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Using augmented reality technologies for STEM education organization

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Abstract. Modernization of the education system and the emergence of innovative learning technologies can improve the educational process. The use of augmented reality technology improves the learning of individual students, their motivation, as well as helps in organizing teamwork, group cooperation. As the topic of augmented reality in education is quite new and little studied for STEM education, the study reviews publications on this topic, describes the concept of augmented reality, the analysis of augmented reality technologies is carried out, which are adapted to the teaching of natural and mathematical disciplines. The role of STEM approach with augmented reality in the educational process is determined. An example of the use of augmented reality as part of a robotics project is given.

1. Introduction

According to the Strategy of development of informational society in Ukraine [3], Project Europe 2030 [7] and Education 2030 Agenda [33], establishment and utilization of computer systems, particularly systems that are based on grid- and cloud technologies, are one of the stages of those strategies for next years. It infers the formation of the new digital infrastructure and digital sphere reassessment including educational sphere. Educational programs should be adapted to these changes. So, YouTube service [5] and mobile applications [11], virtual and augmented reality (AR) are free for students and teachers during classes. It allows to make lessons more interesting [14]. For virtual event recreation, AR elements can be built-in to websites [29], they can be uploaded to social media and work on PC, notebooks, tablets or VR devices.

In Ukrainian educational sphere, presence of educational and methodical materials which are dedicated to AR organization issues is quite limited due to high dependency of technical equipment, organization of practical part and lack of teachers' preparation. There are relatively a few popular software and available technical equipment for deployment this technology in educational institutions. Therefore, the aim of the research is overview and generalizations of AR technologies utilization methods for STEM education. There are following tasks which were set for aim achievement:

1. Make content-analysis of scientific, scientific-methodical publications related to AR technologies in STEM education.
2. Make analytical overview of AR systems utilization for educational and extracurricular activities of STEM education.
3. Describe existing practices regarding the AR usage during mathematical disciplines, such as robotics.

2. Related works

The organizational base of STEM education [34] is project-related activity where different pedagogical approaches and technological solutions are used [9].

Pedagogical approaches are based on grouped practical work organization for projects. All kinds of activities are united with the ability of student involvement during education process. It is described in analyzed research that efficient studying (studying with practice) raises effectiveness of studying. Moreover, most of teachers who use efficient studying are refusing the traditional lectures making preference to the active studying. So, usual kinds of cognitive activities related to different forms of studying should be first characterized by students' activity and involvement of students for active discussion and problem solving [19].

There are different kinds of interaction between participants within project activity. In work [27], this activity is represented by social interaction. In authors' opinion, interdisciplinary research is team one, which causes social interaction between research team to achieve the interaction between different disciplinary goals. Therefore, social and cognitive elements are used for integration achievement.

Specification of STEM education requires practical activity in laboratories using specialized tools. In case of limited access to technical tools, different approaches to organization of practical activity are used. Authors [4] propose solutions including the flipped classroom model, online practice questions, teleconferencing in place of in-person lectures, involving residents in telemedicine clinics, procedural simulation, and the facilitated use of surgical videos for distance learning. A repository of video lectures the can be watched remotely at any time and learning with simulation in various forms are became the base. But authors notice that limitation is number of video libraries the vary widely in content and quality, with particular concern over the quality of freely available videos on platforms during available simulation.

Among pedagogical factors, vast role plays the 'logistics' of classrooms in AR utilization. Miguel Nussbaum and Anita Diaz providing teachers with different strategies to maintain student interest throughout a range of challenges: the time budget and time segmentation, the physical constraints of the classroom space, and the need to maintain a reasonable level of discipline, to minimize the teachers' workload, or to cope with the heterogeneity of the class [21].

To implement AR technologies to learning process it is needed to familiarize with special software or platforms, that can be used to create one's own mobile applications for its further deployment [20]. It's particularly important during learning 'difficult' disciplines of natural, mathematical branches [17], [16], [25]. Utilization of modern educational trends i.e., innovative technologies such as AR technology itself and STEM technology, gives an opportunity to stimulate students to creativity, to develop their scientific and research skills and abilities, to create motivational conditions for self-determination in future occupation [23], self-development and self-realization, to implement current competence in everyday life.

Technologies of full or partial diving into different kinds of virtual, augmented, mixed reality (AR/VR/MR) are also called immersive methods of learning. AR/VR/MR are interactive instruments of immersive methods of learning.

Immersive methods of learning gained vast popularity in number of countries worldwide. During biological, ecological, evolutional or other natural sciences classes, field practice, students use virtual reality observing and learning organisms in their habitat [35]. Project Physics Playground is oriented to learning sciences using AR and VR technologies, in particular, modeling physical experiments in mechanics [24], laws such as friction, inertia, velocity, trajectory, mass, force and other objects' characteristics in physical world. There are tools in application that gives an opportunity to learn physical processes, do experiments in 3D virtual space [10].

In chemistry sphere, AR applications allow learning a structure of atoms and molecules, perform experiments which are costly or dangerous in real world observing chemical transformations etc. [20]

In biology sphere, AR technologies allow an opportunity to scale organs, cells or even DNA molecules. Interactive features of applications give an opportunity to observe static and dynamic plots, for example, the process of DNA replication [13].

During mathematical learning process with the help of AR technologies it is possible to visualize algebraic surfaces of different degrees [14]. There is a possibility to learn surface as real object, not on a computer's screen or book changing parameters in real time and observe the result. Interactive change of parameters speeds the understanding of equation structure and 3D surfaces [6], [26].

For theoretical basics of AR usage in world formation, authors [8] look at the related fields of e-learning [1] and m-learning [30]. Based on learning object term it was developed the classification of AR tools by group:

- Fundamental: individual digital resource (only content);
- Combined-Closed: small amount of united but not available separately digital resources;
- Combined-Open: big amount of combined and directly available separately digital resources;
- Generative-Presentation: fundamental and combined digital resources combined with logic and structure
- Generative-Instructional: digital resources combined with rated interactions, created for realization of abstract studying strategies (content, context, studying activity and mark) maintenance

Besides the classification authors group resources by user activity: active creation of AR content and passive consumption of AR content. In the first case, user can interact with AR actively studying or creating them. In the second case, AR carries demonstrative, informative or entertaining character.

Teemu H. Laine and Hae Jung Suk [15] consider AR as gamification technology and its organization in game mechanics point of view. Authors rely on inner motivators such as challenge, competition, control, cooperation, curiosity, fantasy and recognition for involvement of students for creating AR. Students implement Immersion, Scientificalness, Competitiveness, Adaptivity and Learning (LSCAL) model.

In work [6], authors consider abilities of usage AR applications in usability at the classroom level, design principles, the hardware environment point of view. In usability point view authors define the circles of usability: consideration individual constraints such as the user's previous experience and his or her cognitive load; the quality of conversations, the richness of deictic gestures, and the smoothness of turn taking; the constraints of the classroom. In the system design authors make general design principle: "Classroom usability increases if the learning environment satisfies all classroom constraints". Authors define intrinsic as a list of constraints (i.e., how to make people cognitively learn) and extrinsic (how to effectively shape classroom practices with the presence of technologies). In the article was proposed five principles proved to be good design choices: integration, empowerment, awareness, flexibility, minimalism [36].

Lucinda Kerawalla, Rosemary Luckin, Simon Seljeflot and Adrian Woolard research [12] focuses on the exploitation of individuals-using-technology-in-settings. Their work presents using the TinkerLamp: an environment developed to train vocational apprentices in the domain of logistics. During development and deployment of this tool there were made following design requirements:

- content flexibility and ability of its adaptation to different students' needs;
- Studying AR material should be used in parallel with traditional studying methods;
- AR content should be interactive for maximization of studying methods effectiveness;
- AR development should consider concrete user studying traits such as age.

AR technology combined with STEM education and ICT greatly widen the list and possibilities of available methodology, technics, work format which contribute the modernization of educational sphere, gives the possibility to enhance educational process.

However, there is unresolved issue in mentioned works related to abilities of AR technologies in STEM education usage, in particular robotics which is quite popular. Using these new technologies in STEM education is possible to widen the specter of available teaching methods, work formats and learning approaches, to modernize its content.

3. Results

AR elements deployment into STEM education requires corresponding changes in usage of different organizational forms and being oriented to formation and expansion of mentioned resources. Each of these forms influence the development and formation new competences. In particular, it is common for all formats of learning to have the development of cognitive skills by bridging theoretical and practical activities [31].

Realization of STEM education tasks requires utilization of different types of cognitive activities which provide the formation of corresponding STEM competences. Among the kinds of activities, it is needed to mention the activities that make difference between STEM education and other ways:

- Explaining of usage of physical phenomenons and laws. In most cases, these types of activities are provided by AR content demonstration and manipulation with it.
- Natural, physical and technical laboratory works, experiment demonstration using models and mock-ups. One of the features of STEM education is the usage of technical resources, in particular measurement devices, robotics constructors etc. In case of absence of technical resources utilization ability, AR aims to construct the skills of controlling and measurements with these devices.
- Project activity performance. Creation of objects with AR gives an opportunity to student to build objects oneself, geometric objects as well, creation of digital content using the predefined patterns encourage students to deeper learning of learning material, creating one's own action plot develops skills of planning and process organization, using ready AR programs allows using qualitative content for experiment performance, make them more observable without diving to inner structure.

The usage of AR in STEM education research showed that it is needed to make available 3 types of resources:

1. *Electronic educational resources* and their search, creation and fulfilment of course. Working with electronic materials is usually quite long. Is possible to use existing models, or creating one's own.

2. *Methodical supervision* (control and quality of education recommendations, content). There are changes in traditional forms of learning – forms that were not widely used un educational process before are becoming more popular such as distance learning.

3. Teaching specialists to create content, teachers. Advanced training pre- and in-service teachers is actual. Is also important to teach specialists who can help teachers in projecting of educational environment and its formation. The environment should satisfy main criteria: simple management of educational resources, understandable and qualitative instructions for tasks, obvious criteria of evaluation.

According to this, there are different existing AR tools: development tools and reading tools. There are systems that support both functions where AR function is implemented. We have done solution search that would allow to create elements of AR in robotics classes.

We have analyzed AR applications on Google Play for STEM lessons. Among the results there were found 146 applications which implement principles and approaches of STEM education. From found applications a part (12%) were applications for books. A part of applications uses AR images for material illustration (53%). Those images can represent basic movements such as rotation or user interaction. There is wider category – game-like learning applications. They contain materials in test format or learning occasions (35%). Those applications are more comfortable to use for concrete topics within discipline plan. It is possible to create and manipulate virtual objects. As the example, there is applications (AR VR Molecules Editor) where it is possible to create substances or demonstration of other learning topics (StanLear: AR Books & VR Worlds). Table 1 contains an overview of applications.

Building any robotics device requires knowledge of following aspects: mechanics (construction building, form definition), electronics (utilization of electric schemes and devices that manage mechanisms), programming (creating plot/rules of actions triggered on environmental changes). The process of creation robotics schemes consists of several stages [22]. Elements of AR can be used on each stage.

Table 1. Systems for AR, VR development.

Application name	Description
CreatorAVR	Users are able to create interactive and immersive lessons AR and VR lessons without needing any coding or advanced technological knowledge.
AVRplatform	AR and VR library for education purposes
Vuforia	In real-time tracks flat images and simple three-dimensional objects, recognizes cylindrical markers and text.
Blippar	AR constructor
STEM Kids: Science, Technology, Engineering & Math	STEM Kids contains hundreds of articles, videos and pictures to kick start your child's education in STEM subjects. Early education in sciences. Kids can read the interesting facts and explanations themselves
SnapLearn: AR Books & VR Worlds	STEM – Visualize abstract concepts with interactive 3D Models Geography/History/Architecture – Travel across time & distance on virtual tours. Language – Practise listening and speaking skills in immersive context. Picture Books – Watch your favorite characters pop up from the pages.
Augment - 3D Augmented Reality	Visualize your 3D models in AR, integrated in real time in their actual size and environment
AR-3D Science	Learners can build selective compounds by combining elements flashcards. Narration in the app helps learners to understand the relevance of chemistry to everyday life.
LearnLive AR	The digitized renditions of concepts, theories, and processes.
UniteAR	AR platform where you can build your own AR experience without writing a single line of code
ScanAR - The Augmented Reality Scanner	The app enables you to scan special products, images and illustrations and discover secret content using AR
Paint Draw AR	In this app, you can paint and draw in 3D space using AR. Using the app is as simple as touching on the screen to paint in 3D space
360ed's Elements AR	Learners can build selective compounds by combining elements flashcards. Narration in the app helps learners to understand the relevance of chemistry to everyday life.
3DBear	All the lesson plans and challenges for assignments. Creating AR scenes with various 3D model collections. Import millions of models (Sketchfab, Thingiverse, Import own models) to create engaging homework for students
AR GPS Compass Map 3D	The AR 3D Compass with an integrated split-screen map. Locating landmarks (e.g. via latitude / longitude)
AR Ruler App	Uses AR technology to tape measure the real world with your smartphone's camera
AR VR Molecules Editor	AR VR Molecules Editor allows one to build and manipulate 3D molecules models of organic and inorganic compounds in a smartphone VR headset
Sparklab - Chemistry app in AR/VR	Interactive chemical experiments in AR/VR. Interactive and futuristic Periodic Table in Sparklab chemistry app. Chemistry quizzes. Informative and interesting videos about Science

The following list shows applications for organization of mentioned stages:

1. *Formation and research the problem, search for a technical solution*. On this stage, the problem is defined, corresponding material is learned, solution methods for the problem are defined, existing solutions are observed. At this stage, a learning scenario is built, which is then implemented by students.

- Google Lens – AR neural network based image recognition technology developed by the Google [2]
- Anatomy – structure of human body and organs, “expedition” into body
- Google Expeditions – virtual expeditions and observing objects in AR with the effect of diving, or observing objects in AR. It can be used for learning natural and local conditions for measurement constructions. It can be used for quest organization as well [28]
- Augmented Reality Development Lab is an experimental laboratory where projects are created. Usually they are three-dimension objects which can be used in learning

2. *Modeling or constructions, planning actions*. On this stage technical solution is created which will the base of robotics system. The distinction of the stage is detailing the plan of creation of engineering and technological aspects, choice of materials for construction, justification of chosen scheme of detail joining reliability, creation of instructional scheme of construction assembly. On this stage, issues about functionality, ergonomics and interface of future construction are resolved. This influences the aspects of technical solution such as comfort, security and simplicity of usage. The outlook design is also important on the stage.

- Occupational Safety Scaffolding is the reliability of engineer constructions. It is possible to build a construction in examine its hardness
- Melchemistry – application, for chemical experiments with wide range of features for observing different kinds of processes. For example, virtual process of photo-polymerization where multi-layer disk which is built with stacking layers, which are formed from “thin traces” (or informative layers)

3. *Constructing, building mock-up*. This stage carries applied character, in the result, prototype of solution and physical model are created. On this stage includes the creation of construction, mechanical and electric nodes as assembly, functional nodes assembly, construction assembly. The important aspect is construction testing and construction amending, if necessary.

- Electricity AR – application which helps to tech how to work with analogue scale of measurement devices and to make measurements with AR, to understand electrical scheme bitmaps
- CG-physics – demonstration of physical laws. Ability to perform one’s own physical (electronics) experiments
- Physics Playground – physics reference where physical forces and mechanical interaction can be observed

The example of a project of vehicle with autonomous control building is presented. It was implemented by students to participate in the Robotraffic competitions [22]. One of the stages of the competition is the movement of autonomous transport. It was necessary to develop an autonomous robotic vehicle capable of moving along the line (without leaving its lane) and be part of the urban transport model, following the road traffic regulations. The development of such project consists of two interrelated processes: the physical model construction (the vehicle is made to technical requirements) and the model programming (the rules of behavior in certain situations are described). It is necessary to consider the requirements of the environment. For example, traffic lights, road signs, and a pedestrian model should be used to build the urban traffic model. At this stage, it was built in AR environment, which determined the path that the vehicle should take (figure 1).

As a result of the project, students developed the model of a vehicle with autonomous driving, which was tested and participated in competitions. They conducted an empirical study of the concept of vehicle autonomy: collecting information on various implementations of autonomous traffic and systems that support it, development of options for implementing autonomous traffic using different hardware, experimental work to test hypotheses about the suitability of a variant of autonomous control system, testing and evaluation of the vehicle. In the course of this design and research work, a holistic view of the problem of solving road safety was formed as a complex scientific task that requires the integration of knowledge in physics, mathematics, algorithmization, and programming and has a socially significant component.

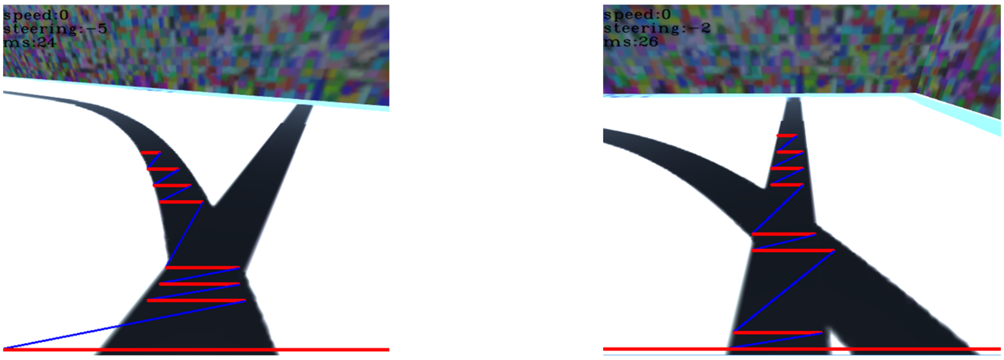

Figure 1. Path simulation in AR.

In this way, integration of AR into educational process is possible for robotics projects. This help to join not only scientific researches and different kinds of experimental activity but to make them more visual and available, according to current level of technological achievements. This helps with involving the young people to innovational activity.

4. Conclusions and outlook

During the problem of professional training of future pedagogical and mathematical teachers to utilization of AR technologies in education worldwide research all issues were resolved and the results were received. Based on the results there were made following conclusions:

1. Analysis of utilization of AR experience for interactive learning materials development concluded the conception of AR induced the development of new access interfaces to computer system for human. At the same time, regardless of long (more than 60 years) period of theory and practice development of such systems, only during last 20 years there were technological conditions for their wide deployment due to mass spread of mobile Internet devices [18], [32]. Methodical conditions of usage of virtual reality systems worldwide were tested in laboratory conditions, today they also need correction in mass technologization of pedagogical process.
2. Analyzed the experience of usage of AR worldwide, in particular during natural or mathematics classes. Among problems existing with deployment of those technologies worldwide, first of all, it is needed to note the deficit of specialists in educational projects preparation, limited technological preparation of teachers in this way. To make AR inseparable part of educational process, it is necessary to form strong interest for teachers to utilization of AR and show its advantages as versatile learning approach.

Method definition and forms of deployment augmented reality into process of preparation of future natural and mathematical disciplines teachers belong to further researches.

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