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Integration of virtual learning environments into school education in Scotland

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Abstract. The purpose of the study was to determine the impact of using virtual learning environments on students' assimilation of educational material and the development of their skills and abilities. The methodology included content analysis of types and examples of the use of virtual reality in schools in Scotland, conducting a pedagogical experiment at Stirling High School (Stirling) and Portobello High School (Edinburgh), and the development of an algorithm for integrating such environments into the educational process. It was established that virtual learning environments that cover technologies of immersion, addition and interaction with digital objects create conditions for deeper study of the material, development of practical and cognitive skills and increase learning motivation. The analysis demonstrated the possibility of using various immersive solutions for teaching History, Geography, and Ecology, in particular for virtual excursions, demonstrating 3D models, and conducting safe laboratory experiments. The pedagogical experiment showed that students in the experimental group had significantly higher levels of engagement (M = 4.3; SD = 0.5), cooperation (M = 4.1), and self-regulation (M = 4.0) compared to the control group (3.6; 3.5; 3.4, respectively). ANOVA statistical analysis confirmed significant differences between the groups (F = 15.21; 11.47; 13.05), indicating a positive impact of using interactive virtual environments on learning activity, interaction, and student autonomy. Based on the results, a five-stage algorithm for integrating virtual learning environments was created, which involves identifying learning needs, selecting technological solutions, training participants, planning classes, and evaluating results. The practical significance of the study lies in the possibility of applying the results obtained by teachers for the effective implementation of virtual learning environments, school administration – for planning innovative educational programmes, and developers – for creating interactive educational content

Keywords: students; teachers; critical thinking; virtual platforms; study subjects

INTRODUCTION

The use of advanced digital technologies in the educational process creates new opportunities for personalising learning and developing digital literacy. Virtual platforms provide access to interactive materials, modelling complex phenomena, and student collaboration in a safe environment. However, insufficient teacher training, limited access to equipment, and uneven development of digital skills among students make it difficult to use these technologies effectively. Such factors reduce the activity of students and limit the potential of innovative approaches in teaching. Therefore, research in this area determines the best strategies for implementing technologies and helps to increase the readiness of teachers to work in a digital environment.

The use of virtual learning environments in school education in Scotland creates conditions for maintaining learning activity and developing student independence. W. Jantanukul (2024) investigated how augmented, virtual, and mixed reality technologies affect the learning process,

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in particular, student engagement, motivation, and assimilation of knowledge. AR (Augmented Reality), VR (Virtual Reality), and MR (Mixed Reality) technologies influence the learning process by creating a high presence and interactivity, which activates students' attention and promotes understanding of educational material through experiential assimilation. H. Crogman *et al.* (2025) investigated how the application of virtual, augmented, and mixed reality technologies is changing the paradigm of experimental learning, allowing students to learn through modelling real-world situations and interacting with digital objects. The paper analysed the positive impact of such technologies on the development of practical skills, critical thinking, and the ability to apply theoretical knowledge in real contexts. The study by K. Alhazzaa & W. Yan (2025) showed how AR and VR technologies affect the user experience and participants' level of engagement during training simulations. In practice, this happens by immersing students in virtual building design scenarios, where they can experiment with energy efficiency parameters in real time and observe the consequences of their decisions in an interactive format.

Research conducted by N. Assaf & D. Gan (2021) showed that distance learning provides active interaction of students with educational material and forms self-control skills, while effectiveness depends on clear structuring of courses and availability of technical resources. Technological support and pedagogical organisation of materials are necessary for the effectiveness of online education. During a comparative analysis of the perception of online learning by students of higher educational institutions, D. Cranfield *et al.* (2021) found that distance learning promotes flexibility in planning educational activities and developing self-control skills. This confirms the importance of supporting student self-regulation, which is implemented in Scottish schools through structured online courses and supporting learning materials.

Collaborative tasks in online environments, highlighted by G. Demosthenous *et al.* (2020), stimulate social interaction and the development of critical thinking. Active interaction between students and teachers ensures the assimilation of material and the development of team skills, which confirms the importance of joint projects in Scottish virtual schools. Evaluation of distance learning methods and factors of effective content delivery, conducted by O. Gluoksnyte (2022), emphasised the need to adapt materials to the online format and regular feedback. It turned out that the interactivity and structure of courses increases student engagement and promotes the development of independent learning skills, which was actively used in Scottish schools. The research by G. Mangione & G. Cannella (2020) demonstrated that technological solutions provide equal access to learning resources even in small and isolated communities. This discovery confirmed the possibility of effective use of digital platforms in remote regions of Scotland and highlighted the importance of technology support to ensure equal learning opportunities. The development of virtual schools for students with experience living in educational institutions, as shown by L. McIver & M. Bettencourt (2024), allows creating personalised educational trajectories and maintaining the psychoemotional state of students, developing their academic achievements. These results complement previous findings about the value of flexible and adaptable online resources. Innovative learning methods through virtual platforms and applications, according to M. Sofi-Karim *et al.* (2022), promote greater student engagement and digital skills development, while providing opportunities for interactive interaction and a personalised approach to learning. The experience of T. Walters *et al.* (2021) demonstrated that maintaining a psychoemotional state and access to adapted materials determines the learning performance of secondary school students. Adapted materials include learning resources adapted by difficulty level, presentation formats, and interactive elements to support students' psychoemotional state.

Despite the results highlighted by the aforementioned researchers, gaps remained in the scientific field related to the impact of virtual learning environments on the educational trajectory of schoolchildren in Scotland. Evaluation of the effectiveness of virtual reality platforms was not sufficiently presented, which made it difficult to identify learning opportunities for all students. There was a lack of generalised conclusions about the optimal combination of pedagogical strategies and technological tools that can guarantee stable and reproducible learning outcomes in a virtual environment. The purpose of the study was to evaluate the effectiveness of using virtual environments in learning, students' interaction with the material, and the development of competencies. The objectives of the study were: to carry out a content analysis of virtual learning environments used in school education in Scotland; to assess the features of integration of immersive technologies (VR, AR, MR) in the teaching of Geography, History, and Ecology, and their impact on the assimilation of educational material; to develop an algorithm for integrating virtual learning environments into the educational process of secondary schools.

MATERIALS AND METHODS

The study conducted a content analysis of various forms of VR technologies, in particular, ClassVR (n.d.) and Engage VR (n.d.) platforms. Additionally, AR technologies were considered, namely, Merge Cube (n.d.), CoSpaces Edu Training & Projects (n.d.). Mixed reality (MR) analysis included applications such as Microsoft HoloLens (n.d.), zSpace (n.d.). These programmes were selected because of their extensive use in teaching and their ability to display various formats of immersive educational environments. The analysis was conducted based on the following criteria: the level of user immersion in the educational process, interactivity of materials, the ability to personalise and adapt to individual needs of students, the development of critical and creative thinking, the promotion of teamwork and communication, technical accessibility, and ease of use for teachers and students.

A pedagogical experiment was conducted between March and May 2025 with the participation of Secondary School students in such schools in Scotland as Stirling High School (Stirling) and Portobello High School (Edinburgh). These institutions were chosen because of their willingness to implement innovative digital tools and the availability of the necessary infrastructure to work with virtual learning environments. The sample included 120 students aged 13-15 years, who were divided into control (CG) and experimental (EG) groups (60 students in each group). The inclusion criteria were regular school attendance during the last academic semester, written consent from parents/guardians, and no medical contraindications to the use of immersive technologies. The exclusion criteria were recent epileptic seizures, visual impairment, lack of consent, or prolonged absence from classes. In addition, six teachers participated in the study (three in the experimental group and three in the control group). The inclusion criteria for teachers were the qualification of a high school teacher and at least two years of practical experience in teaching the subjects studied. The exclusion criteria were lack of consent to participate or inability to complete a short methodological training. The control group was trained in the format of conventional lessons using printed materials, frontal explanations, practical tasks, and group discussions. The experimental group worked for 45 minutes twice a week with virtual learning environments that included VR simulations, AR applications, and virtual labs. Classes were held for twelve weeks and covered individual practical tasks in simulators, pair and group projects in 3D environments, thematic quests, and reflexive entries in digital magazines. All topics and expected learning outcomes were identical to those used in the control group, which ensured comparability of the data. To assess academic achievements, author's tests were conducted before and after the experiment, which included questions of the same content. The use of a 12-week interval and the absence of a list of correct answers after the first test made it impossible to mechanically remember questions and ensure the validity of the measurement. All questions were evaluated as a percentage of correct answers, where 70-100% of answers meant a high level of knowledge, 40-69% – an average level, and 0-39% – a low level of assimilation of the material. In particular, the test included 15 questions with multiple choice answers in three subjects (History, Geography, Ecology). The questions were as follows:

1. What was the main function of castles in medieval Scotland?

A – Housing for farmers
B – Defensive structures
C – Religious centres
D – Workshops for gunsmiths

2. What weapons were most common during the Battle of Bannockburn?

A – Crossbow
B – Long sword
C – Roman gladius
D – Knights' pikes

3. What was the main reason for the rapid urbanisation in Victorian Scotland?

A – Tourism development
B – The Industrial Revolution
C – Development of navigation
D – Religious reforms

4. What element was an important part of the Scottish Highland clan culture?

A – Samurai sword
B – Tartan (checkered clothing)
C – Greek chiton
D – Roman toga

5. Who built the Hadrian's wall?

A – Vikings
B – Goths
C – Romans
D – Picts

6. What is the name of Scotland's main mountain region?

A – Lowland
B – Highland
C – Midland
D – Northland

7. What type of terrain does Arthur's Seat in Edinburgh belong to?

A – Karst plateau
B – Coal mines
C – Volcanic topography
D – River delta

8. What is the most important resource for the coastal regions of Scotland?

A – Oil and gas
B – Wood
C – Cotton
D – Hard coal

9. What is the typical climate for Scotland?

A – Tropical
B – Arctic
C – Temperate marine
D – Continental

10. What is the most likely cause of soil depletion in pastures?

A – Excessive grazing of livestock
B – Lava flows
C – Earthquake
D – Gold mining

11. What process corresponds to the transfer of nutrients in the soil to plants?

A – Photosynthesis
B – Osmosis
C – Diffusion
D – Evaporation

12. What process describes rain formation?

A – Crystallisation
B – Condensation
C – Sublimation

D – Subatomic decomposition

13. Who is at the top of any food chain?

A – Predator

B – Plant

C – Parasite

D – Decomposer

14. Which gas is the main factor in the greenhouse effect?

A – Oxygen

B – Carbon dioxide

C – Nitrogen

D – Hydrogen

15. What is required to preserve biodiversity in an ecosystem?

A – Complete removal of all predators

B – Regulation of human activity and conservation of the natural environment

C – Prohibition of new plant growth

D – Use of all resources without restrictions

Statistical analysis included comparing the gains in scores between groups using variance analysis (ANOVA) with a significance score at $p < 0.05$ and providing indicators of the magnitude of the effect (η^2); additionally, teachers assessed the level of involvement, cooperation and self-regulation of students on a 5-point Likert scale (Koo & Yang, 2025), which were also analysed using ANOVA. At all stages of the study, ethical requirements were met based on the Scottish Educational Research Association (2005), including written informed consent from parents/guardians and consent from students, and data anonymisation was ensured. An algorithm for implementing virtual learning environments in secondary schools was formed, which ensured the systematic integration of technology into the educational process and increased the effectiveness of lessons. The algorithm included evaluating students' learning goals and needs, selecting appropriate technological tools based on the criteria of immersion level, technical capabilities, and learning objectives, preparing teachers and students to work with virtual learning environments, planning lessons with consistent use of immersive exercises, and evaluating learning outcomes and correcting the process based on the data obtained. A limitation of the study is that it covered only two secondary schools and three academic subjects, including History, Geography, and Ecology.

RESULTS

Content analysis of the use of virtual, augmented and mixed reality in the educational process in Scotland

Virtual reality involves technology that creates a fully digital, immersive environment in which the user experiences presence and interacts with objects and processes that simulate the real or imaginary world. It is implemented using special devices, such as virtual reality headsets, controllers, motion sensors, and software for reproducing 3D scenes and simulations. In the broader context of extended reality (XR) technologies, there is a distinction between fully immersive virtual reality, where the user is separated from the real environment and interacts only with the digital world; augmented reality, which overlays digital objects on physical space via tablets, smartphones or smart glasses; and mixed reality, which combines digital and physical objects, enabling the interaction with both simultaneously (Musa *et al.*, 2022). In the educational context, virtual reality is used for modelling laboratory experiments, creating interactive simulators, 3D modelling, organising virtual classrooms and training tours, contributing to the development of practical skills, critical thinking, and teamwork. Schools in Scotland are actively implementing VR technologies: for example, in 2018, the East Renfrewshire Council purchased more than 900 ClassVR helmets for 30 schools, which gave students access to hundreds of virtual learning scenarios (Eichler, 2018). In Highland, Daviot Primary School students use ClassVR (n.d.) specifically to "travel" to historical locations and natural environments, which increases their interest (Munro, 2019). Futhermore, Engage VR (n.d.) allows organising large groups of up to 50 participants, setting up VR classes and training scenarios (Llanos-Ruiz *et al.*, 2025). In addition, Skills Development Scotland (2022), together with Balfour Beatty, introduced a VR tool that allows high school students to "visit" a construction site virtually as part of career guidance. According to Education Scotland (2021), VR environments are used to explore historical locations, artefacts, and create immersive educational experiences, although there are barriers such as cost, connectivity, and device management.

CoSpaces Edu Training & Projects (n.d.) provides the ability to programme and animate objects, supports the design of interactive AR/VR scenes, and joint editing of projects, which encourages creativity and project thinking. Merge Cube (n.d.), which allows interacting with virtual 3D objects in hands and using them to study anatomy, geography, chemistry, and STEM (Science, Technology, Engineering, Mathematics) modelling. Contemporary educational technologies that include virtual reality, augmented reality, and mixed reality provide opportunities for developing students' practical skills, creative and critical thinking (Thangavel *et al.*, 2025). Augmented reality on tablets and smartphones overlays digital objects on the real world, allowing to demonstrate learning models, experimental processes, or interactive circuits without completely disconnecting from the physical environment, and is convenient for quickly explaining complex topics in natural, technical, or humanitarian disciplines. Mixed reality presented by Microsoft HoloLens (n.d.) and zSpace (n.d.) combines digital and physical objects, allowing the user to simultaneously interact with both, control models with gestures and voice, which creates an effective environment for modelling professional processes, conducting joint projects and educational demonstrations. Thus, all these technologies differ in the level of immersion, type of interaction, and opportunities for developing practical, creative, and collective skills (Table 1). Fully immersive systems and mixed reality are most suitable for practical and professional simulations, while augmented reality effectively demonstrates objects in a physical environment, virtual laboratories provide safe experiments, and panoramic environments support visual cognition of the world and stimulate learning activity. Together, these formats form a fully digital educational environment in which the student can immerse themselves in educational content and interact with objects and tools using controllers or touch devices. The table shows that different formats of XR technologies differ in functionality and pedagogical potential. Thus, fully immersive VR provides the deepest sense of presence and allows simulating complex situations, but requires special equipment and limits large-scale group interaction. AR, on the other hand, is more accessible and easier to use, giving students the freedom to choose the material, but provides a lower level of immersion. MR combines the advantages of both approaches, enabling the work with holographic objects in real space and maintaining a high level of interactivity and analytical capabilities, although its implementation is constrained by cost and technical complexity. In general, the data show that each format has its own educational advantages: VR enhances immersion and decision-making, AR – accessibility and practical interaction, and MR – spatial thinking and depth of analytical work, which allows choosing the best solutions in accordance with the educational goals and resource capabilities of the educational institution.

Table 1. Content analysis of VR, AR, and MR technologies in school education

XR type/ Platform	Immersion level	Interactivity	Personalisation and adaptation	Development of critical and creative thinking	Teamwork and communication	Technical accessibility and ease of use
Fully immersive VR (Class VR; Engage VR)	High level of immersion. Students find themselves inside recreated historical battles or natural locations, can move, view objects in 360°	Students manipulate objects, interact with NPCs (Non-Player Characters), and complete tasks in scenarios	Ability to choose the mission difficulty level or route in VR, but changes are limited to content	Necessary to make decisions in simulated situations, for example, plan a strategy in battle	Limited: two or three students can simultaneously be in space and coordinate actions	Requires special helmets, sensors, and a personal computer with a powerful video card; installation is difficult
Augmented reality AR (Merge Cube; CoSpaces Edu Training & Projects)	Average level of immersion. Students can see real classrooms/squares with superimposed 3D objects, such as historical monuments in the classroom or animals in geography	Ability to rotate, scale, view 3D objects, and perform the "find an object" task	Students choose their own subject or topic for research in the application	Analyse the location of objects and make comparisons between models	Students can work in pairs by commenting or adding their own notes	Available on devices that are already in school; applications are installed quickly
Mixed reality (Microsoft HoloLens; zSpace)	High level of immersion. Students can see real space and holograms, such as architectural models of locks on the desk	Ability to move holograms, take them apart, and take measurements	Ability to select the level of detail of the model or display additional data	Students analyse the structure of objects, find errors in constructions	Limited: up to 4 students work with the same model simutaneously	Helmets are expensive, require customisation, and teacher training is required

Source: compiled by the authors based on the study of Microsoft HoloLens (n.d.), CoSpaces Edu Training & Projects (n.d.), Engage (n.d.), zSpace (n.d.), Merge Cube (n.d.), Engage VR (n.d.)

Assessment of the integration of VR, AR and MR technologies in the teaching of geography, history, ecology, and their impact on the assimilation of educational material

To ensure the validity of the experimental study and the correctness of further comparative analysis of the influence of VR, AR, and MR technologies on the assimilation of educational material at the initial stage, the same starting conditions were created for the control and experimental groups. All students were enrolled in an identical curriculum in History, Geography, and Ecology, had a comparable level of preliminary training, and were not informed about the use of immersive technologies in the educational process before starting the experiment. This made helped to minimise the impact of external factors and ensure comparability of results between groups.

Initial testing was carried out before the introduction of any VR, AR, or MR tools and was aimed at fixing the basic level of subject knowledge of students. The assessment used author-developed tests with identical questions for both groups, covering key topics from three academic disciplines. The results obtained allowed testing the uniformity of the sample and substantiating further use of experimental design to evaluate the effect of implementing XR technologies. Table 2 shows the results of students' pre-experiment testing, presented as a percentage of correct answers for each question on History, Geography, and Ecology for the control and experimental groups. A summary of the results of the initial testing presented in Table 2 indicates a comparable level of educational training of the control and experimental groups in History, Geography, and Ecology. The average percentage of correct answers from History in the control group was approximately 54-55%, while in the experimental group it was 53-54%, which corresponds to a difference of about 1 percentage point. A similar situation was observed in Geography: the average indicators of correct answers in CG and EG ranged from 52-53%, and the difference between the groups did not exceed 1-2 percentage points. In Ecology, both groups showed slightly higher results compared to other subjects: the average level of correct answers in the control group was approximately 58-59%, in the experimental group – 57-58%, with a total difference between the groups of about 1 percentage point. The overall average score for all three disciplines in the control group was slightly higher than in the experimental group, but the total difference did not exceed 1-2%, which indicates the uniformity of the sample at the initial stage of the study. Analysis of the structure of academic achievement shows that students of both groups learned better tasks focused on factual and applied knowledge related to specific historical events, geographical objects, or environmental phenomena that can be observed in real life. Instead, questions that required abstract thinking, generalisation, or understanding of complex causal relationships were more difficult for a significant proportion of students, regardless of the group. This distribution of results indicates the predominance of reproductive and applied levels of knowledge acquisition before the start of experimental training. Thus, the data obtained confirm the absence of significant differences between the control and experimental groups in terms of the level and structure of initial knowledge, which creates correct methodological prerequisites for further analysis of the influence of VR, AR, and MR technologies on the dynamics of students' academic achievements. Table 3 shows the test results after the experiment was completed.

Table 2. Results of testing students before the experiment

Question	A (CG/EG) %	B (CG/EG) %	C (CG/EG) %	D (CG/EG) %
What was the main function of castles in medieval Scotland?	12/13	63/62	15/14	10/11
What weapons were most common during the Battle of Bannockburn?	18/17	52/53	10/11	20/19
What was the main reason for the rapid urbanisation in Victorian Scotland?	10/11	66/65	12/13	12/11
What element was an important part of the Scottish Highland clan culture?	9/10	71/70	12/11	8/9
Who built the Hadrian's wall?	7/8	10/9	72/71	11/12
What is the name of Scotland's main mountain region?	14/13	64/63	12/13	10/11
What type of terrain does Arthur's Seat in Edinburgh belong to?	11/12	9/8	68/67	12/13
What is the most important resource for the coastal regions of Scotland?	58/57	16/17	10/11	16/15
What is the typical climate for Scotland?	6/7	9/10	72/71	13/12
What is the most likely cause of soil depletion in pastures?	61/60	14/15	12/11	13/14
What process corresponds to the transfer of nutrients in the soil to plants?	8/9	11/12	69/68	12/11
What process describes rain formation?	10/11	74/73	9/10	7/6
Who is at the top of any food chain?	14/15	62/61	12/13	12/11
Which gas is the main factor in the greenhouse effect?	13/12	11/12	63/64	13/12
What is required to preserve biodiversity in an ecosystem?	11/12	10/9	68/67	11/12

Source: compiled by the authors based on a pedagogical experiment

Table 3. Results of testing students after the experiment

Question	A (CG/EG) %	B (CG/EG) %	C (CG/EG) %	D (CG/EG) %
What was the main function of castles in medieval Scotland?	13/8	64/78	14/10	9/4
What weapons were most common during the Battle of Bannockburn?	19/10	51/76	11/8	19/6
What was the main reason for the rapid urbanisation in Victorian Scotland?	11/7	65/79	13/8	11/6
What element was an important part of the Scottish Highland clan culture?	10/5	72/80	11/9	7/6
Who built the Hadrian's wall?	8/5	9/9	71/82	12/4
What is the name of Scotland's main mountain region?	15/9	63/77	11/8	11/6
What type of terrain does Arthur's Seat in Edinburgh belong to?	12/7	10/10	67/78	11/5
What is the most important resource for the coastal regions of Scotland?	59/45	15/20	11/12	15/23
What is the typical climate for Scotland?	7/4	8/10	71/80	14/6
What is the most likely cause of soil depletion in pastures?	60/45	15/18	13/14	12/23
What process corresponds to the transfer of nutrients in the soil to plants?	9/5	12/10	68/80	11/5
What process describes rain formation?	11/7	73/81	10/8	6/4
Who is at the top of any food chain?	15/9	61/78	11/8	13/5
Which gas is the main factor in the greenhouse effect?	12/8	12/10	62/79	14/3
What is required to preserve biodiversity in an ecosystem?	10/7	11/10	69/81	12/2

Source: compiled by the authors based on a pedagogical experiment

After completing the experimental stage of training, there were clear differences between the control and experimental groups in all three academic disciplines. In the control group, which studied according to the conventional curriculum using printed materials, frontal explanations, and standard practical tasks, the overall level of academic achievement remained close to the initial indicators. Instead, in the experimental group, where VR, AR, and virtual laboratories were systematically used, there was a significant increase in the average percentage of correct answers.

As part of the History course, the average number of correct answers in the experimental group exceeded the corresponding number in the control group by about 10-15 percentage points. The greatest increase was observed in tasks related to spatial and contextual understanding of historical objects and events. This is explained by the fact that the students of the experimental group worked with virtual reconstructions of medieval castles, interactive models of historical battles, and three-dimensional visualisations of cultural artefacts, which contributed to the development of a holistic view of the historical space and socio-cultural context of the era. In terms of Geography, the difference between the groups was also stable and averaged 10-14 percentage points in favour of the experimental group. The use of VR panoramas, 3D terrain models, and AR visualisations of geographical objects allowed students of the experimental group to better navigate the spatial characteristics of Regions, terrain features, and climatic conditions. In the control group, the assimilation of these topics was mainly limited to the reproduction of educational material. The most noticeable effect of using immersive technologies was observed in the Ecology course, where the difference between the average indicators of the experimental and control groups reached 12-16 percentage points. Students in the experimental group demonstrated a better ability to explain dynamic natural processes, in particular, the cycle of substances, atmospheric phenomena, and relationships in ecosystems. This is conditioned by the use of virtual laboratories and simulations that allowed observing processes in development, and not just in a static description.

Thus, the results obtained confirm that the introduction of VR, AR, and other immersive technologies in the educational process provided not only a quantitative increase in correct answers, but also qualitative changes in the knowledge structure of students in the experimental group. In contrast to the control group, where the reproductive level of material assimilation dominated, the experimental group increased elements of applied and analytical thinking, which creates prerequisites for deeper and more stable learning. Table 4 presents the results of an expert assessment of students' level of engagement, cooperation, and self-regulation.

Table 4. Teachers' assessment of students' level of engagement, cooperation, and self-regulation in subjects (5-point scale)

Subject	Engagement (M ± SD)	Cooperation (M ± SD)	Self-regulation (M ± SD)
History	4.2 ± 0.5	4.0 ± 0.6	3.9 ± 0.5
Geography	4.1 ± 0.6	3.9 ± 0.6	3.8 ± 0.5
Ecology	4.3 ± 0.5	4.1 ± 0.5	4.0 ± 0.5

Source: compiled by the authors based on Likert scale (Koo & Yang, 2025)

Analysis of the results showed that the highest level of student engagement was observed when studying Ecology, while in History and Geography courses this indicator was slightly lower. A similar trend was observed in relation to cooperation: students who studied Ecology showed a greater tendency to work together compared to other subjects, while in Geography this indicator was the least pronounced. The level of self-regulation was also highest in the Ecology course, while in History and Geography studies it was characterised by moderately lower values. In general, the results obtained indicated more favourable conditions for the development of active participation, interaction and independence of students in the process of studying ecology in comparison with other subjects. In general, teachers' assessments indicate a high level of activity, interaction, and self-learning ability of students, with small differences between subjects, with ecology standing out as the discipline with the greatest engagement and effective collaboration. Table 5 provides comparative data on the level of student engagement, collaboration, and self-regulation between the experimental and control groups.

Table 5. Comparison of students' level of engagement, collaboration, and self-regulation

Indicator	Experimental group (M ± SD)	Control group (M ± SD)	F	p	η^2
Engagement	4.3 ± 0.5	3.6 ± 0.6	15.21	<0.005	0.25
Cooperation	4.1 ± 0.6	3.5 ± 0.7	11.47	0.005	0.20
Self-regulation	4.0 ± 0.5	3.4 ± 0.6	13.05	<0.005	0.22

Note: effect value $\eta^2 \approx 0.01$ – small effect; $\eta^2 \approx 0.06$ – average effect; $\eta^2 \geq 0.14$ – large effect; $p \leq 0.05$ – statistically significant difference; $p > 0.05$ – no statistically significant differences were found

Source: compiled by the authors based on the ANOVA method

Analysis of the average values showed that the experimental group showed higher levels of engagement, collaboration, and self-regulation compared to the control group. The results obtained showed that the introduction of an experimental approach affected the nature of students' learning activities. In the experimental group, a higher level of involvement in the educational process was observed, which indicated an increase in interest, active participation and motivation compared to the conventional organisation of training. Cooperation between students was also more pronounced, which was manifested in readiness to perform tasks together, mutual support, and exchange of ideas. The level of self-regulation in the experimental group indicated a better ability of students to plan their own activities, monitor the performance of educational tasks, and be responsible for learning outcomes. But in the control group, these characteristics were less pronounced, which indicated the limited possibilities of conventional methods in the development of active, collaborative, oriented, and independent learning behaviour of students. ANOVA statistical analysis confirmed a significant difference between the groups for all indicators ($p \leq 0.05$), which indicates a noticeable effect of using innovative technologies. The best results of the experimental group are explained by the use of MR, AR, and VR technologies, which contributed to greater interest of students, active interaction during training and the development of skills of independent organisation of the educational process. Interactivity and visibility of the material in virtual environments allowed students to better assimilate knowledge and collaborate more effectively, which was reflected in the increased average indicators.

Based on the analysis of contemporary educational technologies and the experience of school education in Scotland, an algorithm for involving virtual learning environments in the secondary school educational process was formulated. The algorithm covers several consecutive stages that ensure effective integration of immersive technologies (VR, AR, MR) into training programmes. Table 6 provides a structured step-by-step algorithm for implementing virtual learning environments, which summarises the key steps of their successful adaptation to school education.

Table 6. Algorithm for involving virtual learning environments in the learning process

Stage	Stage content	Key actions
1. Analysis of the needs of the educational process	Identification of learning topics and competencies where immersive technologies can improve efficiency	curriculum analysis; identification of topics where visualisation/modelling is required; school readiness assessment
2. VR integration planning	Development of a plan for using virtual learning environments in specific subjects and age groups	selection of VR/AR/MR resources; planning lessons with immersive activities; preparation of methodological materials
3. Technical and pedagogical training	Ensuring technical conditions and readiness of teachers	equipment setup; teacher training; development of safety instructions
4. Conducting lessons	Implementation of interactive immersive activities in the educational process	use of virtual laboratories, simulations, excursions; support of students during work; monitoring of educational activities
5. Evaluation of results and improvement	Analysis of the effectiveness of using immersive technologies and correction of approaches	collecting feedback; analysing student performance; optimising lesson scenarios

Source: compiled by the authors based on own research

The practical application of the algorithm assumes that the school first identifies learning topics and competencies that can be enhanced with immersive digital tools, and then prepares the technical infrastructure. At the final stage, the school evaluates the effectiveness of using immersive technologies, updates methodological strategies, and plans further development of components of the virtual learning environment. Thus, the proposed algorithm provides a systematic integration of virtual learning environments into school education and a holistic and pedagogically sound implementation of XR technologies, making learning more interactive, efficient and adapted to the needs of students. It helps to increase students' motivation and interest, deepen their understanding of complex concepts through immersive exercises, develop practical, creative, and critical skills, improve digital competence, and create conditions for continuous improvement of the educational process.

DISCUSSION

In school education in Scotland, virtual learning environments are used to conduct immersive lessons, virtual excursions, research historical events and support career guidance for high school students, which helps to increase motivation and develop students' practical skills. Augmented, virtual, and mixed reality technologies create an interactive educational environment in which students can simultaneously interact with digital and physical objects. Providing schools with immersive devices and implementing national methodological guidelines allows developing digital competencies, critical thinking, cooperation, and self-regulation skills. The use of XR technologies in training contributes to the development of both subject competencies (deeper study of material on History, Geography, and Ecology) and metasubjects – critical thinking, self-regulation, planning, information analysis, and effective interaction. Due to the immersive, interactive, and practical nature of such technologies, students have the opportunity to experiment, model situations, and apply knowledge in a virtual environment.

The conclusions obtained were consistent with the opinion expressed by A. Barrable (2019) that a virtual educational environment forms students' ability to make independent decisions and supports learning activity. In addition, the results were consistent with the observations of M. Adhikariparajuli *et al.* (2021), who found that integrated approaches to reporting and evaluation in education, in particular testing, improve management efficiency and promote transparency of educational processes in Scotland, Northern Ireland, and Wales. After the experiment, students showed an improvement in knowledge and skills in History, Geography, and Ecology, which was confirmed by an increased percentage of correct answers in standardised tests, and the development of skills to analyse information, work in a team, and independently plan educational activities due to the integration of VR, AR, and MR technologies into the educational process. The study showed similarities with the study by J. Crow & J. Murray (2020), where the virtual learning environment was presented as a resource for building a community that fostered a sense of belonging and emotional presence. It was found that this sense of inclusion increased students' readiness for active interaction and long-term digital engagement. However, the results obtained regarding adaptive approaches in virtual learning were confirmed in the conclusions of U. Apoki *et al.* (2022), S. Chandra *et al.* (2022), who emphasised the effectiveness of various types of virtual learning. Students can use various types of virtual reality in their studies, including VR simulations for modelling historical events or natural processes, virtual laboratories for conducting experiments in Chemistry, Physics and Biology, 360° videos and panoramas for virtual excursions and geographical landscapes research, AR applications on tablets and smartphones for interactive study of objects and phenomena in a real environment, and MR environments for creating and interacting with 3D models and group projects in a mixed real and virtual space.

After the experiment, the experimental group showed an improvement in results compared to the control group in questions on History, Geography, and Ecology, where the percentage of correct answers increased to 76-81%, while in the control group the indicators remained almost at the previous level of 52-74%. Parallel conclusions were observed in the papers by R. Al-Maroof *et al.* (2021), Z. Duraku & L. Hoxha (2020), which pointed out the effectiveness of using VR, AR, and MR technologies in teaching, which depends on several factors, in particular, on the quality and interactivity of digital content, the level of immersion of students in a virtual environment, the regularity and duration of classes. The study defined virtual reality as an interactive digital environment that completely immerses the user in simulated reality using special devices, such as VR helmets or touch controllers, creating a sense of presence in another space. It includes 3D models of objects and locations, interactive simulations, audio-visual effects, the ability to interact with digital objects and the environment, and tools for educational, research, or entertainment tasks. Similar conclusions were obtained by B. Danmuchikwali & M. Suleiman (2020) and D. Bahanshal & I. Khan (2021), who emphasised that virtual reality is effective when its use has a clear educational or practical purpose and is integrated into the educational process as an additional tool, rather than as a replacement for conventional methods. It should be used to increase motivation, develop critical thinking, practical skills, and develop competencies through interactive and immersive tasks.

The average values of engagement, collaboration, and self-regulation were also higher in the experimental group (4.0-4.3) compared to the control group (3.4-3.6), which indicates that the use of VR, AR, and MR technologies contributed to better assimilation of the material, active interaction between students, and the development of their key competencies. This was confirmed in the results of the study by Y. Gambo & M.Z. Shakir (2021), who noted that virtual learning environments encourage the development of learning material processing and learning planning strategies. This shows that virtual platforms can create conditions for the development of autonomy and responsibility for the educational process. The results obtained during the analysis of the use of virtual tools in training indicate an improvement in critical thinking skills, which is partly consistent with the conclusions of J. Hsiao & J. Chang (2023) and S. Cruywagen & H. Potgieter (2020), who pointed out that critical thinking in learning is necessary because it allows students not only to remember information, but also to analyse, compare, and evaluate different sources and ideas. It promotes the ability to draw informed conclusions, solve problems, make informed decisions, and effectively apply knowledge in various life and professional situations. In addition, according to A. Kundu & T. Bej (2020), the availability of integrated digital resources contributes to higher levels of student engagement and engagement during tasks, reflecting their willingness to use technology for learning. Students were evaluated for their level of engagement, collaboration, and self-regulation, which showed higher rates in the experimental group due to the use of VR technologies.

The study by K. Martzoukou *et al.* (2020) found that having skills to use online resources effectively makes it easier to complete tasks and allows for more active participation in learning. The results showed that since the control group was trained using standard methods without using VR technologies, its results remained lower compared to the experimental group. This trend supports assumptions about the need to develop digital skills, namely the study by I. El-Sayed Ebaid (2020) found that students should be instructed to effectively interact with virtual learning platforms. In this study, students in the experimental group were pre-instructed on the safe use of VR equipment, which included rules for setting up helmets, maintaining a proper fit, avoiding prolonged use without interruptions, safe movement in space, and behaviour when working with interactive environments.

The proposed algorithm for integrating virtual reality into school education fully coincides with the conclusions of a number of researchers regarding the influence of digital and immersive environments on the educational process. As noted by M. Shoaib *et al.* (2025), adapting VR and AR platforms to the needs of different groups of learners helps to increase their engagement and learning effectiveness, while interactive tasks and teamwork stimulate the development of critical thinking and collaboration, which is consistent with the findings of Z. Yu & M. Li (2022) and A. Oke & F. Fernandes (2020). The use of gamification elements in the algorithm, in particular, project tasks, 3D modelling, and 360° video, supports internal motivation and regular activity of students, which confirms the conclusions of J. Xu *et al.* (2021). Thus, the results of the study showed that a systematic approach to the introduction of virtual reality and the integration of interactive game elements correspond to previously identified patterns of improving learning efficiency and developing key competencies of students. The results obtained showed that the use of virtual reality platforms contributes to improving the study of educational material in various subjects and the development of competencies. Students can improve their knowledge and skills through active use of interactive technologies, practical exercises in virtual environments, participation in group projects and independent analysis of the material, which contributes to the development of critical thinking, self-regulation, and skills to apply knowledge in practice.

CONCLUSIONS

The content analysis of the use of XR technologies in school education in Scotland showed that various formats of virtual, augmented, and mixed reality form a multi-level digital learning environment with varying degrees of immersion and pedagogical potential. VR technologies provide a high level of immersion and create conditions for modelling complex historical, natural and scientific scenarios, which contributes to the development of strategic and spatial thinking, provided that appropriate technical support is available. AR tools are more accessible and support analytical and comparative study of educational material, while MR technologies combine physical space and holographic objects, deepening understanding of complex structures and relationships, although their practical implementation is limited by technical complexity and cost.

The results of the pedagogical experiment confirmed the comparable initial level of training of the control and experimental groups in History, Geography, and Ecology, which ensured the correctness of further analysis. After integrating VR, AR, and MR technologies, the experimental group showed a steady increase in academic achievement in all the disciplines studied, while the results of the control group remained close to the initial ones. A summary of the post-test results showed that the average level of correct answers in the experimental group exceeded the control group by about 10-15 percentage points in History, 10-14 percentage points in Geography, and 12-16 percentage points in Ecology.

The resulting dynamics indicates not only a quantitative improvement in the results, but also a change in the nature of the assimilation of educational material – from mainly reproducible to a more applied and analytical level, especially in topics related to spatial representations and dynamic natural processes. Along with the growth of subject results, positive changes in the learning behaviour of students in the experimental group were recorded: increased levels of engagement, cooperation, and self-regulation, which was confirmed by statistically significant differences with a large effect size. Summarising the results of the study, it can be concluded that the integration of immersive technologies into the educational process of secondary schools creates favourable conditions for a deeper understanding of educational material, the development of critical thinking, and the development of skills for independent organisation of training. Prospects for further research are related to the integration of artificial intelligence to personalise learning and support adaptive educational platforms.

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