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Reseach Article

ROLE OF VISUALIZATION IN ENGINEERING EDUCATION

Renata Lis[1]

[1] Faculty of Fundamentals of Technology, Lublin University of Technology, Nadbystrzycka 38, 20-618 Lublin, Poland, e-mail: r.lis@pollub.pl

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ABSTRACT
The article includes an analysis of the results of research on the influence of visualization on the effectiveness of training. It analyzes the application of visualization in engineering education with a particular focus on visual design principles. Examples of the use static and dynamic visualization in multimedia learning in technology and computer science are presented.

Keywords: visualization, visual design principles, multimedia education.

INTRODUCTION

The development of new information technologies affected the way of providing and assimilating information, focused on a monitor and digital environment rather than a book and a piece of paper. New media require having not only the abilities of reading and writing but also the so-called new abilities – visual literacy and digital literacy [8]. This situation forces a change of manner in conveying knowledge by education establishments. More and more information, provided in an inappropriate way, causes information overload. According to researches, information visualisation enables to convey knowledge in a condensed manner, increasing its assimilation, compared to traditional text transmission [15].

INFORMATION VISUALIZATION

The term 'visualisation' is defined in many ways [3]. However, the dominating one is that of perceiving it as a mental process occurring while thinking and as an iconic representation. The first case concerns a mentation which occurs during perception of visual phenomena supporting visual/spatial thinking; the second one – a presentation of information, knowledge, processes with the use of static and dynamic pictures. In both cases, we can distinguish the following types of visualization:

- infographics,
- visualization representation of numeric values,
- visualization concepts, procedures, processes,
- architectural visualization,
- 3D visualization [15].

The general distinction divides visualisation into a static and a dynamic one. Static visualisation includes:

- illustration – a presentation of visual elements using various media and such techniques as a hand drawing, a painting made with oil paint or a computer graphic;
- photograph – a faithful reflection of the state of affairs;
- 3D model – a digital reflection of the reality;

whereas the dynamic one consists of:

- animation, understood as a series of pictures simulating motion;
- video, which means a series of pictures in a video technique;
- interactions, i.e. pictures triggered by a user [3].

The sole ability of using advanced graphics software is not sufficient for correct designing education animations, drawings, diagrams and multimedia presentations. What is needed is the understanding of cognitive processes occurring while visualisation perception [5].

RULES OF VISUAL DESIGN

Rules of visual designing originated from the Mayer's theory of multimedia learning and gestalt psychology [11].

The theory of multimedia learning assumes that human brain receives information via two channels: a visual and a verbal one (see Figure 1). Such visual materials as: illustrations, photographs, charts and animations are processed in one channel and verbal information in the other. R.E. Mayer states that each channel has a limited capacity, therefore, it can process only limited amount of verbal and visual information in a specified time. Learning process occurs while processing information in information channels and organizing it into a comprehensive verbal or visual model and creating own knowledge in the final stage. However, cognitive overload often occurs, which is a result of inappropriate conveyance of knowledge by the teaching person.

According to the multimedia education theory, such rules as the following should be obeyed in the process of designing information visualisation:

- **the rule of contiguousness of visual and verbal contents** – visualisation helps the education process if the pictures and text layers of a message correspond to each other at the level of meanings [15];
- **the rule of personification** – didactic transmission should be personalised; messages should be written and spoken in the 1st and 2nd person and knowledge should be conveyed in a form of a dialogue;
- **the rule of modality** – visualisation is effective if supported by a narration; researches indicate that students who saw pictures and text and heard accompanying narration achieved up to 50% higher scores in the subsequent knowledge tests, compared to those who only saw picture and the text which was to be read in the screen;
- **the rule of logicality** – the researches of Mayer reveal that better results of education are achieved if additional sounds, recordings, videos or narrations which are not a direct element of educational program, are removed; seemingly, it can attract the pupil, but it was proved that they do distract and dissuade from the main transmission of the content;
- **the rule of interactivity** – it relies on frequent overloading the presentation screens with information; if part of the elements are included in an interactive form – opened on a click – the learner controls his/her own cognitive processes, therefore increasing the effectiveness of learning;
- **the rule of redundancy** – the researches revealed that the use of visualisation containing text, picture and narration causes an effect of visual channel overload, thus the materials are less clear than those containing e.g. only a picture and text;
- **the rule of signalling** – the structure of education materials creates a specified space; to emphasize the crucial elements and relations between them, signalling certain terms and relations between them is important; the researches of the author of the theory of multimedia learning reveals that the examined ones achieved better effects when the education material was divided into signalled elements than in the situation without them;
- **the rule of parallelism** – effectiveness of learning increases if visualisation and verbal narration occur not subsequently but simultaneously; asynchronous and non-parallel

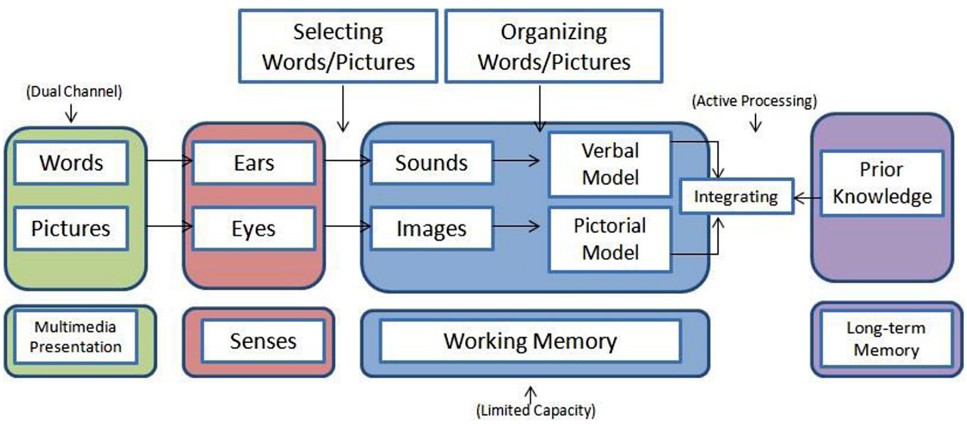

Fig. 1. Process of multimedia leaning R.E. Mayer [11]

occurrence of picture and verbal contents does not provide the learner a possibility of combining them in operating memory and relating them appropriately to the previous knowledge [9,11].

In the process of designing visualisations rules of perceptual grouping (which are described in laws of the gestalt psychology) are used.

- **Law of similarity** – elements with similar appearance are perceived as one. Eyesight groups unconditionally those elements which are characterised by similar relations resulting from the same shape, size or colour. This law is used quite often for selecting active links and buttons. Due to this issue, users have got no problem with navigation of these elements, they identify them upon the same features, e.g. colour which enables to combine them into groups.
- **Law of proximity** – the mind groups neighbouring elements. Approximation of appropriate elements increases the effectiveness of information perception. Application of such a mechanism improves the clarity of the material and facilitates the identification of the elements. The researches of G.H. Bower, M.B. Karlin and A. Dueck confirmed the suitability of using descriptions below pictures. Their experiment consisted in presenting pictures to a group of volunteers. Some of them only watched the presented works, whereas the second group not only saw the pictures but also had a possibility of reading their descriptions. The following stage of that experiment was to indicate the pictures which the participants saw among various ones. Obviously, the group who saw pictures with descriptions achieved better results. Due to the description, an observer can understand the presented content better [4].
- **Law of continuity** – it indicates that it is easier to perceive objects with soft shapes than those whose edges change sharply and rapidly. Objects creating lines or curves or any identifiable element, are perceived as connected with each other. A good composition is characterised by elements perceived as a whole despite the use of different colours or shapes. In this case, eyesight perception groups elements upon their location, not features. By using this law, recipient's attention can be directed towards specified elements [1].

Not only do the described rules and laws define how to design the visualisation. Having in mind the fact that every visualisation contains a picture, it is worth remembering the features of the picture which are related to strengthening the transmission.

EXAMPLES OF USES OF VISUALIZATION IN ENGINEERING EDUCATION

Visualisation is very significant in engineering education because this kind of education is a specific form which requires orienting towards the practical aspect of the described processes. For appropriate conveyance of knowledge a visualisation of a given process, e.g. friction one, is often necessary.

An example of application of visualisation in the education of future engineers in the technical and informatics education field of study is a multimedia course concerning technical mechanics with strength of materials created by a student of the above-mentioned field of study, as a part of its degree dissertation [7]. That course realises such issues as:

- calculation of friction factor with the use of inclined plane;
- calculation of efficiency of screw-nut system;
- analysis of stresses and calculation of G shear modulus (Kirchoff's) in a twisted pipe;
- examinations of deformations and stresses in a bent beam;
- static attempt of stretching the material;
- elastic buckling of a straight rods.

The course consists of many training screens containing static and dynamic visualisation in a form of photographs, illustrations and interactive pictures (Figure 2). It presents photographs and illustrations of research stations enabling conducting individual lab classes on technical mechanics. A simulation of operation of the individual research stations was included.

Another example is an interactive course of architectural modelling in Autodesk 3ds Max 2013 software, where an interactive visualisation and visualisation of procedures are very significant. Students deal with a simulation of operation of an actual 3ds Max software. Initial training screens have static visualisations in a form of screenshots of its interface, the next ones – interactive exercises relying on dynamic visualisation (Figure 3). This course requires a constant com-

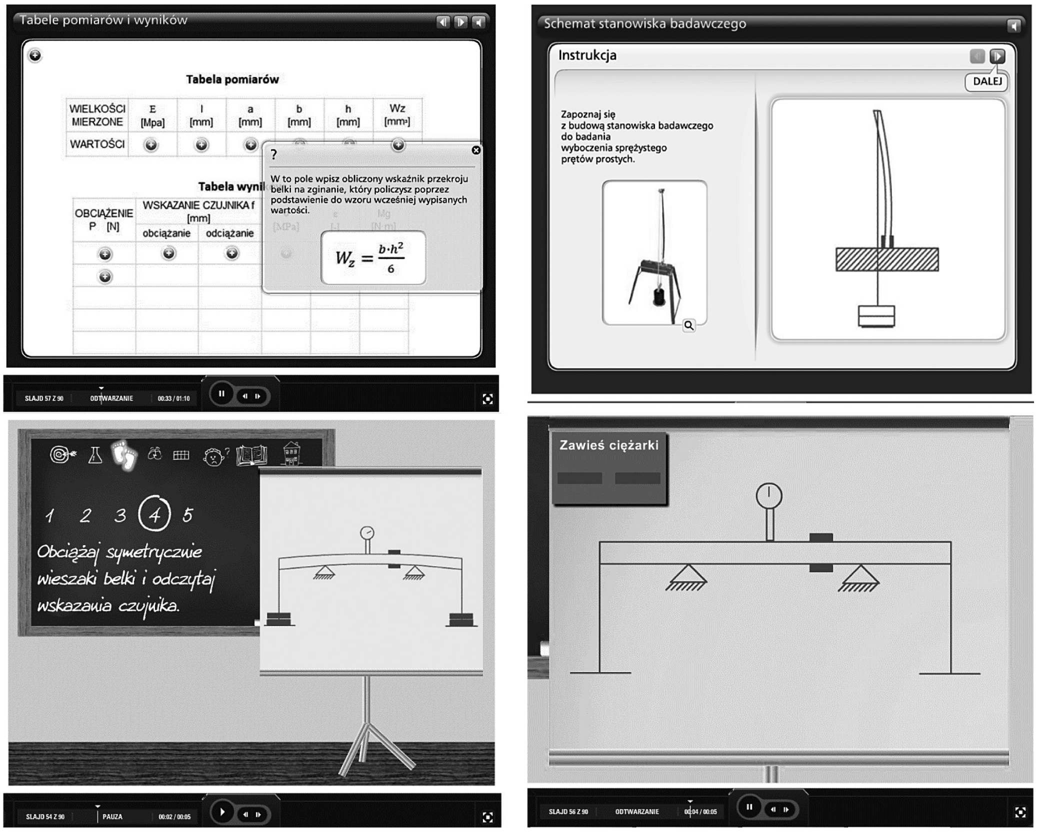

Fig. 2. Training screens containing visualisations from the course of technical mechanics with strength of materials [7]

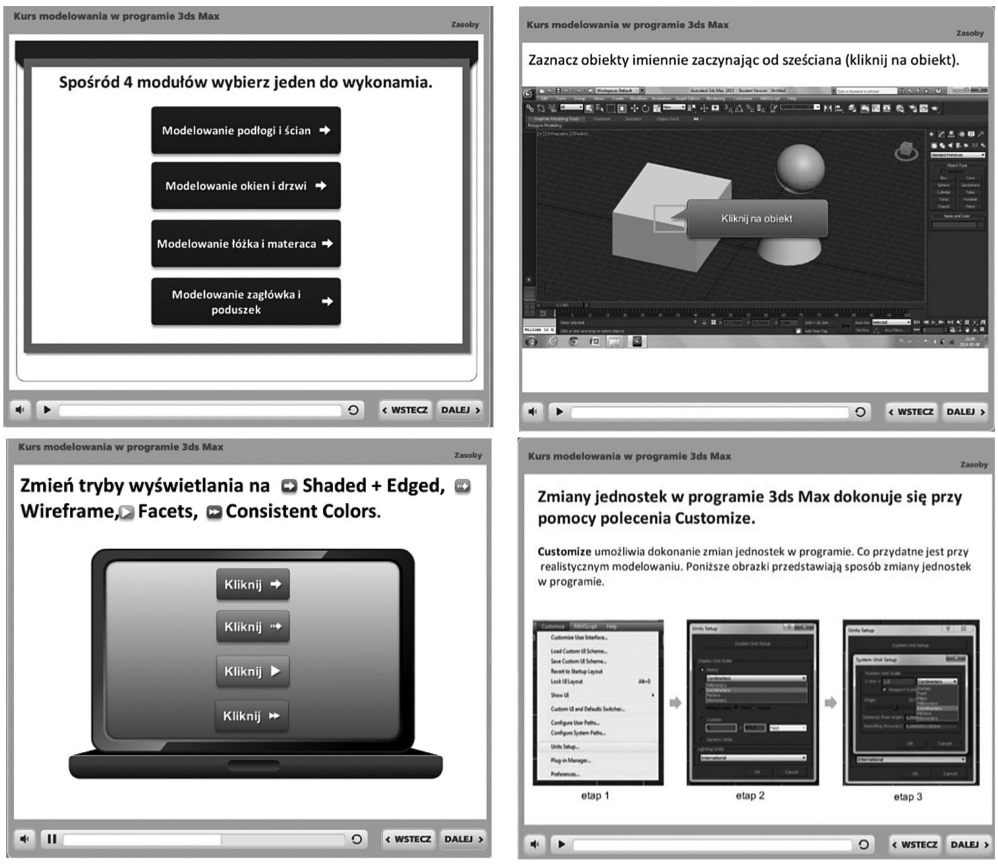

Fig. 3. Training screens containing visualisations from the course of architectural modelling in Autodesk 3ds Max 2013 software [6]

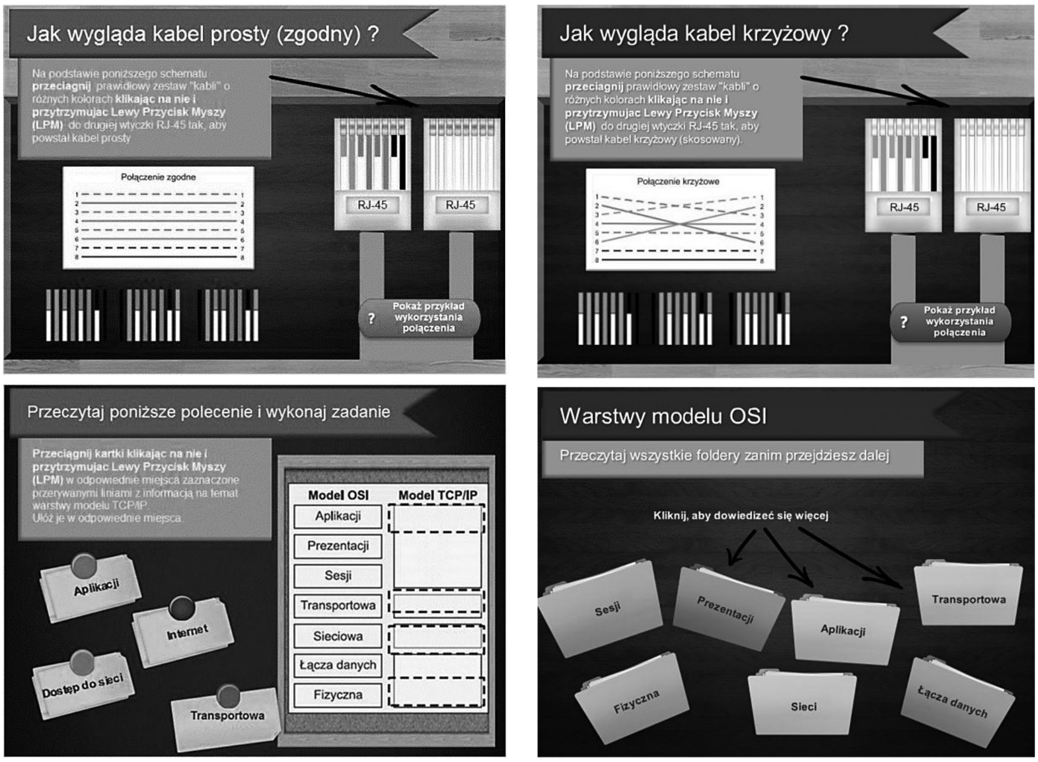

Fig. 4. Training screens from computer networks construction course [10]

mitment from students. If they do not click on the given option appropriately, they will not be able to proceed to the next screen, thus to complete the course. The range of the course comprises of basic knowledge on 3D modelling, 3ds Max 2013 software interface and utilitarian object and room modelling [6].

The last example of application of visualisation in engineering education concerns computer networks construction course [10]. It presents such issues as: computer networks topology and TCP/IP and OSI models, terminating cables, elementary hardware for designing the network, what an IP address and subnetwork mask are and area-based classification of computer networks.

The presented examples of multimedia courses became a subject of author's own researches, concerning the impact of visualisation on education effectiveness in technical and informatics courses.

VISUALISATION IMPACT ON EDUCATION EFFECTIVENESS RESEARCH

Education effectiveness is understood here as a level of implementation of the presumed didactic aims and the following knowledge increase indicator was used for measuring it [4]:

$$PW = \frac{Wpost - Wpre}{Wmax - Wpre} \times 100\%$$

where: PW – knowledge increase indicator,

$Wmax$ – possible maximal score of the researched one's competence measurement,

$Wpre$ – score of the researched one's competence measurement before the didactic process,

$Wpost$ – score of the researched one's competence measurement after the didactic process.

In the researches conducted by the author, the measurement of competence was made in a form of filling in a test of knowledge of a given range which was a part of the multimedia course. The researched ones had to fill it in before attending the course (a pre-test) and after it (a post-test). The acquired data were the basis for calculating the knowledge increase for each participant using the presented formula. Therefore, the data was averaged for the researched group.

In the case of multimedia course of technical mechanics [7], the researches were conducted in 2013 on a group of first-year students of the technical and information technology education first-cycle studies. Students were divided into two groups, one of which had got a task of acquainting with a course containing static visualisations in a form of photographs and illustrations as well as dynamic visualisations in a form of interactions and animations, and the second one – with materials containing the same issues but in a form of text. The test of initial knowledge (the pre-test) and of eventual knowledge (the post-test) was carried out in both groups. The tests were the same for each group and consisted of 9 questions. Single choice questions were used. For each correct answer a point could be scored. Maximal achievable amount of points were 9.

60 respondents participated in the research, 30 people per group. The first of the examined groups consisted of people who had got the task of completing the course containing visualisations in a form of pictures and interactions. The task of the second one was of completing the course including only text element. Essential content of both courses was the same.

Table 1 presents the average scores achieved by the researched in the pre-test and in the post-test as well as the percentage knowledge increase in the individual groups.

In the group participating in the course without visualisation, the result increased by 2.1 points, whereas the knowledge increase, calculated with the use of the formula presented earlier, was 43.6%. In the second one, which participated in the course with visualisation, the knowledge increase was very significant, because it was 82.35%. The points average increased by 4.7 points. Therefore, the impact of visualisation on the level of assimilated material in the range of technical mechanics is significant. Students participating in the course with dynamic visualisation assimilated almost 40% more information than those in the one without it.

The next experiment concerned the impact of dynamic and static visualisation on the level of knowledge in the range of architectural modelling in Autodesk 3ds Max 2013 software [6]. Those were conducted in a computer room of The Faculty of Fundamentals of Technology at Lublin University of Technology with the participation of second-year students of the technical and information technology education first-cycle studies in the Spring Semester of 2014. Two lab groups were examined, a total of 33 people. The first group, 15 students, was asked to complete a course containing static visualisation in a form of illustrations and photographs; the second one, 18 people, attended to a course including dynamic visualisations in a form of animations and interactions. The test consisted of 7 single choice questions; maximum achievable amount of points was 7.

Table 2 presents the average scores achieved by the researched in the pre-test and in the post-test as well as the percentage knowledge increase in the individual groups.

The students participating in the course with static visualisation achieved 67.60% knowledge increase in the range of architectural modelling and the points average increased by 3.27. In the group with the course containing dynamic visualisations, increase of points was similar at 3.39 and the knowledge increase indicator equalled 69.63%. Therefore, students

Table 1. Average scores from the tests in the researched groups and percentage knowledge increase indicator after the participation in the course of technical mechanics

Type of educational material	Type of test	Average points scored (max=9)	Increase of knowledge
Course without visualization	Pre-test	2.4	43.60%
	Post-test	4.5	
Course with dynamic visualization	Pre-test	2.3	82.35%
	Post-test	7.0	

Table 2. Average scores from the tests in the researched groups and percentage knowledge increase indicator after the participation in the architectural modelling in Autodesk 3ds Max 2013 course

Type of educational material	Type of test	Average points scored (max=7)	Increase of knowledge
Course with static visualization	Pre-test	1.73	67.60%
	Post-test	5.0	
Course with static and dynamic visualization	Pre-test	1.61	69.63%
	Post-test	5.5	

Table 3. Average scores from the tests in the researched groups and percentage knowledge increase indicator after the participation in the computer network construction course

Type of educational material	Type of test	Average points scored (max=7)	Increase of knowledge
Course with dynamic visualization	Pre-test	0.9	86.35%
	Post-test	5.6	
Course without visualization	Pre-test	1	39.87%
	Post-test	3.56	

participating in the course with static visualisation achieved similar scores compared to those participating in the course with visualisations including not only illustrations but also animations and interactions. It can be concluded that – in the case of 3D modelling issues – the impact of introducing dynamic visualisation on the level of assimilating knowledge is minor, because it is quite expensive and time-consuming in its preparation.

The last course of the ones presented in this article concerned the computer network construction [10]. The research on visualisation impact on the level of knowledge in this range was conducted in the Spring Semester of 2014 at The Faculty of Fundamentals of Technology at Lublin University of Technology among the second-year students of the technical and informatics education first-cycle studies. They were divided into two groups which were independent from each other, each one having a task of completing a course containing dynamic visualisations or one without them. The text content of the course was the same in both cases. A total of 50 people participated in the research, 25 per each group. Table 3 presents the scores achieved by the researched in the pre-test and in the post-test, as well as the percentage knowledge increase in the individual groups.

The examined who participated in the course without visualisation in the range of computer network construction achieved an average knowledge increase by 2.56 points. The average knowledge increase was 39.87%. The second group, which was participating in the course with visualisation, raised its score by 4.7 and the knowledge increase was as high as 86.35%. Probably, numerous interactions and animations included in the course had a strong impact on that score.

The presented results of the researches have a preliminary and partial character. However, they can provide certain hints for designing visualisations and multimedia didactic materials.

CONCLUSIONS

The conducted researches aimed at specifying how the application of visuals in engineering education affects the effectiveness of acquiring knowledge and if dynamic visualisation is more effective than the static one.

The presented analyses reveal that the application of visualisation in the multimedia technical and informatics courses improved the assimilation of knowledge in that range significantly. In the case of the two courses, in which the scores of students participating in the course with visualisation and those in the one containing only a text version of the materials were compared, the average increase of knowledge equalled 40%. Whereas in the research carried out among the students participating in the courses including visualisations but varying in dynamicity no significant differences were observed. It can be presumed that a high importance on the level of knowledge increase among the participants of the courses containing visualisations was the sole matter of the courses, convergent with their field of studies as well as completing the courses in accordance with the rules of multimedia education.

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