REVIEW

by Prof. Dr.Sc. Galia Mladenova Angelova, Department Artificial Intelligence and Language Technologies, Institute of Information and Communication Technologies (IICT), Bulgarian Academy of Sciences (BAS)

for Plamen Dimitrov Petrov's dissertation
"*Models and methods for application of virtual and augmented reality in education*",
presented for the award of the educational and scientific degree "Doctor of Philosophy" (PhD)

Pursuant to order No. 304/27.10.2022 of the Director of IICT-BAS, I have been appointed as a member of the Scientific Jury for the defense of the submitted thesis in Scientific Specialty: "Informatics", Professional Area: "4.6. Computer sciences". The dissertation is related to some of the hottest problems in education: employing new models and methods for deepening the interest and improving the achievements of learners in the field of the STEM disciplines (Science, Technology, Engineering, Mathematics); introduction of modern e-learning technologies corresponding to the increasingly complex human-machine interfaces accessible to learners from an early age; investigating the positive aspects and the effect of new technologies as well as the negative aspects; creating next-generation learning resources. These questions are part of the recently dominant trend worldwide to train more experts with competence in the STEM disciplines. The optimistic expectations for the development of both the educational infrastructure in our country and the human capacity of competent teachers are associated with them.

Formally, following the Regulations on the implementation of the Act on Development of the Academic Staff in the Republic of Bulgaria, I note that regarding the indicators "Г", more than the minimally required 30 points are collected for the scientific publications that disseminate the dissertation's results. With this, the requirements of the Act for obtaining the educational and scientific degree "PhD" are satisfied and exceeded. The results of the dissertation are presented in 7 publications (all co-authored) as follows:

- 4 papers are published in Proceedings of prestigious international conferences, indexed by WoS Conference Proceedings Citation Index or Scopus,
- 1 paper is published in the Proceedings of an international conference, included in the digital library https://www.sgemsocial.org/ of the SGEM World Science (SWS) Society,
- 1 paper is published in the Bulgarian Journal *Information technologies and control*, published by the Union of Automation and Informatics "John Atanasov",
- 1 paper is published in the Bulgarian Journal *Problems of Engineering Cybernetics and Robotics*, published by IICT-BAS.

The dissertation contains a list of 41 spotted citations of the author's works, almost all of them by foreign scholars. Having in mind that during the PhD period scientific results were mostly

distributed virtually due to the epidemic situation, we should consider this publication and citation record as very successful.

The thesis consists of 140 pages including 42 figures, 18 tables, a list of abbreviations and 121 titles in the references. The text is organised into an Introduction, 4 Chapters, a Conclusion, Directions for future work, List of dissertation publications and their citations encountered so far, and a Statement of originality. Chapters end with a summary, overview of results, and/or list of open research questions. The material is extremely carefully arranged in a tight and compact narrative, focusing on the essential aspects, with an easy-to-understand sequence and appropriate illustrations, and represents an enjoyable and informative reading.

Chapter 1 (Analysis of modern teaching models and methods) presents an analytical overview of modern technologies that inevitably enter e-learning. Multiple definitions and main trends are presented: to target content to the individual user, with the aim of providing them with knowledge, skills and positive experiences – i.e. to put the person at the center of the learning process; to introduce standards in platforms and interoperability of learning content; to use modern equipment and technologies for virtual, augmented and mixed reality. Various studies indicate that Augmented and Virtual Reality (AR/VR) are among the key educational technologies that are relevant to students' perception of information and enable a better understanding of learning material. Citing references from recent years, the goals and possibilities of using AR/VR in education are summarised. The need to propose new models for the application of virtual learning resources for certain target groups is motivated, as well as the need for specific methods, tools, examples of scenarios and approaches allowing their effective use in the learning process. Risks and disadvantages of implementing AR/VR in education are discussed. A taxonomy of the types of VR platforms used in education is given. The analysis and the conclusions drawn motivate the objective and tasks of the dissertation work. The objective is *to propose models and methods for using augmented and virtual reality in education.* The following tasks are defined: *(i)* to develop a model for the use of augmented and virtual reality in STEM education, taking into account the different educational goals and specifics of individual subjects; *(ii)* to propose a model for combining augmented and virtual reality with physical learning environments; *(iii)* to develop a model for combining augmented and virtual reality with project-based learning in a unified training scenario; *(iv)* to propose methods for evaluating the effect of combining learning environments extended with augmented reality, implemented to improve the learning process and understanding of learning material for specific learning objectives.

Chapter 2 (Models for the application of augmented and virtual reality in education) presents the developed models for the application of AR/VR in the training in biology, mathematics and arts with different educational objectives and the possibilities of combining them with a project-based approach and a specially designed physical environment. The introduction of definitions of the concepts "model" and "method" makes a good impression. Combining AR/VR technologies with

different teaching techniques, environments and scenarios is proposed as well. The aim is to investigate the impact of these tools on student learning outcomes.

There is a brief introduction to the zSpace® AR system running on a PC and a virtual reality monitor, which provides a realistic learning environment and creates immersive and interactive realistic experiences. Experiments conducted with target groups of pupils to introduce AR/VR technologies in the teaching of mathematics, biology and arts are described. In general, the basic model is to first conduct traditional learning with outcome testing and then show students a set of pre-prepared AR-based exercises, followed by tests whose results are compared to achievement after traditional learning. The candidate Mr. Petrov has the huge advantage of working as a professional teacher in informatics and information technology and Head of the ICT department in a well-known secondary school already established as an innovative school some 5 years ago. This allows him to plan and conduct sufficiently representative practical lessons and classroom tests without facing the ethical constraints imposed on learning experiments involving children. Chapter 2 presents a study that aims to investigate the effect of using the augmented reality module of GeoGebra (an interactive application designed for learning mathematics and natural sciences) on the development of students' spatial mathematical skills when working with different mathematical objects. A model for using augmented reality in arts education is also presented. Uses of AR can range from displaying content to transparent AR-video (displaying a screen with augmented data superimposed on camera-captured objects). Augmented reality simulates "physical presence", "immersion" and helps achieving a personalised learning experience for students, which facilitates to absorb the learning material. It is possible for learners to explore collections, museums and galleries, or create their own AR works adding a virtual dimension through animations, video and music. An approach to integrating AR/VR technologies into project-based learning is also presented, where students work in groups to solve problems in STEM disciplines (e.g. to build a house from natural materials, using energy in a sustainable way). In the last section of chapter 2 it is shown how specific interior solutions allow the transformation of classrooms into appropriately decorated offices for embedding AR and VR equipment in order to achieve the maximum effect of personalising the learning process and promoting inclusive and active learning.

Chapter 3 (Evaluation of the effect of the implementation of AR/VR in education in different subject areas) presents detailed evaluations of the developed models for using AR/VR technologies in education in secondary school.

The first group of assessment experiments concerns the verification of knowledge about the compulsory biology lessons on topics related to human anatomy. Three different groups of students (from humanities, STEM and IT profiles with 28, 28 and 24 students respectively) were formed, who studied the same material without prior experience of using AR technologies before the experiment. Four benchmark tests were conducted with well-defined learning objectives in (a) traditional learning and (b) using the Zspace® system in which engaging learning experiences were created. The average scores for the three groups show an improvement in scores (in points) when using AR technologies by 46%, 32%, and 31%, respectively. A paired t-test examination

of the collected score data before and after using AR technologies showed a statistically significant difference in the level of understanding of the learning material.

Another experiment allows a comparison of two ways of using AR in Geo Gebra: (a) in a personalised learning experience provided by the AR module to students through the Geo Gebra 3D Calculator mobile application and (b) in teaching mode when teachers share stereoscopic 3D experience with your students through the combination of zSpace, GeoGebra and a special zView camera. Three groups of 24-26 testing students were formed, who study different specialties - foreign languages, natural sciences and IT. Each group is divided into a control and an experimental subgroup, with the experimental subgroups undergoing further intensive training in using the 3D and AR modules of GeoGebra including the augmented reality system zSpace in "3D Grapher" mode in combination with the zView camera, together with the 3D module of GeoGebra. The test results of the experimental subgroups show an improvement in the success rate of about 30%.

Similarly, the effect of AR application in arts education has been evaluated. It involves 5th grade pupils exploring physical spaces and artwork through the Google Arts & Culture app. The tasks are to examine an ancient artifact, a specific gallery/painting, and draw a picture with space left for a virtual object to be created there later. The results of the experimental group improved by up to 20% and kids' engagement by up to 38%. The evaluation of the effect of combining project-based learning with AR/VR technologies also shows that the integration stimulates creativity, increases student achievement and their motivation to learn.

Chapter 4 (Development of educational materials with the means of AR/VR) presents the software environments for creating and the hardware infrastructure for using AR/VR educational materials. The updated and adapted to digital technologies Bloom's Taxonomy is considered (with a top activity "create") and its relevance to the development of standards-based AR/VR educational resources is examined. A SWOT analysis of the application of AR/VR technologies in education is made. It has been shown that the difficulty of creating learning materials, the need for experienced teachers and the relatively high cost of hardware equipment are factors that slow down the widespread and rapid adoption of AR/VR technologies in education. On the other hand, the benefits and advantages are undeniable.

The Conclusion summarises the achieved results and lists the scientific and applied contributions of the dissertation. I accept the thesis contributions as the author has formulated them. The indicated guidelines for future work are no less ambitious than the goals that the Mr. Petrov set for himself 5 years ago when starting the present work. Due to the relatively large number of quickly appearing citations by foreign authors, I believe that they indicate huge interest in the reported results and represent a kind of approbation of the achievements. In this sense, the topic of the dissertation is hot, advanced and timely for Bulgaria, where the system of innovative schools is still developing.

The Abstracts in Bulgarian and English correctly reflects the content of the dissertation.

Finally, a technical remark: at page 100 of the dissertation volume, in the reference of the paper P. Petrov, T. Atanasova, G. Kostadinov. Types, Technologies and Trends in E-Learning, Information technologies and control (ITC), vol. 3, 2019. Online ISSN: 2367-5357 DOI …
there is a technical mistake in the DOI-number, which actually is 10.7546/itc-2019-0015 (the last digit „5" is omitted and the number is written 10.7546/itc-2019-001). I find the paper mentioned in Internet only at the URL http://www.aksyst.com:8081/Sai/Journal/Docum/Vol_3_05_2019.pdf. Therefore I do not consider this paper included in the ACM Digital Library. The DOI-number with missing last digit is repeated in the Abstracts and the data sheets prepared for NACID so it needs correction in all documents. This technical comment in no way detracts from the merits of the dissertation.

Conclusion. I believe that the obtained results and the published scientific papers prove the Mr. Petrov's expertise and qualities to carry out independent research, which is required by the Act on Development of the Academic Staff in the Republic of Bulgaria for awarding the educational and scientific degree "Doctor of Philosophy" (PhD)".

The dissertation impresses with the author's ability to detect in his practical teacher's work topics and tasks that can serve as a basis for applied research (probably Mr. Petrov was guided by his scientific supervisor when extracting research tasks from the routine teacher's daily life, but his decisive contribution to this activity cannot be doubted). In the painstaking process of preparing the experiments described in Chapter 3, great care has been taken to cover all the models introduced in Chapter 2 by meaningful test scenarios. The presented dissertation demonstrates the PhD student's deep knowledge of AR/VR technologies, the e-learning paradigm and the relevant hardware and software environments, and shows Mr. Petrov as a mature and respectful specialist in ICT in education (and probably a well-liked teacher by his students).

On these grounds, **I will vote positively for awarding the degree and I confidently suggest to the respected Scientific Jury to award Plamen Dimitrov Petrov the educational and scientific degree "Doctor" (PhD).**

27 November 2022

На основание
ЗЗЛД

Member of the