software on a given basis, where educational simulation software occupies an important place. This type of software allows some real or abstract theoretical systems to be represented by computer models and to simulate the processes of those systems. With the help of simulation, the structural and functional characteristics of the studied systems can be seen. Taher and Khan (2015) believe that simulation is an extremely powerful teaching tool when used in conjunction with traditional teaching. Educational software for simulation and visualization of theoretical systems is precisely the subject of research in this paper.

3. Use of software systems in education

Hamada and Hassan (2017) propose interactive tools to improve the learning process, i.e. computer environments that integrate different groups of software modules, allowing students to experience learning topics in a simple and expressive way. Educational software should enable multimedia access to teaching contents, as well as their easier and more successful understanding and adoption. The teaching and learning process will be more efficient and interesting by encouraging students to be more proactive and creative in class. An interactive class implies greater engagement of students by using appropriate media for learning, usually simulation software or a system for the visual representation of algorithms, as a two-way communication between teachers and students. In this way, the visualization of textbook content attracts students' interest so that they can master the material faster and easier and later apply what they have learned (Dewi et al., 2018).

There is more research dealing with the study of algorithmic visualization systems, a more comprehensive review can be found in (Shaffer et al., 2010). A large number of authors in their research papers present results that confirm the hypothesis that the use of such systems increases student engagement and positively affects learning efficiency. Hansen et al. (2002) found that in some cases the results of using animation to teach algorithm behavior were unsatisfactory, not because of a flaw in animation as a learning tool, but because of the approach used to convey the animations. They believe that visualization is a really powerful tool for effectively conveying the dynamic behavior of algorithms, but that it is necessary to design algorithmic animations well with the application of appropriate pedagogical norms. Relying on research on cognitive science and human-computer interaction, they developed an architecture for multimedia presentations of halvis algorithms and showed that the degree of learning among students who used halvis was significantly higher than among those who used traditional teaching tools. Velazquez-iturbide et al. (2013) prove the hypothesis that the application of explicit pedagogical goals increases the quality and effectiveness of the visualization system, and therefore, from the programmer's point of view, the requirements for visualization and interaction can be identified more easily. Implicit goals also arise from explicit goals that expand the range of tasks supported by the visualization system.

Simulators as educational tools to aid learning have attracted considerable attention, as evidenced by numerous scientific papers (Lindgren et al., 2009) that talk about the positive aspects of their use. Rutten et al. (2012) review a large number of experimental studies on the effects of software simulations in teaching that have been published over a decade. A large number of studies reviewed in this paper compare working conditions with and without simulations, showing positive results in favor of using simulations to enhance traditional learning methods. Simulations offer students the opportunity to follow the consequences of their choices through a graphical demonstration of abstract concepts, where they may be asked to use mathematical, observational, and note-taking skills. Thus, simulation software tools allow students to experiment with theoretical constructs, giving them immediate information about the results of the experiment.

It is already well known that games can also be used for educational purposes. Pivec et al. (2004) describe game-based learning as an innovative educational paradigm that is considered fit for purpose. Relevant authors in the field have published excellent articles describing the notion of "play" as a natural way for human beings to learn, proving how games can be considered "serious" didactic resources for any stage - learning context (Gee, 2004).

In recent years, software tools to aid learning have become present in all phases of education. Educational software systems are available today for almost every field of science. A large number of simulation systems are used in the field of electronic sciences, renewable energy sources, microbiology, genetics , surgery. Software systems are successfully used for learning mathematical algorithms, probability theory, statistics, graph theory. Also, learning support systems have found application in the field of musical arts, for example for playing the violin, the piano, as well as composing music (Farbood, Pasztor and Jennings, 2004).

4. Conslusion

Educational software systems are developing rapidly, especially in the field of computer engineering. Jovanović et al. (2019) present simulation systems intended for the study of computer networks. An educational computer system with a web-based simulator, designed to assist in the teaching and learning of computer architecture, was presented by Đorđević et al. (2005). Visual simulators have also found application to aid in the learning of data protection algorithms. A detailed analysis of a number of systems for visualizing artificial intelligence algorithms is presented in (Stamenković et al., 2023). The conclusion is that educational software systems are used in almost all scientific fields where they record positive results in terms of improving traditional teaching. Numerous authors also suggest them for learning topics in the field of programming translators to help bring many abstract theoretical constructs to life.

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