Model of Immersive Educational Instruments of Behavioral Analysis and Management in Distributed Educational Teams

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2024 14th International Conference on Advanced Computer Information Technologies (ACIT) | 979-8-3503-5004-3/24/$31.00 ©2024 IEEE | DOI: 10.1109/ACIT62333.2024.10712486

***Abstract*—Current work presents an attempt to model a process of comprehensive behavioral analysis of immersive educational tools to develop a clear method of their classification and application guidelines. The research question posed by current study is the following: "What elements of immersive education tool are associated with the highest amount of student learning engagement?". The hypothesis which we test to answer the research question is formulated as "Salient elements of visual representation of immersive educational instrument are engaging most of respondents on pre-attentive processing stage". Key aims of the study include development of a model of implementing immersive educational instruments into conventional educational setup and discussion along with analysis oriented on distributed educational environments. We developed a comprehensive study design allowing to perform behavioral experiments on reaction to stimuli which represent the core elements of immersive educational tools. Presenting a design of multimodal behavioral experiment including eye-tracking, facial expression analysis and biometrical data analysis we indicate key factors providing evidence of immersion effectiveness for various classes and types of educational instruments. The discussed component-based model not only serves as an organizational tool for establishing a digital infrastructure for innovative distributed universities but also offers a novel framework for understanding the underlying architecture of immersive educational tools. Furthermore, the behavioral study design presented in this article goes beyond conventional approaches by focusing on identifying the specific elements of immersive educational tools that lead to the highest levels of learner engagement, thus contributing to a deeper understanding of the mechanisms underlying immersive learning experiences. The results of current study will be of interest to a wide range of educational institutions utilizing innovative educational techniques in their practice.**

Keywords—immersive education, innovative university, behavioral analysis, eye-tracking

I. INTRODUCTION

Modern higher education systems are facing several challenges posed by dynamically changing political, social, and economic situations. Even though traditional teaching and learning techniques can be transformed to use in various educational setups, the use of immersive instruments requires additional effort from educational management. The current situation in higher education worldwide is welcoming towards various innovative technologies aimed at addressing several challenges posed by dynamically changing political, social and economic situations [1; 2]. The viability of modern higher education system can be tied to a configuration of an "educator's toolbox" employed in the learning process. Diversity and effectiveness of learning tools forming such a toolbox define the competitiveness of the higher education system. This is especially applicable to modern distributed educational systems when tutors and learners are forced to use information and communications technologies and traditional teaching/learning techniques are less applicable. Immersive learning tools such as AR, AR+, VR, etc. are offering an overhaul of the educational landscape by introducing a completely new level of learner's engagement in the educational scenario. Even though traditional teaching and learning techniques can be transformed to use in various educational setups, the use of immersive instruments requires additional effort from educational management.

Current study deals with background of distributed educational environments which prevail in modern landscape of higher education. We present a model of distributed university teams functioning and management including behavioral analysis interface between university management and e-learning system. We came up with behavioral experiment design template allowing to keep learners' engagement level controlled in distributed educational environments. The research question we pose in proposed behavioral study template is the following: "What elements of immersive education tool are associated with the highest amount of student learning engagement"? The hypothesis which we propose to test to answer the research question is formulated as "Salient elements of visual representation of immersive educational instrument are engaging most of respondents on pre-attentive processing stage". Presented model of distributed university might be recommended for implementation for Ukrainian universities forced to work in conditions of relocated personnel and online learning due to continued Russian aggression against Ukraine [3; 4]. Behavioral study design template will be interesting for all educational institutions implementing immersive learning instruments in their workflow.

II. LITERATURE ANALYSIS

The landscape of modern literature on topic highlights the inevitable digitalization of all educational processes, as well as corporate environments [5; 6; 7; 8; 9]. Innovative and

digital economies require rapid reaction to challenges presented by constantly developing counteragents [10]. Current educational systems are aimed at transferring from "spoon-feeding" learning towards immersive learning and building bridge communications allowing learners to be actively engaged in the educational process [11; 12; 13; 14]. Among immersive tools allowing to create a new generation of educational environment, virtual reality (VR) tools are particularly promising [15; 16; 17; 18]. However, as stated by J.Radianti, T.Majchrzak, J.Fromm, I.Wohlgenannt, "the majority of authors treated VR as a promising learning tool for higher education, however, the maturity of the use of VR in higher education is still questionable" [19].

Immersive instruments have no competition in providing online capabilities in skill-based learning, where practical application of manual skills is required but cannot be implemented due to various reasons [20; 21]. Such situations can often occur in medical education when the learning team is forced to work remotely [22; 23]. Evidence suggests that immersive VR tools facilitate effective learning through simulated real-life context [24]. Widely applied is the eye-tracking technology to measure the engagement level through visual attention distribution of learners [25; 25; 27; 28]. Sources indicate, that behavioral analysis of immersive learning tools tend to be the most effective metric to evaluate the learners engagement in immersive learning scenario. Questions of immersive educational systems management have been a point of interest for some researchers [29; 30; 31] as well as authors of current work [16; 32]. Evidence suggests that modern education management tend to lean towards various agile models that offer quick and effective decision making process for distributed educational teams [33; 34; 35].

We supplement conventional literature review with bibliometric analysis conducted using VOSviewer software presented in Figure 1. We use Scopus database, query to analyse is "immersive education", years of publication 2020-2023, number of articles – 2000. The results presented are grouped into 5 thematic clusters with total 15830 links between items. The largest cluster containing "virtual reality" item with 344 links and 975 occurences indicate that immersive education tools such as virtual reality are used in various learning and research scenarios. Item "e-learning" with 307 links and 472 occurences indicate that modern e-learning environments largely incorporate immersive learning techniques and are encorporated across various knowledge fields (Figure 2).

The articles [36; 37] explores an integrated approach for implementing immersive learning at the university level. This approach includes the establishment of a specialized laboratory equipped with virtual and augmented reality technologies, the incorporation of immersive learning methodologies into university curricula, the development of software and hardware solutions for immersive learning, and the assessment of the effectiveness of these immersive learning techniques. The authors also describe products designed to fulfill the university's third mission – ensuring the well-being of citizens. AR/VR technologies offer significant promise in the educational technology space due to their immersive capabilities, innovative information-sharing methods, and potential to provide virtual experiences that overcome cost and distance barriers [38]. In higher education, AR/VR facilitates the understanding of abstract concepts and offers hands-on experience in low-risk virtual environments.

The paper [39] introduces a socially immersive learning (SIL) pedagogy, addressing the need for a new skill set in a fragmented socio-economic landscape, emphasizing connectivity and collaboration. Current HEIs systems are predominantly designed for on-campus students, often neglecting the unique needs and experiences of online learners, thus overlooking the potential relational strengths of e-learning communities. The evolving educational landscape requires permeable departmental silos and increased collaboration to address complex global issues, challenging traditional education designs and fostering student-centric engagement and new learning opportunities.

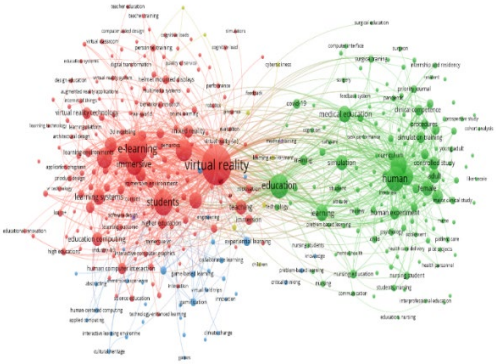

Fig. 1. Bibliometric landscape by query "immersive education"

Source: original research, VOSviewer

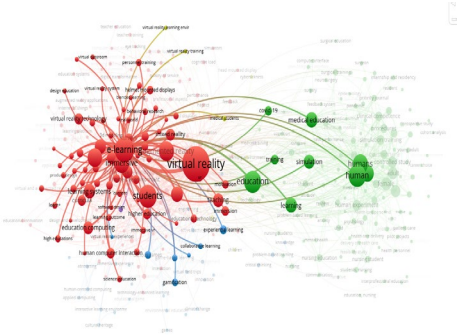

Fig. 2. "e-learning" item links to other items in landscape

Source: original research, VOSviewer

Various sources [40; 41; 42; 43] have examined different methods of utilizing immersive learning in the contemporary world. Immersive role-playing and simulations have long been foundational components in learning and development programs globally. Based on the analysis of the research landscape in the area, we clearly recognize additional effort required from educational management for the successful integration of immersive instruments into higher education systems. This suggests potential challenges in terms of resource allocation, training, and infrastructure development. Despite the promising potential of virtual reality (VR) tools in enhancing learning experiences, there remains a gap between theoretical discussions and practical implementation in higher education. Bridging this gap requires targeted efforts such as establishing interdisciplinary collaborations between educators, technologists, and researchers thus fostering a culture of experimentation and innovation within educational institutions. This work proposes a comprehensive set of tools to set grounds for such collaboration through providing a clear organizational setup and experimental study design for using multimodal behavioral analysis.

III. METHODOLOGY

Considering the results of literature review and bibliometric analysis, the aim of the article is set on proposing a comprehensive model of immersive learning tools implementation and effectiveness assessment in distributed educational environments. For the full systematic description of such model, we use UML component diagram to present a workflow incorporating distributed university concept along with behavioral engagement assessment interface. The methodological choice of UML component diagram not only facilitates a clear delineation of the model's components but also affords a practical tool for stakeholders seeking to establish a digitalized infrastructure open to the realization of innovative distributed universities.

As indicated by literature review, one of the most popular modalities allowing the studies of visual attention in educational materials is eye-tracking [24; 44]. Study design proposed in the current article focuses on defining the elements of immersive education tool that are associated with highest levels of learner engagement. For a minimal-scale focus group providing relevant results it is best to use at least 20 participants with even gender and age distribution All participants should have no or corrected vision defects. All participants should have no exposure to the purpose of the study and/or study design. After completing the full experiment, the purpose of the study is disclosed to each participant. Participants must provide verbal informed consent before commencing the experiment. Trials should be performed in normal working conditions: during daylight, no artificial lighting, no flares on the computer screen. Participants sit on a chair in pose instructed by equipment operator. Equipment necessary to conduct presented study design: eye-tracker, webcam for collecting face expression data, galvanic skin response kit and controlling software suite for presenting stimuli and collecting data. Supposedly, salience of visual representation elements will be the defining factor in attracting learners' attention during the immersive scenario. Utilizing presented study design as a deliverable, educational institutions that are forced to operate in distributed manner can seamlessly incorporate the behavioral studies as the part of the management process.

IV. RESULTS

Figure 3 depicts a comprehensive component diagram illustrating the operational framework and managerial structure of distributed university teams. Within this diagram, the Distributed University component is prominently featured, showcasing its pivotal role in the network. Notably, the Distributed University component exhibits a port facilitating communication connectivity with the Stakeholders Pool, thereby establishing a crucial dependency relationship with external stakeholders affiliated with the university. Upon closer examination of the Distributed University component, it becomes apparent that it comprises subordinate components, functioning as integral subsystems within the university's operational architecture.

Internal Faculty Team as the component describes the operation of internal university team not affected by relocation of personnel. However, the austerity of working conditions might affect the operation of internal team. This component is interfaced with University Management component through Direct Communication Interface. This direct communication includes face-to-face contacts as well as mailing, messaging, etc., and features low-latency management-faculty responses and vice versa. Internal Faculty Team component features self-explanatory dependency on University Management component. Functioning of Internal Faculty Team is ensured by following ground-level components: Research Staff and Teaching Staff that operate depending on Department Level Management. Department Level Management in the internal team setup provides the level of independence from higher-level decision making thus liberalizing providing friendly and agile working environment. Educational and scientific content along with standard operational deliverables are supplied onto the outgoing port connected to the Direct Communication Interface. The Internal Faculty team retains full access to ICT System interface and, hence, E-learning system in order to provide learners with educational content. External Faculty Team component models the operation of faculty not included to the internal team due to relocation or any other reasons. This component is interfaced with E-learning system component through ICT System interface. Distributed teams are forced to operate mainly through means of digital communication, therefore, using proprietary ICT system for access to e-learning environment might pose a challenge due to the issues of accessibility. On the other hand, proprietary ICT offers customization abilities that allow us to tailor the system to the needs of particular educational disciplines. External Faculty team operates in a manner like Internal Faculty Team, however, establishing Department Level Management in a remote office-less setup is nearly impossible. Therefore, the proposed model offers operation based off regulatory framework that provides guidance for remote Research and Teaching Staff. Outputs of these components are communicated to the outgoing port of External Faculty Team component and then supplied towards the ICT System interface.

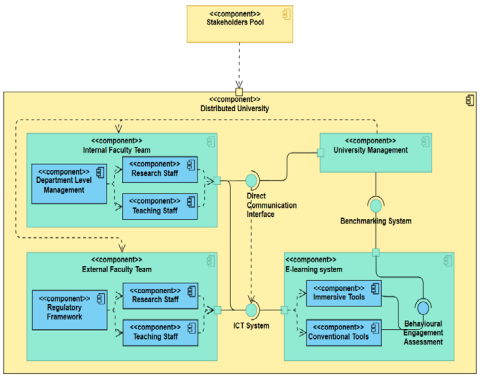

Fig. 3. Component diagram of distributed university teams functioning and management

Source: original research, Visual Paradigm online

E-learning System component include sub-systems that realize the educational process through conventional learning tools ("spoon-feeding" teaching, seminars, webinars, lectures, etc.) as well as immersive learning tools (VR-simulations, immersive problem-solving scenarios, feedback-based lectures, etc.). Operation of these components is governed by Research and Teaching Staff through ICT System. In the proposed model both conventional and immersive learning instruments are subject to behavioral analysis aimed at assessing learners' engagement level. Multimodal behavioral experiments can be used to assess the distribution of visual attention and emotional response towards presented stimulus. Modalities that serve this purpose include eye-tracking, facial expression analysis, galvanic skin response (GSR) analysis, heart rate signal tracking, etc.

Figure 4 presents the template of a study design allowing to measure learners' engagement in the immersive educational environment. In the framework of the proposed model, immersive and conventional learning tools are subjected to regular behavioral assessment of engagement which is realized through corresponding interface within E-learning System component. Results of such assessments are supplied to the output port of E-learning System component and to Benchmarking System interface. From this interface, the behavioral analysis reports are accessed by University Management and incorporated into the decision-making process regarding forming an overall educational landscape.

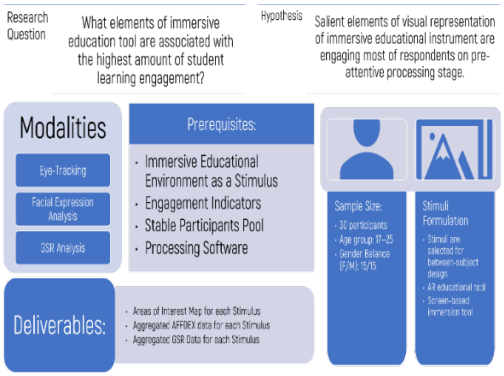

Fig. 4. Study design for behavioral analysis of immersive education tools

Source: original research, MS Powerpoint

University Management components operate as conventional management units in any project. However, a recommendation can be offered within the proposed model to incorporate agile methodologies for managing distributed educational teams. This approach allows for effective and timely decision making that serves the needs of all system components as well as external stakeholders. Figure 4 presents the study design for behavioral analysis of immersive education tools. In this template oriented towards research question and hypothesis stated above, we propose to use multimodal behavioral experiments as the assessment framework for immersive learning tools. Deliverables stated by current study design allow to obtain necessary data to use in decision making by university management. Areas of interest map allow to modify visual representation of a stimulus to keep learners engaged even at the opening experience with learning tools. Aggregated data form facial expression analysis and GSR data allow to define learner's initial emotional response when interfacing with immersive stimulus. Note that current study design focuses on the preattentive processing stage. This stage of perception defines the further experience with visual stimulus [45; 46] and must be considered in the learning tool design. Next, we attempt to present a context for operation of proposed model in Ukrainian educational landscape. We investigate Global Innovation Index (GII) data to illustrate the level of innovation in Ukrainian education and compare it to peer economies in the same income group. Table 1 provides a comparison of GII indicators across top-5 countries in lower middle-income group as defined by GII: Ukraine, India, Viet Nam, Iran, and the Philippines. Table covers the following innovation input indicators: expenditure on education as a percentage of GDP; graduates in science and engineering as a percentage of the total number of graduates; researchers as a full-time equivalent (FTE) per million population; QS university ranking within the top 3 universities; access to ICT (information and communication technology).

The Table 1 presents the rank and score for each of these indicators for each country and we analyze this data from Ukrainian perspective. Ukraine ranks 27th in indicator "Expenditure on education" with a score of 49.5, indicating that the country spends a moderate amount of its GDP on education. However, there is room for improvement in this area as there are many countries that spend a higher percentage of their GDP on education.

TABLE I. GII INNOVATION INPUT INDICATORS ACROSS TOP 5 COUNTRIES IN LOWER MIDDLE-INCOME GROUP

GII Indicator	Ukraine		India		Viet Nam		Iran		Philippines	
	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score
Expenditure on education, %	27	49.5	60	37.9	75	32.9	94	27.3	83	30.7
Graduates in science and engineering, %	41	50.0	11	82.0	54	44.6	2	99.8	52	45.1
Researchers, FTE/mn pop.	54	9.6	82	2.7	60	8.5	47	18.9	84	1.8
QS university ranking, top 3	48	20.3	24	46.0	66	8.1	43	25.8	48	20.3
ICT access	66	86.6	99	70.4	41	90.5	63	88.0	100	69.4

Source: Global Innovation Index, indicators selected, and table composed by authors

There are a few factors that could potentially contribute to Ukraine's higher expenditure on education: 1. Historical emphasis on education: Ukraine has a long history of emphasizing the importance of education, with high literacy rates and a strong tradition of academic excellence. This cultural emphasis on education may translate into a higher level of investment in education. 2. Economic policies: Ukraine government made a conscious decision to prioritize education spending as part of its economic policies. Investing in education has long-term economic benefits, such as increasing productivity, promoting innovation, and reducing poverty. 3. International assistance: Ukraine receives international assistance in the form of education aid, which could contribute to its higher expenditure on education.

Ukraine ranks 41st in indicator "Graduates in science and engineering" with a score of 50.0, indicating that the country has a moderate percentage of graduates in science and engineering fields. While Ukraine has a long history of excellence in STEM education, the country could focus on increasing the number of graduates in these fields to improve its ranking in this category. The contrast is particularly notorious comparing Ukraine's scores with India (rank 11, score 82) and Iran (rank 2, score 99.8). However, such high

indicators of graduates in science and engineering fields may indicate disbalance in country educational policies. Ukraine ranks 54th in indicator "Researchers" with a score of 9.6, indicating that there are relatively few researchers in the country. This suggests that there is a need for greater investment in research and development to increase the number of researchers and improve the quality of research in Ukraine. However, comparison to other economies of lower middle-income group suggests that Ukraine possess stronger research infrastructure, with a higher number of researchers per million population compared to all countries listed in the table except Iran. However, there are factors that influence a country's research capabilities, such as the quality of research institutions, availability of research funding, and the level of collaboration between academia and industry. Regarding the indicator "QS university ranking" we can see that India and Iran have the highest scores in the QS university ranking indicator across top 5 countries in lower middle-income group, ranking 24th and 43rd in general GII respectively. Ukraine and the Philippines have the same score, ranking 48th. Vietnam has the lowest score in this indicator, ranking 66th. This suggests that India and Iran have stronger university systems, with more universities ranked among the top 3 in their respective fields, than Ukraine and the other countries listed in the table. However, it's worth noting that QS university rankings are just one measure of a university's quality and should be interpreted with caution. There are many other factors that could influence a country's higher education system, such as the availability of research funding, the quality of teaching and research, and the level of international collaboration. Finally, comparison across indicator "ICT access" suggests that Vietnam has the highest score in the ICT access indicator, ranking 41st out of the 128 countries listed, followed by Ukraine and Iran with relatively high scores as well, ranking 66th and 63rd, respectively. It is evident that Ukraine, Vietnam, and Iran have better access to ICT infrastructure and services, such as internet connectivity and mobile phone usage, compared to India and the Philippines. However, one should note that measures of a country's digital readiness are not limited to ICT access. Overall digital competitiveness of a country can be also influenced by factors such as the level of digital skills, innovation capacity, and government policies supporting the digital economy.

V. Discussion

This article proposes a comprehensive model for implementing and assessing the effectiveness of immersive learning tools in distributed educational environments, based on the results of a literature review and bibliometric analysis. To fully describe this model, we use a UML component diagram to illustrate a workflow that includes the distributed university concept and a behavioral engagement assessment interface. Current study aims to create a model for integrating immersive educational tools into traditional educational settings and explores their effectiveness in distributed learning environments. To achieve this, we developed a comprehensive study design that includes behavioral experiments using stimuli that are central to immersive educational tools. Our multimodal approach involves eye-tracking, facial expression analysis, and biometric data analysis to identify key factors that contribute to the effectiveness of immersion in different types of educational tools and classes. We provide a contextual overview of the proposed model's applicability in the Ukrainian educational landscape. To achieve this, we analyze data from the Global Innovation Index (GII) to illustrate the level of innovation in Ukrainian education and compare it to other economies in the same income group. Specifically, we compare Ukraine's GII indicators to those of the top five countries in the lower middle-income group as defined by GII: India, Vietnam, Iran, and the Philippines.

VI. Conclusion

The model proposed in current research represents a comprehensive approach that allow to incorporate immersive educational instruments into workflow of universities that are facing challenges of working in distributed fashion. Behavioral analysis techniques are proposed as a tool to supplement decision-making process on the management level with hands-on data about educational process outcomes. Discussed component-based model can serve as an organizational chart for establishing a digital infrastructure for innovative distributed universities. Behavioral study design presented in this article focuses on identifying the elements of immersive educational tools that lead to the highest levels of learner engagement. Discussed findings will be relevant to a wide range of educational institutions that incorporate innovative educational techniques into their teaching practices.

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PART NUMBER:
CFP24S92-PRT

ISBN:
979-8-3503-5003-6

ISSN:
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