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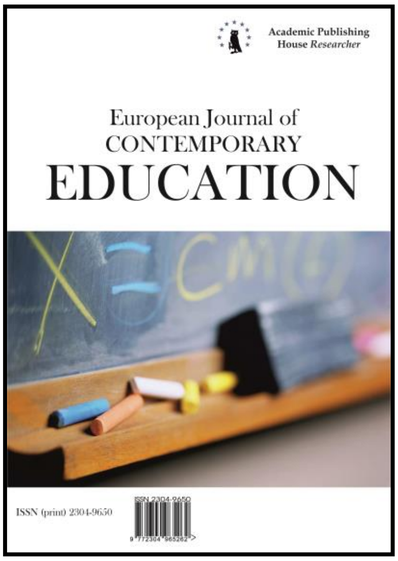

The Applicability of Visualization Tools in the Meta-Design of an Educational Environment

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Abstract

At the stage of designing an educational environment, one of the most significant problems is the creation of effective visualization tools for collecting, organizing and analysing educational information. Existing approaches to visual information analysis have a number of disadvantages, which include a significant resource intensity and high requirements for preparation for those who are involved in the analysis. This article demonstrates the feasibility of using visualization tools for the design assessment of educational environments, which enables the development of necessary tools for tasks with a large amount of educational information, as well as in the event of their change or accumulation. The purposeful use of visual perception features and the proposed approach to the organization of educational activities create perspectives for visualization tools, while working with a large amount of information. A number of features of a student and educational environment interaction have been identified, which are designed according to the principle of meta-design.

Keywords: visual information, visual analysis effectiveness, perception, meta-design, educational environment.

1. Introduction

The general direction of information and network technologies development runs parallel with user involvement in active cooperation. The Internet is a platform on which people can not only receive information, read news, and listen to the radio, but also self-educate and collaborate with another people. Such a model of activity is being implemented today in areas such as management, business, education, marketing and trade. There are no obstacles left to obtaining the

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necessary skills and tools for creating visual, musical, interactive or educational content. Restrictions on distributing new content to an interested audience are quickly disappearing. The educational environment is becoming increasingly accessible, and the only thing that is required nowadays from a person is the desire to learn and create.

The inclusion of a student in constructive activities, when he or she uses not only prepared educational resources, but also actively participates in their development, ensures the task is appropriate to his needs and learning environment creation. However, an increase in volume of information, including collecting processes, systematizing processes, information processing and analysing and, accordingly, the information equipment a person possesses, confronts developers with the problem of creating tools that can increase the speed of educational material assimilation. Thus, in the last decade there has been a transition from educational environment design to meta-design.

2. Discussion

Definition of educational environment metadata

The philosophy of "pedagogy of social constructionism", which unites the ideas of constructivism and social constructionism and was developed by the work of L.S. Vygotsky, D. Dewey, J. Piaget, E. Glasersfeld (Vygotskij, 1991; Piazhe, 2003; Glasersfeld, 1978) is expedient for developing a learning environment by the principle of meta-design. These directions show the main ideas and principles of humanistic pedagogy, which were developed by people, as mentioned above and also by S.L. Rubenshneyn, K. Rogers et al (Roghers, 1994; Rubinshtejn, 2002). The student's cognitive activity, his personality, abilities, intellect, features of development and perception are at the centre of the educational process developed by this approach. In this context, a teacher acquires a new status – that of a designer, a mentor, an organizer and a partner in the trainee's cognitive activity. At the same time, previously dominant interaction models, which featured a strong separation of "designers" and "users", are transformed into a model of cooperation: "designer-teacher" and "co-designer-student". Thus, meta-design (Fischer et al., 2006) is an evolving approach that uses information technology to promote education and development as support for collaboration and communication.

Within the framework of humanistic pedagogy, an educational process is considered a trilateral active one: the teaching subject is active, the learning subject is active and the environment between them is active (Vygotskij, 1991; Hutorskoj, 2008). Such a process assumes that by interacting with an environment, a person develops himself and changes the environment. One of the advantages of meta-design is that the basis of any learning is an interpretation of received information through the prism of previously acquired knowledge. This means that learning is much more effective if a student creates something for others, and conveys his knowledge and experience. A person is not considered as a product of an environment and an idea of personality is formed, as a product of human interaction with an environment.

In the pedagogical context, modern meta-design involves educational activities' planning in such a way that students can not only be passive readers and viewers, but also active content creators. Because of the students' directed actions, an environment should be created in which users can implement their own digital histories and models and, based on these, form unique teaching content. Meta-design social aspect expands this definition to the level of interaction in groups. Meta-design development makes it necessary to formulate and to substantiate fundamental laws that characterize students' interaction with the reality full of information.

Problems of learning environment formation

The concept of a "learning environment" in pedagogical science shows the interconnection of conditions which ensure human development (Vygotskij, 1991; Hutorskoj, 2008; Averchenkov et al., 2015). The learning environment acts as a dynamic system, which is an integral set of educational situations that progressively replace each other. A system of psychological, pedagogical and didactic conditions and stimuli arises, which puts a person in front of necessity of a conscious choice, adjustment, formation and implementation of his own learning model, that means independent educational activities' implementation.

Issues of learning environment organizing, of creating an environment and tools that consider the individual characteristics of a student, and of multi-channel and multi-sensory perception, become relevant for organizing a sequence of educational situations characterized by high efficiency. Educational process effectiveness, in this case, is the formation speed of the system of knowledge necessary for a student.

Educational environment formation occurs sequentially in stages, through the accumulation, synthesis and systematization of educational information. This allows the accumulated resources to be used not only for those who participate in its creation, but also to further students. A teacher, while developing a learning environment, is a moderator and a mentor who creates analysis and the communication tools necessary for the integration and adaptation of educational material. To make a student an active participant in the educational process, it is necessary to have tools that will allow an educational trajectory to be formed independently and its effectiveness to be evaluated.

The problem of the selection and analysis of available information is a modern and relevant one. Not all available data is valuable – according to the IDC, by 2020 useful information will make up only 35 % of all generated information (BigData, 2013). Accumulated educational information is poorly structured and not fully utilized. Therefore, there is a need to use such tools that will allow the collection, systematization and analysis of educational information with high efficiency. One of the perspective areas in the development of operational information analysis tools is specialized visual analytics tools' development, which purposefully takes advantage of visual perception.

The multisensory approach means learning based on the perception channels of all senses: hearing, sight, touch and smell, which makes new material perception and memorizing easier (Gardner, 1993). While creating meta design tools, it is advisable to focus on visual perception, which is dominant for most students. Strengthening the perception of the visual channel is one of the possible implementations of the multisensory approach in meta-design.

This theory has great significance for pedagogical science in general, and for the presented work. This statement originates from the results of the research conducted by the authors to solve the problem of creating educational information visualization tools aimed at increasing selection effectiveness and speed, educational information systematization and assimilation.

Visualization of information

In the case of the traditional approach to attracting visualization capabilities, the task of interpreting visualized data could be solved only in exceptional cases, characterized by high level formalization and by experience in studying similar issues. A possible direction for visual analytics development is the creation of visualization tools that use the cognitive potential of interpreting dynamic images (Shklyar, 2016). In this case, dynamic means not only informative characteristics, containing information depending on time, but also any values whose interpretation is carried out by comparing different values. Existing visual analytics creation approaches mostly do not use the visual perception features of changing visual images, which significantly differ from the observation of static images, and could become the basis for increasing the effectiveness of educational information usage.

A practical study of visualization capabilities in meta design is associated with the need to match visual analytics with scalability requirements. The reason for this is the widespread need to reformulate an existing task of researching data into an individual version of studying only a fragment of data or, even more difficult, into a version with data accumulation. Visualization usage as an analytical tool offers a natural solution to this problem; for example, through the use of targeted visual perception features, providing a simultaneous holistic perception of information related to different objects, but combined in a visual field into a generalized informative image (North, 2006).

Visualization tools effectiveness

The comparison of visual analytics opportunities with other approaches implies the existence of a quantitative measure that allows a conclusion to be made in favour of one of the compared options. The duration of procedures, which exist while developing or using visualization tools, might be the simplest numerical evaluation. However, the need for a high level of processing, transfer, accumulation, and usage of educational information processes formalization is an obstacle hindering the development of this approach.

The effectiveness of meta-design processes can be assessed by the amount of resources necessary for solving an educational problem. Based on this, and considering the diversity of efforts involved in data analysis, the importance of different types of used resources and their interchangeability have a valuable meaning (Sacha et al., 2014). To determine the effectiveness, along with the main types of resources – time and computing resources – It becomes relevant to consider efforts made by a person or a group of people to achieve the goal, including intellectual, physical or emotional efforts.

A visual data model

The model M in metadata D (a visual data model) is an object of visual perception (image), which is associated with this data according to the predefined rule F, i.e. M = F (D). Accordingly, the rule F, formulated on the basis of a number of additional factors, makes it possible to determine data visual image properties and is defined as a visual presentation function. Defined in this way, function F is a mean of influencing meta-design effectiveness and should be determined based on the need of its increase. The choice of the visual presentation function depends on data D properties, presented in an educational environment, in time constraints of an educational process and in users' characteristics $U = \{U_1 .. U_n\}$, which are essential for achieving educational processes goals.

Semantic interaction

The increase in the amount of data, which exists in an educational environment, is a characteristic feature of meta-design. One complication is that data models used for their analysis, selection or use have a natural limit, the excess of which renders previously developed means of interaction with information useless. A perspective direction could be the organization of cognitive and computational resources sharing (Endert et al., 2014). The advantage of systems focused on semantic interaction implementation is the adaptation of the data visual presentation function to the mental analytical structures of an observer. This allows for the combination of student's visualization metaphors and associative patterns, which creates conditions for reducing a visual model's complexity.

Visual analytics development in this direction necessitates the existence of a detailed understanding of functioning patterns of human thinking, which interpret visual information. In this case, it is necessary to move away from the model of cognition as a "black box" which receives perceptual data, and where knowledge integrated into an existing system of human concepts is formed at the output (Chen, 2008). Thus, one of the actual tasks of meta-design is the study of multisensory information interpretation principles, especially its visual component.

Perception principles

Perception is a process that provides individual communication with external information sources. In addition, perception could be defined as the result of the direct effects of objects or phenomena on sense organs (Wijk, 2005), which act as information external sources analysers. Among the existing types of analysers responsible for vision – hearing, touch, smell, taste and kinaesthesia – the visual channel is the most informative and loaded one.

External objects' images that appear as a result of perception are a subjective form that includes, in addition to data from analysers, aspects of an individual attitude to an object: interest, motivation and emotional evaluation (Mazza, 2009). The possible influence of subjective factors on the image of an external object leads to the variability of this image in time or to a fundamentally new result of revaluation. Thus, visual models' interpretation by a student (user), aimed at understanding their meaning, as well as at extracting new knowledge, depends on both the visual image objective characteristics and individual characteristics.

Visual perception is one of the perception types in general and has a number of common characteristics. Generalization, objectivity, integrity and constancy of perception should be referred to as essential for substantiating visualization possibilities. The reasonable management of the created visual image properties, considering the characteristics mentioned above, enables visualization interpretability to be controlled. Thus, the reasonable usage of perception subjective aspects creates conditions for increasing the effectiveness of meta-design processes.

Visual examination time

The value of K_A is the amount of new information received by a user while searching and formulating an answer to his existing question using visual data models. New information is the result of the user's interaction with the visual data model, i.e. the message received for a limited time T_A.

$$K_A = \int_0^{T_A} P(I, K, t)dt = K_A(T_A),$$

where P (I, K, t) — is the function of visual perception, K — is the amount of user's knowledge, and I is the perceived image, which is a visual data model. The visual perception function P is considered bounded, piecewise continuous and increasing.

The value of $K_A(T_A)$ could be defined as the cognitive (informative) value of the visualization interpretation process and, accordingly, T_A is studying time, i.e. the time interval spent by a user to achieve the goal of the study. Therefore, an inverse relationship could be defined for time T_A spent on achieving the solution:

$$T_A = T_A\ (P, K_o, S),$$

associating solving time T_A with the task complexity K *, the initial amount of user's knowledge K_o, the process of interpreting P (I, K), and the visual presentation function S = S (t). Thus, a quantitative measure, which allows the visual model's capabilities to be evaluated, might involve an analysis of time T_A, which depends on the task for which solving the visual model would be used, as well as depending on the capabilities of a particular user.

Quantitative assessment of information in a received message, if it is even plain text, is a task that can be solved differently. It is necessary to take into account the fact that the sequence of measured information units that make a message do not determine its overall information value, since for a recipient of a message, this value is subjective (Cui et al., 2007). Therefore, determining the analysis time as a measure of visualization effectiveness allows the problem of measuring the visualization informative value while choosing a visual presentation function to be circumvented.

10. Experimental evaluation of visualization tools' effectiveness

Based on the introduced definitions, the visual interpretation processes effectiveness – which is the basis of meta-design – and a time-dependent value, the main task for data visualization tool developers is to reduce the time spent at any stage of interaction with educational information (Shklyar et al., 2018). Thus, in order to assess visualization tools' effectiveness in educational meta-design, it is necessary to have an idea of the dependence of research time on any factors that have a significant impact on it.

To obtain data which will allow the merits of a particular visual presentation function to be evaluated, the methodology for conducting test solutions has been developed. The proposed technique is about conducting a series of solutions for test problems, characterized by a number of controlled constraints, and measuring time intervals corresponding to the stages of the user's interaction with the visual model. The user's interaction with the model, in this case, implies any operations available to a user, with the exception of changing the visual presentation function and the set of visualized data (Figure 1).

A test solution involves creating a visual data model using the predefined visual presentation function. A user is allowed to formulate an unlimited number of hypotheses for answering the question; each hypothesis is considered to be the next step of the analysis. The formulation of the correct hypothesis means the completion of a problem's solution. Measurements of time intervals spent by a user on the formation of each new hypothesis showed the presence of characteristic stages of deceleration and acceleration during the solving of the analysis problem for the majority of test measurements.

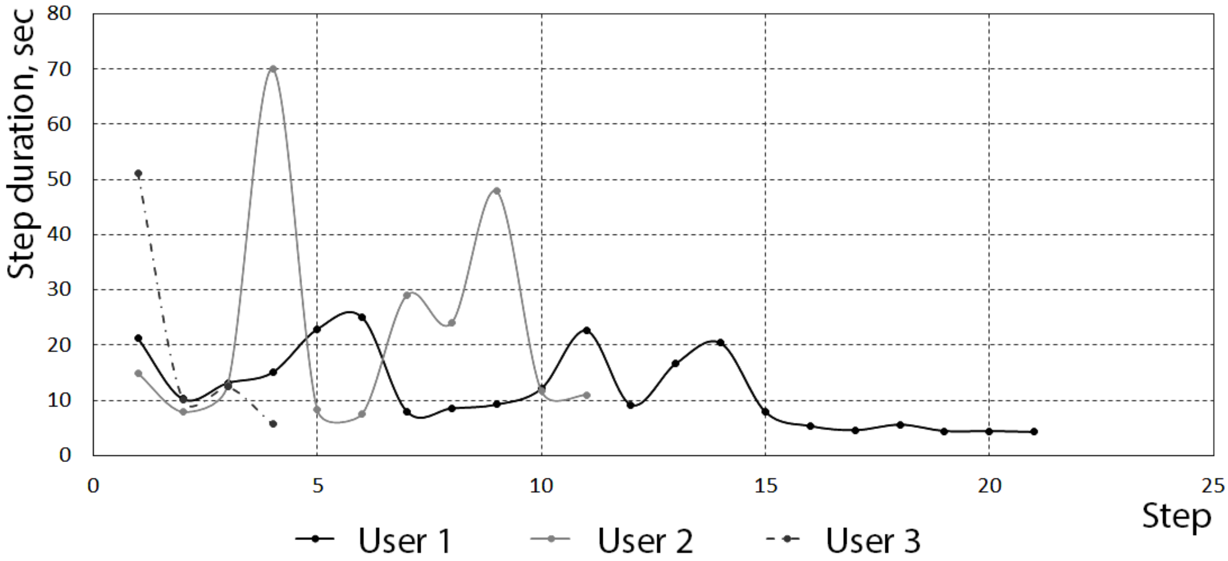

Fig. 1. An example of periodic change in visualization interpretation speed

The stages of the user's interaction with the visual model, during which the time spent on the next decision hypothesis formation is constantly reduced, could be interpreted as "learning" intervals. The reason for this is the time reduction taken to make a new decision if the previous hypothesis is erroneous. Thus, there is an accumulation of new information that is a consequence of the verification of hypotheses proposed by a user (Pirolli et al., 2005). Changing the level of awareness of the K user leads to a reduction in time for building a new hypothesis; however, after the accumulation of new information, as was demonstrated by the results of the studies, the next stage is rethinking, characterized by a significant slowdown in the process of building a new hypothesis (Figure 2).

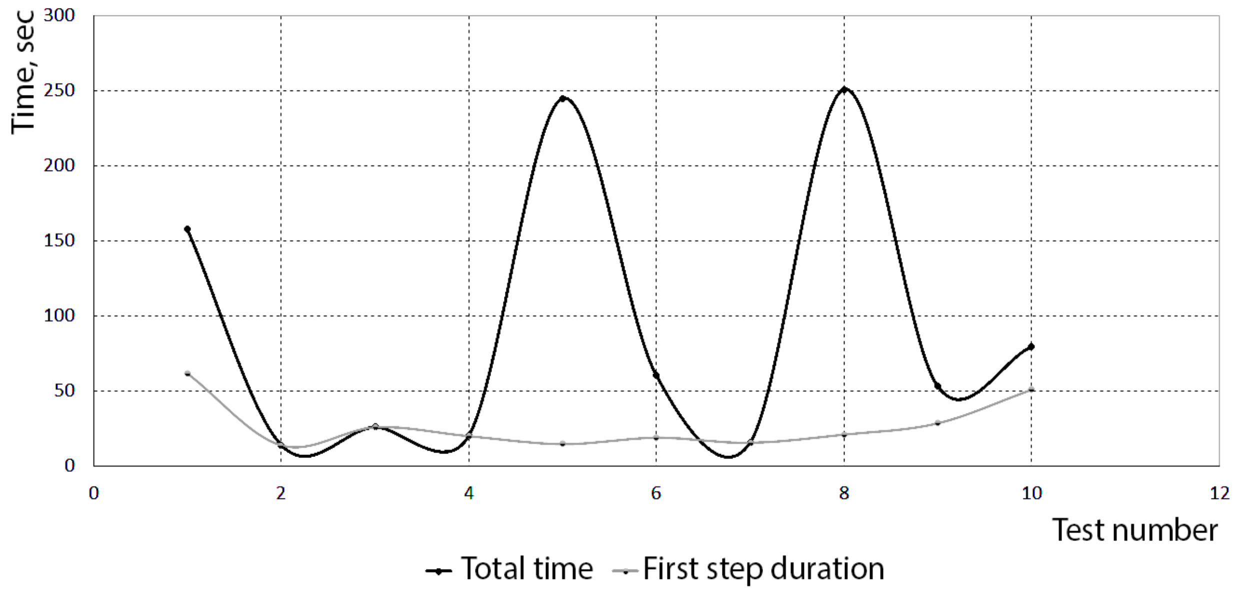

Fig. 2. A change in decision time for different presentation functions

The first stage has a particular importance in this case, which is characterized by an increase in a user's thinking speed, which is presented in most of the test measurements. Unlike the subsequent similar stages, during the first stage, a user is familiarized with the data image and with the visual presentation function features. This assertion is supported by the abbreviation of this stage when a user re-uses the same visual presentation function. Thus, the obtained experimental data could be used to determine the estimated values of learning intervals and information interpretation for the corresponding visual presentation function (Chen, 2005).

Visual model example

In an educational environment that uses meta-design principles, students participate in the systematization and analysis of educational information. The results of this activity are information visual models, the sources of which is also independent research. Models (images of information) are prepared for quick perception, with the possibility of using this model by other participants. As a practical example, the visual model has been proposed, which was used to evaluate student projects (Figure 3) (Shklyar et al., 2017).

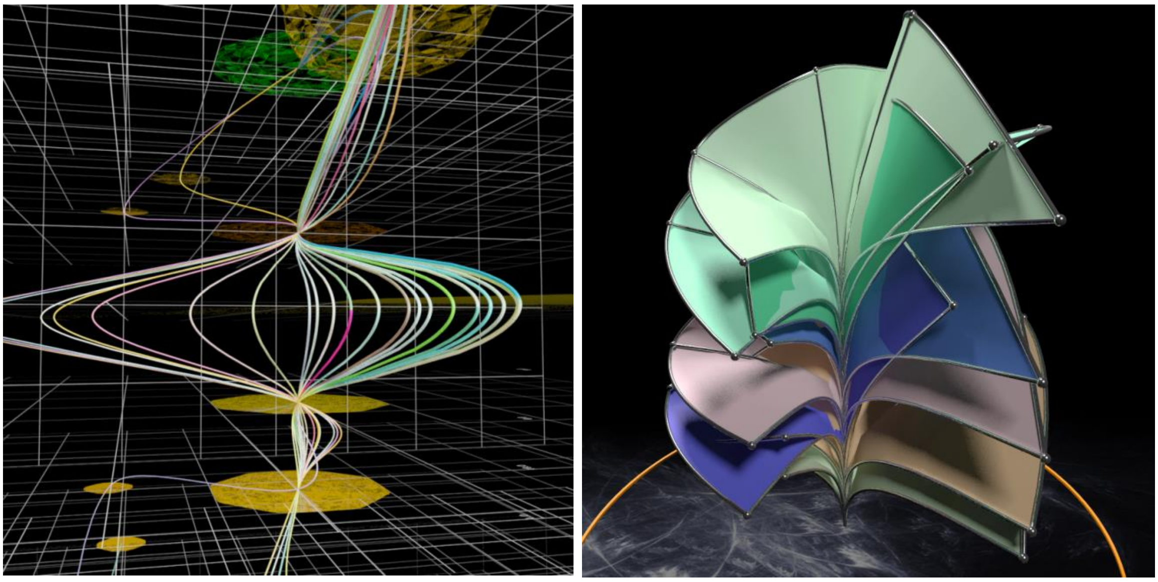

Fig. 3. Model of student projects evaluation

Informative objects that create a volume of visualized information are multi-criteria evaluations of the results of students' project activities. The developed model is a set of horizontal planes, each of which combines data which belongs to a separate property of informative objects. The plane is defined by two orthogonal scales. The main scale represents the nominal values of an individual property. The additional orthogonal scale is used for a visual comparison of objects with each other. Points of different planes that display properties of a single object are combined into a single image of this object, creating a unique visual image that is prepared for comparative analysis. The order of properties' images arrangement relative to each other is used as an independent scale, which shows significant degrees of the selected property for the analysis (Shklyar, 2016).

Based on the study results of visual perception potential in the interpretation of data patterns, the conclusion is that the use of specialized visualization tools in the meta-design of the learning environment is a perspective field. This allows students to increase effectiveness and selection speed, systematization and assimilation of educational information. Simultaneously with the use of visual content by students, a teacher is able to use the same visualization tools as active tools for updating content, as well as for analysing and interpreting the results of students' work in an educational environment.

3. Conclusion

In this article, a method was proposed for evaluating the feasibility of using visualization tools for meta-design, which allows the necessary tools to be developed for tasks that are characterized by the presence of a large amount of educational information, as well as in case of its modification or accumulation. Usage of the proposed method enables a learning environment to be built with the opportunity of benefits maximization for students. This will create a unified and interrelated environment for use in pedagogy, applicable to a wide and diverse range of educational purposes.

Experimental studies revealed a number of features of interactions between a student and an educational environment, designed according to the principle of meta-design. The purposeful use of visual perception features and the proposed approach to educational activities creates a perspective to use visualization tools while working with a large amount of educational information.

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