3D MAPS FOR EDUCATION PURPOSES: NEW CLASSIFICATION AND MODERN DESIGN

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Abstract
The relevance of work in the field of cartographic visualization is related to the global trend of transitioning to three-dimensional space modeling. The implementation of GIS and 3D graphics software in cartography has made it possible to produce high-quality 3D maps, including those used in education. However, the classifications of 3D maps and the terminology used to describe them are often contradictory, and the variety of software tools without an appropriate scientific and methodological basis creates difficulties in creating competent cartographic works. As a result of the analysis and personal practical experience in map creation, a new classification of 3D maps, cartographic models, and other geoimages is developed. The classification is fully applicable to educational maps. Cartographic products are considered in detail by methods of visualization and by the nature of user interaction with the 3D image. This paper also presents cartographic design principles relevant to 3D cartographic products for educational purposes, in particular 3D maps, formulated on the basis of experimental research.

Keywords: *3D map, classification, map visualization, education*

INTRODUCTION

Nowadays the demand for 3D mapping is increasing and the range of consumers of 3D maps is expanding. The changing perception of geographical information, along with the increase in data availability, necessitates new types of cartographic products with high-quality visualization. The use of information technologies in education makes it possible to teach at a higher level, integrating knowledge on the subject. Students feel themselves as active participants in the learning process, to obtain new skills, analyze, compare and be in constant search of new knowledge. Currently, digital 3D maps, which have interactive elements, allow one to examine the 3D cartographic model of the territory from different sides, to spin, to make a flight around the territory. Such maps are an excellent aid for studying landforms in the disciplines of the Earth Sciences module. 3D maps can be integrated into augmented reality (AR) technology (Šašinka et al., 2019).

GIS and 3D modeling technologies make it possible to create 3D cartographic products, but there is a mismatch between the level of technology development and scientific and methodological basis, and there is no unified methodological basis for three-dimensional mapping. Some of the existing classifications of 3D maps contradict each other. Therefore, in order to create a 3D educational map, it is first necessary to identify what 3D cartographic products are.

After determining the role and place of 3D cartographic products in the system of general classification of maps, it is possible to determine the place of 3D maps among educational cartographic aids. The next important stage is to justify the principles of cartographic design of different types of three-dimensional educational maps. Usually, they are set by cartographers for each product separately. This paper presents additional cartographic design principles for static, interactive and dynamic 3D maps for educational purposes. Previously, these principles were not mandatory when used to create 3D maps.

THE PLACE AND ROLE OF EDUCATIONAL 3D MAPS AMONG CARTOGRAPHIC PRODUCTS

In the previous work of the author a review of scientific research and publications on the topic of three-dimensional cartography has been made (Kovaleva and Baranova, 2022). It was noted that to date there is no unanimity of opinions of cartographic scientists regarding the unambiguous interpretation of the term "three-dimensional mapping" and the unified classification of 3D maps**.** As a result of the analysis, it was concluded that the conceptual apparatus fixes the tendency of shifting the emphasis from the result of geodata visualization to the computer technologies of creation of 3D cartographic images based on the use of spatial terrain models and interaction with them by the user in virtual space. Serious differences in approaches to the concepts of "three-dimensional" and "perspective" maps were revealed.

According to the author of this paper, the concepts of "three-dimensional" and "perspective" maps should be distinguished. Although they are often presented together, they generally characterize different aspects of visualization - the presence of the third dimension and the mathematical basis (projection) of the map. Not all perspective map projections create a sense of three-dimensionality. For this reason, we will not talk about perspective projections in this paper, but about perspective maps that are subjectively perceived as three-dimensional, such as panoramic maps.

The third dimension on a 3D map can be various indicators. The three-dimensionality of unfamiliar objects is more difficult to perceive, for example, the distribution of thematic indicators across the mapped territory (Fig. 1).

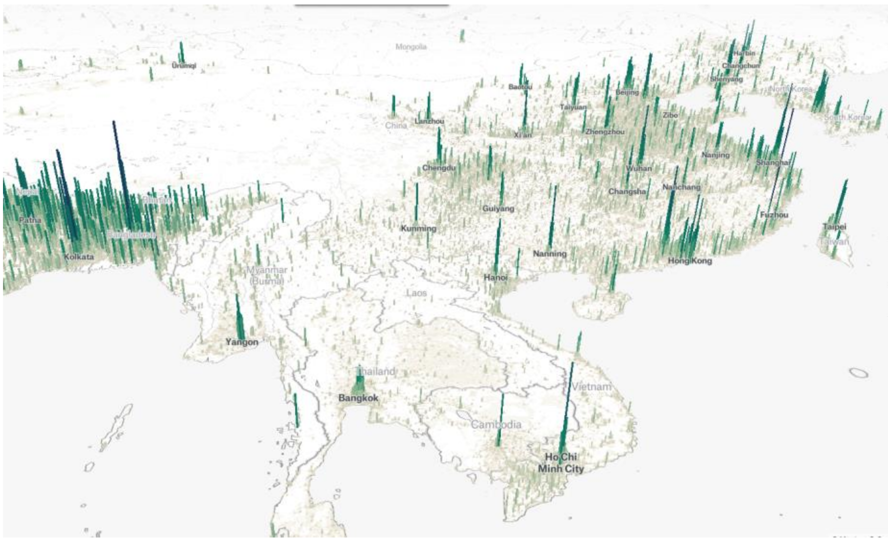

Figure 1. The fragment of the Human Terrain interactive map (https://pudding.cool/2018/10/city_3d/)

And a mapped object that is well known to the map user, such as the relief of the Earth's surface, is easily perceived. In geographic education, elevation and depth values are the main indicator. There are methods and ways of relief representation that allow visual imitation of three-dimensionality on the map: conditional-perspective, including physiographic and painterly methods; hatching method (hachures); shaded relief (achromatic and color hillshade, photo-relief, analytical hillshade); hypsometric (methods of illuminated contours and hypsometric coloring); methods of inclined and vertical cross sections; method of triangular irregular network (TIN); stereoscopic method (Vereshchaka and Kovaleva, 2016). In this case, when viewing a flat image, there is an illusion of a three-dimensional image. This approach is based on human perception of graphic information and is called perceptual.

Cartographic educational aids can combine several types of maps and may be available in both print and web versions. 3D cartographic models, cartographic animations, etc. are also used as additional teaching tools, so the author also considered these products. As a result of the study, a classification of 3D maps, cartographic models and other geo-images for educational purposes was proposed (Table 1).

Table 1. Faceted classification of 3D maps, cartographic models and other geo-images (Kovaleva and Baranova, 2022).

	Facets				
Facet values	A	B	C	D	E
	Applicate, z-axis (Third dimension)	Scale level	Projection type	Way of user interaction with 3D image	Methods of visualization

	A1 Height	B1 Small-scale	C1 Azimuthal perspective	D1 Tactile (or physical)	E1 Conditional perspective
	A2 Thematic indicator	B2 Medium-scale	C2 Perspective-cylindrical	D2 Using stereoscopic instruments	E2 Shaded relief
		B3 Large-scale	C3 Linear perspective	D3 Psychophysiological modeling of three-dimensionality	E3 Hypsometric
			C4 Theatrical perspective	D4 Interaction in a three-dimensional virtual space	E4 Painterly techniques
			C5 Axonometric		E5 Hatching
			C6 Other		E6 Inclined and vertical cross sections
					E7 Triangular Irregular Network (TIN)
					E8 Geometric modeling of buildings and structures

Column E in Table 1 outlines the primary methods of relief visualization. Other methods that give the illusion of three-dimensionality on the map are excluded from the classification due to outdated technologies of their use. A complete classification of methods and techniques of relief visualization is developed by Kovaleva (2012).

The faceted classification method used to create the author's classification reflects the analytical approach to map creation and is the most effective for machine data processing. Faceted classifications are characterized by information redundancy of groupings, in some cases impossible in terms of meaning.

Thus, the presented classification of 3D maps, cartographic models and other geo-images reflects a combined perceptual-analytical approach to the development and practical use of 3D cartographic images. The proposed classification is based on the laws of visual perception, achievements of modern technologies, taking into account the variety of types of 3D maps, including those reflected in the classifications of other scientists (Smirnov, 1982; Atoyan, 1989; Berlyant, 2006; Goralski, 2009; Jenny, 2011; Bandrova and Bonchev, 2013) as well as the author's developments in the field of three-dimensional cartography.

Based on the data from columns D and E and according to the method of visualization and the nature of user interaction with the 3D image there were examined 4 types of 3D cartographic products (Fig. 2).

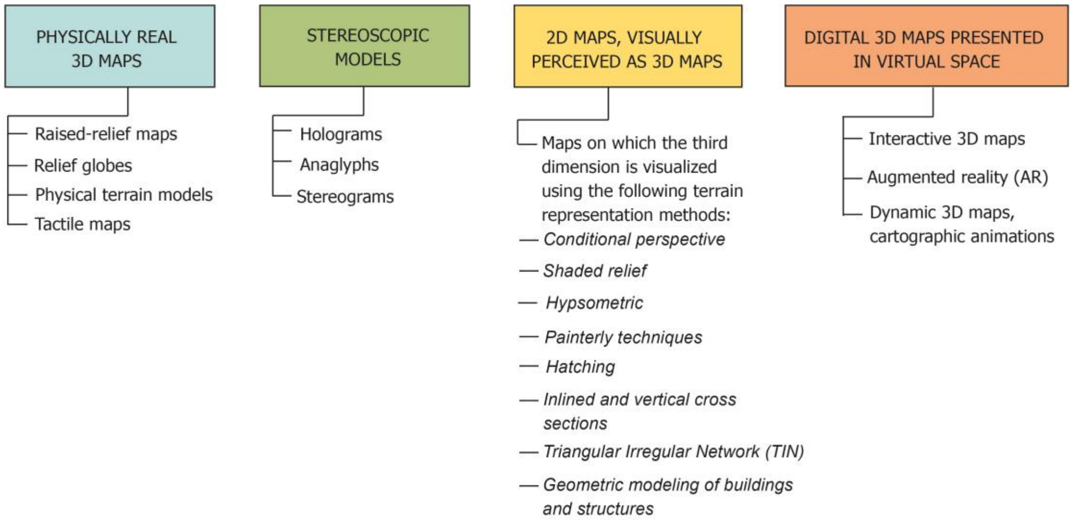

Figure 2. 4 types of some cartographic products included in the classification of 3D maps, cartographic models and other geo-images (Kovaleva and Baranova, 2022).

3D cartographic products can be added to each column depending on the way of interaction. With the first group learners interact physically, in the real space. Here are real 3D geo-images, i.e. those whose volumetry can be felt visually and physically. This includes relief maps and globes (including those intended for use by visually impaired and blind students when mastering geographical disciplines), as well as terrain relief models. The second group requires analog devices to work with cartographic products. These are stereoscopic terrain models. For the third group it is necessary to display a static map on a computer screen or print it and then mentally recreate the image of the terrain. The third dimension is felt visually – through the use of the principles of shadow and color plasticity and other design techniques. For the fourth group, interaction in virtual space is of key importance. Dynamics and interactivity complement the presentation of 3D digital maps in virtual space but are not primary, as animations can be 2D or 3D.

ADDITIONAL CARTOGRAPHIC DESIGN PRINCIPLES OF 3D MAPS

Considering the definition of a three-dimensional map and its place in the general classification system, it is important that learners see or experience three-dimensionality. When developing a map, it is important to determine whether the learner should understand the spatiality of geographical processes and phenomena or should see their volumetry. In the first case, it is sufficient to have a flat cartographic image, and in the second case, it is necessary to visually reproduce the three-dimensionality on the map.

The learner not only sees, but also represents the object of observation, and the map created becomes the basis for the learner to form a mental image of the mapping object. The more complex the map is, the more complex is the process of spatial image formation. A distinction is made between the process of the formation of a primary spatial image and the recognition of familiar objects. The formation of the spatial image is related to the extent to which the object is known and understood by the reader of the map. In order to correctly represent an object, it is necessary to take into account the laws of visual perception, the principles of cartographic design, etc.

The principles of cartographic design for 2D maps are based on the requirements of their readability, visibility, distinguishability, and the relevance of their content and design to the way they are used. Additional principles specific to 3D maps are usually defined independently by the authors for each specific map separately, depending on the scale, purpose, etc. The principles of cartographic design for 3D maps, including educational maps, have been the subject of a number of studies (Bandrova, 2001; Heiberling, 2005; Schnürer et al., 2020; Spiess, 2023).

This paper examines static 3D maps, digital interactive 3D maps, as well as 3D maps in a dynamic form. Considering the educational purpose of 3D maps, the following principles were formulated:

- The map objects and phenomena represented on the 3D educational maps should correspond, in their scope, to the curriculum of the discipline under study. At the same time, it is extremely important to give the opportunity to obtain additional information on the map. The study of a map should be accompanied by scientific, encyclopedic, reference information, elements of infographics and illustrations, which will help to form an imaginative representation of a geographical object, to cause correct associations. Often educational maps are supplemented with an inset map explaining additional information. When using an interactive map, it is necessary to divide the content into basic content that is immediately available on the screen and additional content that is opened when the user clicks on a specific icon or sign. To introduce interactivity with a printed map, QR codes are used.
- In the development of educational 3D products, it is necessary to take into account the laws of visual perception. One of the most important laws is the law of apperception, which expresses the dependence of visual perception of information by a person on their life experience. That is, the perception of a 3D image depends on how well known the cartographic object is to the learner. It is important that the developed conventional symbols were easily associated with their corresponding objects on the ground. It is necessary to take into account the already approved system of conventional signs on educational maps to designate the same objects.
- When designing conventional signs, it is imperative to determine their optimal size and shape in the process of experimental work, as well as linking the fonts, background and stroke images. The size of the objects on the 3D map should be chosen so that they do not overlap each other to the detriment of the readability of the map.
- The methods of cartographic representation should be well readable and visual. As a result of the experimental work carried out, a number of further recommendations have been identified. When designing a static map, it is necessary to ensure the continuity of the linear sign due to the three-dimensional nature of the relief representation. The captions of linear objects are placed along them.

  It is not recommended to use methods of qualitative, quantitative background and cartogram on hillshade maps with a 100 percent background fill. These methods are overlaid on hillshade and reduce readability, making image perception difficult. Therefore, it is necessary to use the above methods in semi-transparent mode. In this case, the experience from previously created cartographic products can be helpful, for example, “Atlas of Switzerland – online” (https://www.atlasderschweiz.ch/). When using other area-based methods on a digital 3D map, it is recommended to check whether all thematic information is visible and readable on the 3D map. The cartodiagram method can be used to display absolute statistical indicators by units of territorial division. Symbols and charts can be created in GIS or imported from 3D graphics programs.

  There are several options for placing captions: they can be laid on the surface of the 3D image, they can be placed on vertical planes or special plates with pointers for better readability and linking to objects, or a combination of the first two options is possible. The typographic design of static maps presents challenges, as captions should be integrated into a realistic perspective image.
- For shaded relief cartographic products, it is important to consider whether the software tools can provide the necessary visualization quality. Depending on this, either GIS, 3D modeling programs, landscape generators or game engines are chosen.
- The observance of the principle of aerial perspective is extremely important for practical realization of the perceptual approach.
- It should be taken into account that on maps for some academic disciplines, objects of general geographical content may also be elements of thematic content.

  For example, on the map “Unique natural objects of the Kamchatka Territory. Kronotsky Nature Reserve” (Fig.3.), relief belongs to the general geographic content of the map, along with borders, hydrography, roads, etc. However, volcano signatures are elements of thematic content, as they reflect the names of volcanoes included in the UNESCO World Heritage Site "Volcanoes of Kamchatka". Thus, the signatures of volcanoes should be different from the signatures of other orographic objects (lowlands, mountain ranges, etc.).

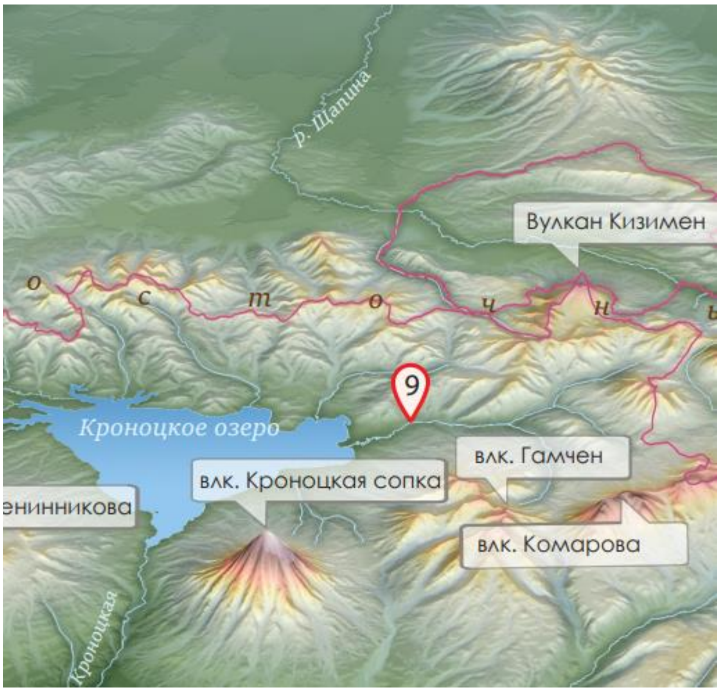

Figure 3. The fragment of the map "Unique natural objects of the Kamchatka Territory. Kronotsky Nature Reserve", the author's work.

- For interactive maps it is necessary to provide interaction according to the needs of learners. It is important to keep in mind that from a digital interactive 3D map it is possible to get a static map by saving a separate 3D scene as a digital map, but from a static map it is not possible to get a 3D interactive map based on a 3D model. It is possible to add interactive elements such as zooming, but this does not provide the kind of interaction with a digital interactive map that this paper is about. For reasons of limitations of static perspective maps, such as distortion of distances, existence of hidden areas, interactivity is a must for effective use of 3D maps.
- For dynamic maps, additional variables are introduced: dynamic, audio, volumetric variables, environmental effects. Such tools have begun to prove their effectiveness in education when displaying educational information in combination with interactivity and provide a qualitatively new level of learning. For dynamic cartographic products it is necessary to take into account the physiology of visual perception and the time required to recognize an object in animation.

DISCUSSION AND CONCLUSION

The paper identifies the place of 3D maps among educational cartographic products. The new classification of 3D maps, models and other geoimages for educational purposes was presented. During the development of the classification, it was found that the classification could also be applied to maps for other purposes if it was supplemented. The choice of necessary combinations of facets for map creation is made depending on the method of use, the nature of the source data and other requirements to the cartographic product. The developed classification is capable of extension.

This paper formulates additional principles of cartographic design for 3D educational maps, and gives the advantages of a digital 3D map presented in virtual space. There are still unresolved issues, for example, the problem of displaying signatures on the map so further work in this area will continue. The presented schemes and recommendations will allow to improve the level of design of the created 3D cartographic products, provide competent perception of the relief image, increase visibility and readability.

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BIOGRAPHY

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