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Evolutionary, cognitive and semiotic foundations of learning in virtual reality

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The article addresses the classical epistemological debate on direct and indirect realism from educational perspectives relating to the studies of Virtual Reality (VR) and Augmented Reality (AR). Recently, D. Hoffman introduced the Interface Theory of Perception stating that senses and thoughts mediate and represent reality similar to interface of computer representing hidden process in a computer. Hoffman goes further and compares the nature of cognition with production of virtual reality. Studies of VR partly confirmed such statements. For instance, due to an interaction of our mind with computer-generated objects (signs), movement and acceleration in VR during a virtual free fall from a parachute experienced as real. By using the Interface Theory of Perception and semiotic theory, the paper examines how the signs and interactions in VR scenarios can replace/construct studied realities and be used for learning. It is argued that VR allows building for learners 'developmental niches' to experience and acquire new skills or conceptual knowledge. Overlays or signs augmented on these VR environments give 'semiotic scaffolding' for learners who re-construct studied social realities or receive instructions for the acquisition of professional skills. These results were investigated in three types of VR environments with different degrees of semiotic scaffolding and evaluated by experts in cultural education. It is shown that VR provides learning environments similar to the real world and provided semiotic scaffolding reduced the cognitive loads in these developmental niches. VR environments for professional learning as well as for general education can benefit from using semiotic scaffoldings in virtual apprenticeship and professional instruction. Augmented Reality could also scaffold and speed-up scientific discoveries through the effective integration of researchers into the 'collective memory' (global databases) and technically scaffolded processes of recognition.

Keywords: virtual reality, augmented reality, representational realism, developmental niches, semiotic scaffolding, extended mind, distributed cognition, interface theory of perception

1. Introduction

Education provides various semiotic scaffoldings for individual development. As an example, we can learn geography, language and culture of other countries without the need to travel. Textbooks and multimedia (presentations, educational videos, interactive blackboards, educational apps, etc.) *represent* a studied reality in the classroom space or at home via different conventional and natural signs. Evolutionary, *advanced ability* of symbolic representation, storage and transmission of knowledge/skills about natural and cultural realities is unique to human societies [Sukhoverkhov, 2015; Il'in, Fomin, 2016; Rozin, 2022]. However, in the case of Virtual Reality (VR) and Augmented Reality (AR), semiotic representation of reality in society was advanced further [Tönnis et al., 2013; Yakovleva, 2022a; Yakovleva, 2022b]. These technologies can partly take cognitive/educational processes on them by playing the role of a virtual assistant or tutor. For example, computer applications with Augmented Reality could give us on the screen of smartphone information about the object being studied (e.g., an unknown plant or insect) and give instructions on what to do with them. In Virtual Reality, training programs which provide instruction can be designed, for instance, assembling cars or conducting a surgery [Hammerschmidt, April 10, 2019; Luca et al., 2020]. These modern achievements confirm ideas expressed in the theories of extended mind and distributed cognition [Clark, Chalmers, 1998; Paolucci, 2011]. Human cognition, as well as the teaching process, could be extended and distributed through intelligent technical systems. Furthermore, we can work with technical representations of the world as effective as with the world itself. Current technologies also provide for extended and distributed human memory. M.A. Rozov, V.G. Gorokhov, V.S. Stepin stated that science, as a social institute and special practice, can be viewed as a mechanism of centralized social memory, which accumulates the practical and theoretical experience of mankind by making it public and shared [Stepin, et al., 1996]. By doing this science helps people to avoid rediscoveries. When, for example, Victoria Falls was discovered by David Livingston in 1855, it became part of global scientific knowledge and this eliminated the possibility of its rediscovery, even though local tribes knew about this waterfall with name Mosi-oa-Tunya long before David Livingston. Modern databases and technologies of image recognition allow everyone to have access to huge, fast growing amount of knowledge that one person or groups of people would not be able to carry in their memory or share with every person on the planet. Creation of virtual realities and software with augmented realities have also given people better and faster access to knowledge accumulated by humankind. Such tools provide extended and distributed technological means for knowledge/skills transmission and constitutes further stages of non-genetic inheritance in social evolution [Sukhoverkhov, Gontier, 2021].

In this context, the paper investigates the cognitive foundation of learning through the technical representations. On the basis of empirical analysis, the research addresses problem how VR scenarios provide designed *developmental* *niches* which have a better sense of immersion into the studied reality than media such as textbooks. Also, it is aimed to explain the cognitive, evolutionary and scientific aspects of semiotic scaffolding of learning in virtual and augmented realities.

2. Theoretical framework

There are two main theories concerning our perception of reality: direct realism and representational realism. *Direct realism* and common sense tell us that the reality we perceive *is given* to us directly and there are physical/objective 'affordances' of our actions and perceptions [Beaton, 2016]. *Indirect or representational realism* argues that senses and thoughts mediate and *represent* reality as signs of reality. D. Hoffman, to prove the validity of the second approach, proposed recently the Interface Theory of Perception. He compared the perception with species-specific 'user interface' (that guides behavior of living systems) similar to an interface of computer or smartphone that represents for users hidden technical process or functions [Hoffman, 2016; Hoffman, 2019]. On this ground, D. Hoffman suggests to describe the nature of cognition similar to processes that happen for the production and usage of Virtual Reality [Hoffman, 2010].

Virtual Reality, which uses computer-generated simulations to produce high fidelity, three-dimensional experiences, seems to confirm the indirect realism theory [Bower et al., 2020]. A heightened sense of presence and immersion causes our senses to experience the movement and acceleration such as during free fall in a parachute, or the excitement in a rollercoaster ride even when there is no movement. This 'indirect realism' has enabled VR to be used for exposure therapy in the treatment of anxiety, phobias and traumas as it enables a safe environment for these experiences [DeWitt & Adams, 2021]. Hence, we interact with objects in VR as these objects are the signs and symbols for virtual actions on the computer to produce virtual events [Brey, 2014]. In a similar way, we use virtual money for purchasing items in virtual transactions in the virtual world [Ibid.], feeling no difference between virtual and real.

Yet, we can find proves for direct realism too. Even if we do not have access to reality in itself, *actions* in the real world are something that scaffolds our individual or social development and reveal objective affordances/properties of things in the environment. As was shown by the proponents of direct realism, cognition and learning is situated, embodied and embedded [Young et al., 2002; Fowler, 2010]. Studies of the language origin and acquisition also show the effectiveness of situated learning, learning from the context and actions because such learning is grounded in 'natural signs' causally connected with their signifieds [Sukhoverkhov, 2012; Nurdin et al., 2020]. In this regard, we can here be in line with the idea of V.A. Lektorsky that future in epistemology belongs to the constructive or active realism [Lektorsky, 2015; Lektorsky, 2018].

2.1. Developmental niches and semiotic scaffoldings in VR education

Learning of conventional and natural signs of reality as well as learning via actions are the main objectives in education based on VR. Designers of VR provide for that special symbolically loaded learning environment that we propose to call 'developmental niches'. The idea of the developmental niches belongs to K. Stotz, who elaborated this concept in the framework of evolutionary theory. She differentiates these niches from ecological and selective niches and defines them as "a multidimensional space of environmentally induced and developmentally regulated, heritable resources that scaffold development" [Stotz, 2017, p. 2]. Such niches provide a link between the generations through the non-genetic or exogenetic mechanisms of inheritance that promote the transitions for young and adult species-typical development. It has to be mentioned, that such niches provide not just physical or biological scaffoldings but complex 'semiotic scaffolding' [Hoffmeyer, 2015; Kull, 2015] of individual development both in nature and society [Stotz, 2010; Knyazeva, 2015; Strugovshchikova, 2023].

Educational system also creates 'semiotic developmental niches' with symbolically and conceptually augmented environments for the learners. Virtual reality makes a step further in this work and optimises the signs and actions for learning through the design of '*virtual* developmental niches' and '*virtual* affordances' for actions. Especially for the special cases when learners do not have available resources in the real world or in the real learning environment. As in case of natural and social scaffoldings (e.g., by means of language and verbal instructions), in instances of technological means of learning we have further extended version of non-genetic inheritance of social memory (cultural traditions and knowledge) and new extended tools to represent and learn the reality.

These human-generated 'niches' scaffold development of individuals via conceptual/semiotic augmentation of everyday experience (e.g., via Google Lens, SkyView Lite or other apps) or design of special learning VRs. In these developmental niches, learners can develop emotionally and experience a change of behavior for example, caring for the environment and making an effort to conserve nature, or learn names and properties of rare plants in parks and national reserves or acquire new cognitive and practical skills in their profession (as in case of BMW where learning occurs with VR [Hammerschmidt, April 10, 2019]). Overlays, signs and instruction augmented on these virtual environments gives semiotic scaffolding for learners, allowing them to *re-construct* cultural or scientific realities that they are learning supplying them with virtual apprenticeship and guidance.

Furthermore, technologies with Augmented Reality can be useful for research and new scientific discoveries. For example, to ensure that the new insect that someone discovered has never been discovered yet, the researcher needs to know all insects of the world, or at least all insects of his/her region or country. Sometimes it is impossible, for instance, for regions like the Amazon rainforest. However, the apps like *Google Lens* with image recognition software could be used to scan the insect and find equivalent images in its database. If there are no matches, it potentially indicates that this insect is unknown to science and we need further research and global sharing of this information. Another challenge for scientists is studies of different species of bacteria. Researchers hypothesize that the total number of these species range from about 10 million to a billion. Without big databases with systems of effective image recognition, it would be impossible to make a well-ordered catalog of these species.

3. Learning in VR: empirical study in Malay University

Most cultural realities ('institutional facts') cannot be 'read' or perceived directly; they are symbolic by nature and need guided explanation and interpretation. In the Department of Curriculum & Instructional Technology (Universiti Malaya), we created virtual reality tours that explain cultural semiotics of different ethnicities in Malaysia. It is very important for Malaysia because as a multicultural country, there is a variety of traditions and religious observances that may be too difficult to understand for foreigners at the beginning. Hence, tourists and travelers who arrive in Malaysia could learn first in virtual reality, the basic skills, traditions and cultures of different religions and nations via virtual tours before their arrival. Explanation of the functions and meanings of objects through the augmented information can help newcomers to Malaysia avoid getting lost in the new environment. For example, you can learn that in Malaysia, some people eat with their hands (but only with the right hand) and be familiar with various types of food and places where you can find these foods, or learn about names of medicinal herbs in a traditional Chinese medicine store.

VR is effective not only for explanation of symbolic realities but also for actions (practical skills) training. It allows to replace affordances for action from real world with virtual affordances. For example, VR is very effective in learning of action-oriented skills like navigating in new environments, doing surgery, or assembling car or engine [Hammerschmidt, 2019; Luca et al. 2020]. Especially VR is effective in a case when resources for practical learning are not available (e.g., playing the organ or exploring how to do surgery of rare diseases) or in case of a pandemic when students have to learn at home.

3.1. Methodology

In this section, several VR scenarios were selected and analysed to determine the extent to which these environments could be used for learning. Experts' opinions were sought to evaluate the VR environments and identify possible developmental niches and semiotic scaffolding in the environments. The experts were selected based on their experience and practice in academia and in multicultural education in Malaysia [Bourne et al., 2014]. Each of the expert had more than 20 years' experience and practice. Their opinions were sought on the different cultural ethnicities in Malaysia when they viewed the VR environments. After the experts had identified and coded the environments, they were interviewed to gather their opinions.

3.2. The VR scenarios

A selection of 360-degree photos related to cultural education in Malaysia was used for this purpose. Some of these 36 0-degree photos had been provided to students in a polytechnic school in Malaysia, and they had developed immersive learning environments in VR by identifying and tagging objects / augmenting these objects with information. The VR produced by the students were used for this purpose.

The VR were categorized into three categories: (1) VR environments without information augmented in the 360-degree photos; (2) VR environments with a little information, such as name of the object augmented in the 360-degree photos; and (3) VR environments with detailed explanation of object augmented in the 360-pdegree photos. There were two VR environments for each category.

3.3. Analysis of the VR environments

Each VR environment was analysed to identify developmental niches and semiotic scaffolding which could contribute to the learning of culture. Notes on the possibilities for learning culture were identified and coded separately by two experts in the area of cultural education. They would determine how these niches could be used for learning independently. Any differences were discussed and the experts would come to a consensus on the data. The data was analysed to identify emergent themes.

4. Findings

Table 1. Analysis of VR environments

VR Environment	**Developmental niches**	**Semiotic Scaffolding**	**Notes**
<u>Environments without information augmented in 360-degree photo</u>			
Malay restaurant	– Types of food – Utensils for eating – Culture and seating arrangement	1. Colour and textures of food denotes spicy food 2. Use of hand for consuming food 3. Too casual interactions between different genders are not encouraged	Indirectly to realise; sensed from nuances in arrangement of people and perceived behavior
Hindu temple	1. Surroundings 2. Statues of deities 3. Colourful structures in the temple	1. Colourful nature of prayer and religious observances	Indirectly seen and perceived

<table>
<tr><td></td><td></td><td>2. Importance of particular deities
3. Offerings to deities</td><td></td></tr>
<tr><td colspan="4"><u>Environments with limited information augmented in 360-degree photo</u></td></tr>
<tr><td>Chinese Restaurant</td><td>1. Types of food
2. Utensils
3. Seating arrangement</td><td>1. Labels of cultural artifacts for decoration
2. Labels for food and utensils</td><td rowspan="2">Labels were for providing verbal information and not much elaboration of culture.
However, perception of arrangement of seats and types of food could help understanding hierarchy and importance of the food.</td></tr>
<tr><td>Chinese temple</td><td>1. Decorations in the surroundings
2. Offerings to the deities
3. Colourful architecture and structures in the temple</td><td>1. Labels of cultural artifacts for decoration
2. Labels of some offerings</td></tr>
<tr><td colspan="4"><u>Environments with information augmented in 360-degree photo</u></td></tr>
<tr><td>Chinese traditional medicine shop</td><td>1. The storage of herbs
2. The position of the salesperson and purchaser</td><td>1. Names and uses of partcular herbs
2. Recommendations of herbs for certain treatments</td><td rowspan="2">Elaboration of significance of objects, and their extended meanings given makes meanings clearer.
It is easier and faster to identify objects and their significance when information is augmented on the 360-environment.
Perception of additional information, which is not elaborated can also be identified from VR environment.</td></tr>
<tr><td>Chinese traditional home</td><td>1. Importance of certain cultural items for decoration
2. Position of furniture for receiving guests</td><td>1. Names and significance of cultural objects and pictures
2. Features and position of spaces in a home</td></tr>
</table>

5. Discussion

Although VR has many benefits and have been used in education, there are still pedagogical issues related to designing learning environments related to VR, for instance, nausea during the usage of VR mask or the large cognitive load in VR. AR which is used in the *Google Lens* or other apps could be used to reduce the cognitive load in VR environments and be applied for scientific discoveries/researches.

As in the case of the Chinese traditional medicine shop and home, augmentation of the meanings of objects created by semiotic scaffoldings also reduced such cognitive load. When VR scenarios with little semiotic scaffolds were used such as at the Malay restaurant and the Hindu temple, the virtual environment provided a developmental niche but had a much higher cognitive load.

We can design developmental niches and their semiotic content in educational environments for professional learning as well as for the curriculum. VR for education and training requires relevant semiotic content from professionals or experts from industries, who could be consultants in designing specific semiotic scaffoldings that should be learned in these niches. Every profession has its unique peculiarities and details that could be augmented in the form of instructions or prompts into the semiotic structure of virtual reality and this could be used to prevent mistakes during the production of goods, repairing of devices and even during medical treatment. In this regard, educational developmental niches create extended 'collective memory' where people accumulate, share and transmit the practical and scientific experience (achievements) for young generations or other leaners. In terms of R. Dawkins, they exemplify 'extended phenotype' that became in society loaded with semiotic and cognitive functions.

The active use of VR and AR technologies will boost number of scientific discoveries in the future and the increased amount of knowledge will only induce further development of these technologies for designing educational environments, for professional learning and training. Because of active (interactive), instructional and developmental nature of these new, highly technological learning environments, we can consider them also as an example of socially and technically distributed cognition and active constituent of non-genetic inheritance in society.

Эволюционные, когнитивные и семиотические основания обучения в виртуальной реальности

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В статье рассматривается классический эпистемологический спор прямого («наивного») и репрезентативного реализма с точки исследований виртуальной реальности (VR) и дополненной реальности (AR) в образовании. Недавно Д. Хоффман представил интерфейсную теорию восприятия, утверждающую, что чувства и мысли опосредуют и представляют реальность подобно тому, как интерфейс компьютера репрезентирует скрытые процессы/функции в компьютере. Хоффман также сравнивает природу познания с процессом создания виртуальной реальности. Исследования VR частично подтвердили такие утверждения. Например, благодаря взаимодействию субъекта с созданными компьютером объектами, движение и ускорение в виртуальной реальности во время имитируемого свободного падения с парашюта воспринимаются как реальные.

Используя интерфейсную теорию восприятия и семиотическую теорию, в статье исследуется то, как знаки и взаимодействия в сценариях виртуальной реальности могут заменять/конструировать изучаемую реальность и использоваться для обучения. Утверждается, что виртуальная реальность позволяет создавать для обучающихся «ниши развития», в которых они могут приобрести новые поведенческие/профессиональные навыки или концептуальные знания. Набор инструментов или подсказки, дополняющие эти виртуальные среды, создают «семиотический скаффолдинг» (semiotic scaffolding) для обучающихся, реконструирующих социокультурные реалии или получающих профессиональные навыки. В статье практика такого обучения была исследована в трех типах виртуальной среды с разной степенью семиотической поддержки и оценена экспертами в области образования в сфере культуры. Показано, что виртуальная реальность обеспечивает учебную среду, аналогичную реальному миру, а «семиотический скаффолдинг» снижает когнитивную нагрузку в виртуальных «нишах развития». Виртуальные среды для профессионального обучения, а также для общего образования могут выиграть от использования «семиотического скаффолдинга» для развития виртуального наставничества и проведения профессионального инструктажа. Дополненная реальность может также способствовать и ускорять научные открытия за счет эффективной интеграции исследователей в «коллективную память» и посредством технически организованных процессов распознавания объектов.

Ключевые слова: виртуальная реальность, дополненная реальность, репрезентативный реализм, ниши развития, семиотический скаффолдинг, расширенный разум, распределенное познание, интерфейсная теория восприятия

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