

Integrating AI-Generated 3D/360° Content into VR-Based Secondary Education

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Abstract: This paper presents a pedagogical framework for integrating AI-generated educational content into Virtual Reality (VR)-based teaching within SmartLab-supported secondary education. The framework addresses the limited classroom adoption of AI and immersive technologies by combining AI-assisted content generation, VR integration, interdisciplinary SmartLab activities, and evaluation of learning outcomes into a structured teacher-centred workflow. The framework was implemented during the second semester of the 2025–2026 academic year in a Romanian technological high school, involving 702 secondary school students and 35 master's students who collaboratively designed and delivered 11 interdisciplinary SmartLab lessons. The evaluation combined classroom observations, Kahoot assessments, discussions, and an anonymous questionnaire completed by 550 students. The results indicate increased student engagement, motivation, interdisciplinary understanding, and positive perceptions of AI-assisted immersive learning. The study demonstrates that integrating AI-generated educational resources with VR technologies enhances classroom interaction while supporting the preparation of future teachers through interdisciplinary practice. The proposed framework provides a scalable model for the digital transformation of secondary education and can be adapted to different educational contexts.

Keywords: Artificial Intelligence, Virtual Reality, SmartLab, Secondary Education, Interdisciplinary Learning, Teacher Training.

1. Introduction

The rapid development of digital technologies has transformed contemporary education, with Artificial Intelligence (AI) and Virtual Reality (VR) emerging as key components of Education 4.0. These technologies support immersive, interactive, and student-centred learning while fostering digital competencies required in modern educational environments (Crompton and Burke, 2023; Tlili et al., 2023; European Commission, 2021). Virtual Reality enables students to explore complex concepts through immersive three-dimensional environments, improving engagement, motivation, conceptual understanding, and knowledge retention. At the same time, generative AI facilitates the creation of educational resources such as images, videos, 3D models, and 360° learning environments, reducing the effort required for developing immersive learning materials (Radianti et al., 2020; Hamilton et al., 2021; Lee and Liu, 2025).

Despite these advances, the integration of AI and VR into secondary education remains limited due to challenges related to infrastructure, teacher preparation, curriculum alignment, and the lack of structured pedagogical models. SmartLab environments provide suitable technological infrastructure, but their educational value depends on effective pedagogical integration rather than technology alone. This paper proposes a pedagogical framework for integrating AI-generated educational resources into VR-supported interdisciplinary teaching within SmartLab environments. The framework combines AI-assisted content generation, immersive VR learning, interdisciplinary instructional design, and teacher-guided implementation into a structured workflow suitable for secondary education.

The framework was implemented during the second semester of the 2025–2026 academic year in a Romanian technological high school involving 702 secondary school students and 35 master's students, who collaboratively designed and delivered 11 interdisciplinary SmartLab lessons. The framework was evaluated through classroom observations, Kahoot assessments, classroom discussions, and an anonymous questionnaire completed by 550 students. The main contributions of this study are: (1) the development of a scalable pedagogical framework integrating AI, VR, and SmartLab technologies; (2) its validation through large-scale classroom implementation; (3) the introduction of a collaborative model supporting the preparation of future teachers; and (4) empirical evidence regarding students' perceptions of AI-assisted immersive learning, contributing to research on digital transformation in secondary education (European Commission, 2021; Crompton and Burke, 2023; Tlili et al., 2023).

2. Literature Review / Related Work

2.1 Virtual Reality in Education

Virtual Reality (VR) has become an important educational technology due to its ability to create immersive and interactive learning experiences. Unlike traditional teaching methods, VR enables students to explore simulated environments that enhance engagement, motivation, conceptual understanding, and knowledge retention, particularly in subjects involving abstract or complex concepts (Radianti et al., 2020; Hamilton et al., 2021).

VR has been successfully applied across disciplines such as science, engineering, medicine, geography, and vocational education, supporting experiential learning through visualization, exploration, and active participation (Dede, 2009; Pirker and Dengel, 2021).

Despite these benefits, the adoption of VR in schools remains limited by infrastructure costs, teacher preparation, and the lack of structured pedagogical models for curriculum integration (Song et al., 2024; Liu et al., 2025). Moreover, relatively few studies report large-scale classroom implementations in secondary education or address interdisciplinary teaching and teacher training within authentic school environments (Lee and Liu, 2025; Zagami, 2025).

2.2 Artificial Intelligence and AI-Generated Educational Content

Artificial Intelligence (AI), particularly generative AI, has become an important educational technology by enabling the rapid creation of images, videos, simulations, 3D models, and other learning resources. These tools support personalized and interactive learning while reducing the time required for educational content development (Crompton and Burke, 2023; Tlili et al., 2023). Recent advances in generative AI have expanded its application to adaptive learning environments, intelligent tutoring systems, and immersive educational resources, supporting student-centred learning and improving the accessibility of digital education (Brown et al., 2020; OpenAI, 2023; Song et al., 2024). However, the adoption of AI in education remains challenged by concerns regarding content quality, ethical issues, teacher preparedness, and pedagogical integration. Moreover, most existing studies investigate AI or VR independently, with relatively few proposing structured pedagogical frameworks that combine AI-generated immersive content, Virtual Reality, interdisciplinary learning, and teacher preparation within authentic classroom settings (Tzirides et al., 2024; Liu et al., 2025).

2.3 Smart Learning Environments and SmartLabs

Therefore, there is a growing need for scalable pedagogical frameworks that combine Artificial Intelligence, Virtual Reality, SmartLab infrastructure, and interdisciplinary instructional design while remaining accessible to practicing teachers. (Gros, 2016). Furthermore, there is limited evidence regarding the implementation of such frameworks at a large educational scale or their role in preparing future teachers for technology-enhanced instruction. This study addresses these research gaps by proposing and validating a teacher-centred pedagogical framework implemented in a real SmartLab environment involving 702 secondary education students and 35 master's students from multiple academic disciplines. (European Commission, 2021).

Table 1: SmartLab Technologies and Educational Activities Implemented During the Study

Technology	Educational Use in This Study	Pedagogical Purpose
ClassVR Premium	Immersive exploration of AI-generated educational content	Experiential and interdisciplinary learning
Educational Robotics	Programming and automation activities	Computational thinking
Artificial Intelligence	Creation of images, 3D models, 360° environments and educational videos	Personalized educational content
Interactive Whiteboard	Classroom collaboration	Teacher-guided instruction
Arduino Platforms	STEM activities	Problem-solving
3D Printer & Scanner	Engineering and modelling	Practical digital competencies

3. Proposed Pedagogical Framework

The proposed pedagogical framework supports the integration of Artificial Intelligence (AI), Virtual Reality (VR), and SmartLab technologies into interdisciplinary secondary education. Unlike approaches focusing on individual technologies, it combines AI-assisted content generation, immersive learning, classroom implementation, and learning evaluation within a scalable teacher-centred workflow. The framework promotes interdisciplinary collaboration and experiential learning while maintaining alignment with curricular objectives (Brown et al., 2020; Song et al., 2024). A distinctive feature of the framework is the involvement of master's students in designing and delivering interdisciplinary SmartLab activities under pedagogical supervision. This collaborative approach supports both secondary school students and the professional development of future teachers. The framework consists of four stages: (1) AI-assisted educational content generation, (2) transformation into VR-compatible learning environments, (3) SmartLab-based classroom implementation, and (4) evaluation of learning outcomes and student engagement (Figure 1).

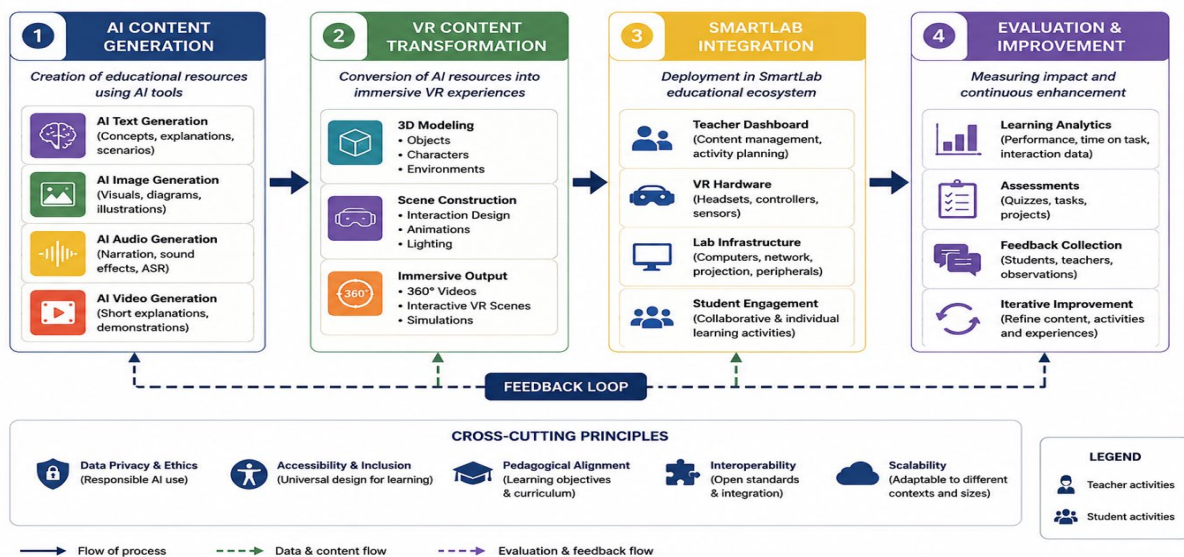


Figure 1: Framework Architecture for AI-Generated VR Learning Environments in SmartLab Ecosystems

3.1 AI-Based Educational Content Generation

The first stage of the framework focuses on generating educational resources using Artificial Intelligence. Generative AI enables the rapid creation of images, 3D models, simulations, videos, and other digital materials that can be adapted to different learning objectives and transformed into immersive VR experiences (OpenAI, 2023; Song et al., 2024). Within the proposed framework, AI-assisted resources support the development of interdisciplinary learning materials while reducing the time and effort required for content creation. Teachers remain responsible for selecting, adapting, and validating all AI-generated materials to ensure their pedagogical relevance and alignment with curriculum objectives. During the implementation, master's students selected AI tools according to the objectives of each lesson and produced images, 3D models, 360° panoramas, educational videos, and other digital resources, which were reviewed by the teaching staff before classroom use (Tili et al., 2023).

3.2 Transformation into Immersive VR-Compatible Environments

The second stage transforms AI-generated educational resources into immersive VR-compatible environments, including interactive 3D models and 360° learning spaces that can be explored using VR technologies (Radianti et al., 2020; Lee and Liu, 2025). These immersive environments support experiential learning by enabling students to explore, observe, and interact with educational content, improving engagement and conceptual understanding compared with traditional instructional materials (Hamilton et al., 2021). The framework includes virtual laboratories, interactive simulations, and 360° educational scenarios compatible with SmartLab infrastructure and ClassVR devices (Pirker and Dengel, 2021). During implementation, students explored virtual environments, identified objects, observed complex processes, interacted with multimedia resources, and

completed inquiry-based activities using the ClassVR interactive joystick. The emphasis remained on achieving learning objectives rather than on technological novelty.

3.3 Integration into Classroom Activities Using SmartLab Infrastructure

The third stage integrates immersive VR activities into classroom teaching using SmartLab infrastructure. Lessons followed a common 50-minute structure consisting of an introduction, presentation of theoretical concepts, 15–30 minutes of VR exploration, collaborative discussion, and formative assessment. The SmartLab laboratory included 16 ClassVR Premium headsets, allowing students to participate in successive groups or collaborative pairs while maintaining continuous engagement. Teachers integrated VR activities through structured pedagogical scenarios aligned with curriculum objectives. Immersive technologies complemented traditional instruction by supporting guided exploration, collaboration, and problem-solving under continuous teacher supervision (Gros, 2016; European Commission, 2021). Beyond VR, the SmartLab environment incorporated interactive whiteboards, educational robotics, Arduino kits, a 3D printer, a 3D scanner, multimedia systems, and 30 educational laptops. These technologies supported interdisciplinary STEM activities and enriched authentic classroom learning experiences (Radianti et al., 2020).

3.4 Evaluation of Learning Outcomes and Student Engagement

The proposed framework was evaluated using a mixed-method approach combining systematic classroom observation, Kahoot assessments, classroom discussions, and an anonymous student questionnaire. This strategy provided quantitative and qualitative evidence regarding student engagement, motivation, collaboration, and learning outcomes. The implementation involved 702 secondary school students, of whom 550 completed the post-activity questionnaire. The collected data enabled the evaluation of student engagement, interdisciplinary learning, digital competence, and overall satisfaction with the proposed framework. The results are presented in the following section. The evaluation also identified challenges related to technical limitations, teacher preparation, infrastructure, and classroom management, highlighting the importance of scalable and pedagogically sustainable approaches for integrating AI and VR into secondary education.

Table 2: Overview of the Proposed Pedagogical Framework

Framework Stage	Main Activities	Expected Educational Outcomes
AI Content Generation	Images, videos, 3D models, 360° panoramas	Personalized educational resources
VR Transformation	Immersive learning scenarios	Active exploration and visualization
SmartLab Implementation	Interdisciplinary classroom activities	Collaboration and experiential learning
Learning Evaluation	Observation, Kahoot, discussions, questionnaire	Engagement and learning assessment

Overall, the proposed pedagogical framework provides a scalable model for integrating AI-generated educational resources, Virtual Reality, and SmartLab technologies into secondary education while supporting continuous pedagogical improvement.

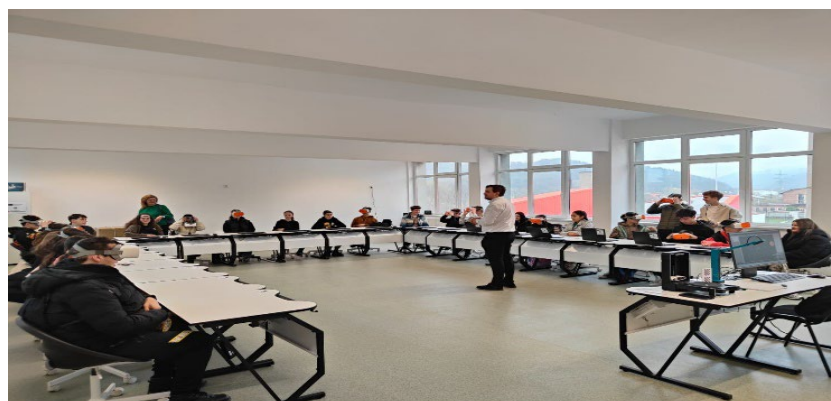


Figure 2: Overview of the SmartLab educational ecosystem integrating VR technologies and collaborative interdisciplinary activities.

4. Case Study

4.1 Educational Context

The proposed pedagogical framework was implemented during the second semester of the 2025–2026 academic year (March–June 2026) in a Romanian technological high school equipped with SmartLab infrastructure. The study was conducted during regular classroom activities to evaluate the practical integration of Artificial Intelligence (AI), Virtual Reality (VR), and interdisciplinary teaching in secondary education. The implementation involved 702 secondary school students from full-time, vocational, and evening education programmes, with an average class size of approximately 24 students. A total of 35 master's students from the Faculty of Science and Engineering participated as future teachers. Representing disciplines such as Mathematics, Computer Science, Biology, Chemistry, Environmental Protection, Economics, and Computer Engineering, they worked in interdisciplinary teams to design and deliver 11 SmartLab lessons under the supervision of the principal researcher. Before classroom implementation, the master's students completed training covering AI, VR, SmartLab technologies, lesson planning, and hands-on practice with the equipment. Each lesson lasted 50 minutes and followed a common pedagogical structure while allowing flexibility according to the educational topic.

Table 3: Participants involved in the educational implementation

Participant Group	Number of Participants
Full-Time Secondary Education Students (Grades 9–12)	305
Vocational Education Students (Grades 9–11)	202
Evening Education Students (Grades 9–13)	195
Total Secondary Education Students	702
Master's Students (Future Teachers)	35

4.2 SmartLab Infrastructure and Technological Environment

The educational implementation was conducted in a SmartLab environment designed to support immersive and interdisciplinary learning through Artificial Intelligence (AI), Virtual Reality (VR), educational robotics, and digital technologies. The laboratory was equipped with 16 ClassVR Premium headsets, enabling students to participate in immersive 3D and 360° learning experiences. Because the number of devices was smaller than the average class size, students worked in successive groups or collaborative pairs, ensuring active participation throughout each lesson. Additional equipment included 30 educational laptops, an interactive whiteboard, a 3D printer, a 3D scanner, Arduino kits, mBot2, Fable GO and Fable Explore robots, a digital weather station, and multimedia systems. AI tools were used to create images, 3D models, 360° panoramas, educational videos, and other learning resources integrated into the ClassVR platform. Students engaged in immersive learning through virtual exploration, object identification, multimedia interaction, educational games, and collaborative problem-solving. Minor technical issues, including occasional wireless synchronisation delays and headset sensor activation, were quickly resolved and had no significant impact on classroom activities. Overall, the SmartLab infrastructure provided an effective environment for integrating AI, VR, and interdisciplinary STEM education while promoting active learning, collaboration, and digital competence.

Table 4: SmartLab Infrastructure and Educational Technologies

Equipment	Educational Purpose
16 ClassVR Premium headsets	Immersive VR learning and 360° exploration
Interactive whiteboard	Teacher-guided instruction and collaborative learning
30 educational laptops	Digital content creation and classroom activities
3D printer	Prototyping and engineering education
3D scanner	Digital modelling and object digitisation
Arduino educational kits	Programming and STEM activities
mBot2 educational robots	Robotics and computational thinking

Equipment	Educational Purpose
Fable GO & Fable Explore	Educational robotics and collaborative programming
Digital weather station	Environmental monitoring and STEM investigations
High-performance audio system	Multimedia educational experiences



Figure 3: SmartLab educational environment during immersive VR-based interdisciplinary learning activities.

4.3 Learning Activities and Implementation Process

The educational implementation consisted of 11 interdisciplinary SmartLab lessons integrating Artificial Intelligence (AI), Virtual Reality (VR), and SmartLab technologies into authentic classroom instruction. The lessons were collaboratively designed by interdisciplinary teams of master's students under the supervision of the principal researcher, ensuring curriculum alignment and pedagogical coherence. AI tools were used to create educational images, 3D models, 360° panoramas, videos, and other digital resources integrated into the ClassVR platform. Each lesson followed a common 50-minute structure comprising: (1) introduction of the topic, (2) presentation of theoretical concepts, (3) 15–30 minutes of immersive VR exploration, (4) collaborative discussion, and (5) formative assessment through Kahoot and classroom reflection. Using 16 ClassVR headsets, students participated in successive groups or collaborative pairs, while those not using VR completed complementary learning tasks and discussions. Within the immersive environments, students explored virtual scenarios, identified objects, interacted with multimedia resources, and solved interdisciplinary challenges under continuous teacher guidance. One representative lesson focused on the human digestive system, integrating Biology, Chemistry, Mathematics, and ICT. Students explored immersive 3D visualisations, analysed digestive processes, calculated caloric requirements, and investigated digital applications supporting healthy lifestyles. This activity illustrated how interdisciplinary learning can connect concepts from multiple subjects within authentic educational contexts. Overall, the implementation demonstrated that combining AI, VR, and SmartLab technologies with interdisciplinary instructional design promotes active participation, collaboration, creativity, and meaningful learning in secondary education.

Table 5: Standard Structure of the Interdisciplinary SmartLab Lessons

Lesson Stage	Approximate Duration	Main Educational Activities
Introduction	5 minutes	Presentation of learning objectives and interdisciplinary topic
Theoretical preparation	10 minutes	Explanation of key concepts and classroom discussion
Immersive VR activities	15–30 minutes	Exploration of VR environments, object identification, interactive learning
Collaborative discussion	5–10 minutes	Reflection, knowledge consolidation, teamwork
Formative assessment	5 minutes	Kahoot quizzes and classroom feedback



Figure 4: Students participating in interdisciplinary SmartLab learning activities using ClassVR immersive technologies under teacher guidance.

4.4 Interdisciplinary Educational Scenarios

The interdisciplinary educational scenarios constituted a key component of the proposed framework by integrating concepts from multiple disciplines into coherent learning activities. Designed collaboratively by interdisciplinary teams of master's students under the supervision of the principal researcher, the lessons combined Artificial Intelligence, Virtual Reality, and SmartLab technologies while ensuring curriculum alignment and clear learning objectives. AI-assisted resources, including 3D models, 360° environments, educational videos, and multimedia materials, were integrated into the ClassVR platform to support immersive learning. Students engaged in virtual exploration, collaborative problem-solving, multimedia analysis, and classroom discussions, promoting inquiry-based and student-centred learning. One representative lesson focused on the Human Digestive System, integrating Biology, Chemistry, Mathematics, and ICT. Students explored immersive 3D visualisations, analysed digestive processes, calculated caloric requirements, and investigated digital applications supporting healthy lifestyles, demonstrating how interdisciplinary learning connects scientific concepts with real-world applications. Overall, the educational scenarios demonstrated that combining AI-generated resources with Virtual Reality within a structured pedagogical framework can effectively support collaborative, interdisciplinary, and experiential learning.

Table 6: Interdisciplinary Educational Scenarios Implemented During the Study

No.	Educational Scenario	Integrated Disciplines	Main Learning Objective
1	Human Digestive System	Biology, Chemistry, Mathematics, ICT	Understanding the digestive system, nutrition, caloric requirements, and digital health technologies.
2	Directed Graphs for Financial Fraud Detection	Computer Science, Economics	Applying graph theory to detect tax evasion and money laundering through real-world economic scenarios.
3	Backtracking Applications	Mathematics, Computer Science, Biology	Understanding recursive algorithms and their interdisciplinary applications through immersive learning.
4	Environmental Pollution Analysis	Environmental Protection, ICT	Analysing natural pollution factors and representing environmental data using digital technologies.
5	European Integration and Erasmus+ Budget Analysis	ICT, Economics	Analysing Erasmus+ project budgets using spreadsheet functions and immersive learning resources.
6	Creativity and Digital Entrepreneurship	Psychology, Entrepreneurship, ICT	Developing creativity, entrepreneurial thinking, collaboration, and responsible digital behaviour.
7	Electric Current and the Human Body	Biology, Electrical Engineering, Automation	Understanding electrical current, conductors, and the physiological effects of electrocution through immersive simulations.

No.	Educational Scenario	Integrated Disciplines	Main Learning Objective
8	Educational Robotics and Programming	Computer Science, Robotics	Developing computational thinking, programming skills, and problem-solving abilities using educational robots.
9	Sustainable Smart Cities	Geography, Environmental Science, ICT	Exploring sustainable urban development through immersive digital technologies and SmartLab resources.
10	Construction of the Future	Engineering, Environmental Protection, ICT	Investigating sustainable construction technologies and modern engineering solutions using immersive educational resources.
11	Nervous System and Human Creativity	Biology, Psychology, ICT	Exploring the relationship between brain functions, creativity, and digital technologies through Virtual Reality.

4.5 Evaluation Methods

The proposed pedagogical framework was evaluated using a mixed-method approach combining qualitative and quantitative assessment techniques. The evaluation included systematic classroom observation, formative Kahoot assessments, guided classroom discussions, and an anonymous Google Forms questionnaire, providing a comprehensive perspective on student engagement and learning outcomes. Classroom observations focused on students' participation, collaboration, interaction with immersive educational resources, and overall classroom behaviour. Kahoot assessments were used to evaluate conceptual understanding and provide immediate formative feedback. Following each activity, guided classroom discussions encouraged students to reflect on their VR experiences, interdisciplinary connections, and overall learning process. These discussions complemented the quantitative findings with qualitative insights. The main quantitative instrument was an anonymous questionnaire completed by 550 students (approximately 78% of participants). It included Likert-scale, multiple-choice, and open-ended questions addressing engagement, motivation, usability of VR technologies, interdisciplinary learning, digital competence, and overall satisfaction with the SmartLab experience. The combined evaluation methods provided a comprehensive assessment of the proposed framework. The statistical analysis of the questionnaire responses and the interpretation of the qualitative findings are presented in the following section.

Table 7: Evaluation Methods Used During the Educational Implementation

Evaluation Method	Purpose	Data Collected
Systematic classroom observation	Student behaviour and classroom interaction	Participation, collaboration, attention, engagement
Kahoot formative assessment	Learning outcome evaluation	Conceptual understanding and immediate feedback
Classroom discussion	Reflection and qualitative feedback	Students' perceptions and interdisciplinary understanding
Google Forms questionnaire	Quantitative and qualitative evaluation	Motivation, engagement, usability, satisfaction, digital competence

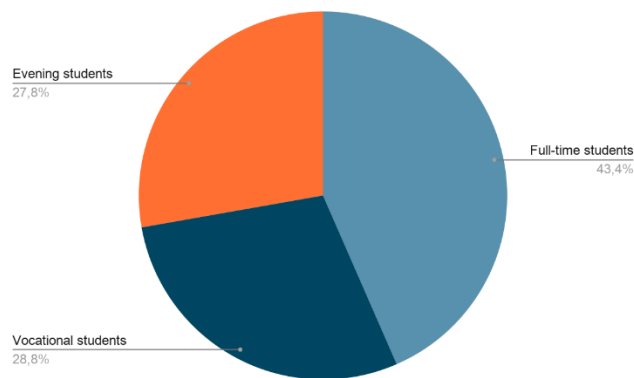
5. Results and Discussion

5.1 Questionnaire Results

An anonymous Google Forms questionnaire was administered immediately after the SmartLab activities to evaluate students' perceptions of Artificial Intelligence (AI), Virtual Reality (VR), and SmartLab technologies in secondary education. A total of 550 students (approximately 78% of all participants) completed the questionnaire, providing a representative dataset for analysing engagement, motivation, interdisciplinary learning, digital competence, and overall satisfaction with the proposed framework. The questionnaire included Likert-scale, multiple-choice, and open-ended questions. Responses were analysed using descriptive statistics, including frequencies and percentages, while qualitative answers complemented the quantitative findings. The following sections present the statistical results and their educational interpretation.

Table 8: Questionnaire Characteristics

Characteristic	Value
Total participants	702
Questionnaire respondents	550
Response rate	78.3%
Questionnaire platform	Google Forms
Question types	Likert-scale, multiple-choice, open-ended


Figure 5: Distribution of questionnaire respondents according to educational pathway.

5.2 Student Engagement and Learning Experience

The questionnaire results indicate that students perceived the interdisciplinary SmartLab activities as highly engaging and educationally valuable, with mean scores ranging from 3.82 to 4.20 on a five-point Likert scale. The highest-rated statement concerned students' willingness to participate in similar activities in the future ($M = 4.204$, $SD = 0.774$), with 81.5% of respondents selecting *Agree* or *Strongly Agree*. Similarly, students highly appreciated the educational value of AI-assisted immersive learning ($M = 4.173$, $SD = 0.752$; 82.7%) and the interactive SmartLab environment ($M = 4.178$, $SD = 0.745$; 82.5%). Virtual Reality also positively influenced classroom participation. Students reported increased attention during VR activities ($M = 4.109$, $SD = 0.768$; 79.1%), considered VR-based learning more engaging than traditional instruction ($M = 4.160$, $SD = 0.737$; 82.2%), and indicated higher learning motivation ($M = 4.029$, $SD = 0.807$; 74.4%). Regarding learning outcomes, students reported improved interest in the studied topics ($M = 4.116$, $SD = 0.778$; 79.3%), better understanding of complex concepts ($M = 3.942$, $SD = 0.879$; 70.9%), improved information retention ($M = 3.842$), and stronger interdisciplinary learning ($M = 3.818$). AI-generated educational resources were also positively evaluated ($M = 3.971$, $SD = 0.789$; 73.5%), confirming their contribution to the immersive learning experience. Overall, the findings demonstrate that integrating AI, VR, and SmartLab technologies created an engaging learning environment that promoted motivation, active participation, and interdisciplinary understanding.

Table 9: Main Student Perceptions of the Proposed Pedagogical Framework

Evaluation Dimension	Mean	Agreement (%)
Future implementation of SmartLab activities	4.204	81.5
SmartLab interactivity	4.178	82.5
Educational value	4.173	82.7
VR compared with traditional learning	4.160	82.2
Interest in the learning topic	4.116	79.3
Attention during VR activities	4.109	79.1

Evaluation Dimension	Mean	Agreement (%)
Overall satisfaction	4.042	76.5
Motivation	4.029	74.4
AI-generated educational materials	3.971	73.5
Understanding of concepts	3.942	70.9

5.3 Educational Benefits of AI-Generated Immersive Learning

The questionnaire results, classroom observations, and formative assessments indicate that the proposed pedagogical framework generated educational benefits extending beyond increased student engagement. The integration of Artificial Intelligence (AI), Virtual Reality (VR), and SmartLab technologies supported interdisciplinary learning, conceptual understanding, and the development of digital competencies. One of the main benefits was the promotion of interdisciplinary learning. By combining concepts from Biology, Chemistry, Mathematics, Computer Science, Economics, Environmental Sciences, Robotics, and Engineering, students explored authentic real-world problems and established meaningful connections across multiple disciplines. AI-assisted technologies simplified the creation of immersive educational resources, including 3D models, 360° environments, videos, and multimedia materials, allowing teachers to focus on pedagogical design rather than content production. Virtual Reality further enhanced learning by supporting visualisation, exploration, and experiential learning, contributing to improved attention, conceptual understanding, and classroom participation. The implementation also promoted digital competencies, computational thinking, creativity, collaboration, and problem-solving through the use of VR, educational robotics, AI-generated resources, and SmartLab technologies. An additional benefit concerned teacher preparation. The involvement of 35 master's students in designing and delivering interdisciplinary lessons provided authentic teaching experience and strengthened their ability to integrate emerging technologies into educational practice. Overall, the proposed framework demonstrates that combining AI, VR, and SmartLab technologies provides a scalable model for interdisciplinary, student-centred, and technology-enhanced learning in secondary education.

Table 10: Educational Benefits of the Proposed Pedagogical Framework

Educational Dimension	Observed Educational Benefit
Student engagement	Increased motivation and classroom participation
Interdisciplinary learning	Integration of knowledge across multiple subjects
Conceptual understanding	Improved visualisation of complex concepts
Digital competence	Development of digital literacy and computational thinking
Collaboration	Enhanced teamwork and peer interaction
AI-assisted learning	Rapid creation of personalised immersive educational resources
Teacher training	Practical preparation of future teachers through authentic classroom implementation

5.4 Challenges and Limitations

Although the proposed framework produced positive educational outcomes, several technical, organisational, and methodological challenges were identified. These findings provide practical recommendations for future SmartLab implementations and are consistent with recent studies on AI and Virtual Reality integration in education (Song et al., 2024; Liu et al., 2025). One challenge concerned the management of the 16 ClassVR headsets, which required students to participate in successive groups or collaborative pairs due to the average class size of 24 students. Occasional wireless synchronisation delays and headset sensor activation issues were observed but were quickly resolved by the teaching staff without affecting the learning process. Another limitation was the time required to prepare interdisciplinary lessons, including AI-generated educational resources, lesson planning, testing, and classroom organisation. However, these resources can be reused and adapted for future activities, reducing preparation time. The study was conducted in a single Romanian technological high school, which may limit the generalisability of the findings. Furthermore, the evaluation relied

mainly on classroom observations, formative assessments, discussions, and students' perceptions. Future research should include longitudinal studies, comparative analyses across multiple schools, and objective measures of learning performance. Despite these limitations, the challenges were primarily organisational and technical rather than pedagogical, confirming the feasibility of integrating AI, VR, and SmartLab technologies into interdisciplinary secondary education.

Table 11: Challenges Identified During the Educational Implementation

Challenge	Impact	Implemented Solution
Limited number of VR headsets	Not all students could use VR simultaneously	Student rotation and collaborative pair work
Wireless synchronisation	Occasional connection delays	Immediate reconnection through the ClassVR management platform
VR proximity sensor	Some devices remained in energy-saving mode	Correct adjustment of the headset position
Lesson preparation time	Increased workload for teachers and master's students	Collaborative lesson design and reusable educational resources
Generalisability	Implementation conducted in one educational institution	Future multi-school validation studies

5.5 Discussion

The findings demonstrate that the proposed pedagogical framework provides an effective and scalable approach for integrating Artificial Intelligence (AI), Virtual Reality (VR), and SmartLab technologies into interdisciplinary secondary education. The combination of AI-generated educational resources, immersive learning, and collaborative instructional design promoted student engagement, interdisciplinary understanding, and digital competence (Song et al., 2024; Liu et al., 2025). The questionnaire results, classroom observations, and formative assessments indicate that AI-assisted VR environments effectively complement traditional teaching, supporting previous research while extending it through the validation of a structured pedagogical framework implemented in an authentic SmartLab environment (Radianti et al., 2020; Hamilton et al., 2021). A key contribution of this study is its interdisciplinary approach, demonstrating that immersive technologies can successfully integrate concepts from multiple scientific disciplines within authentic classroom activities (Zagami, 2025). In addition, AI was used as a creative tool for generating immersive educational resources, reducing content preparation time while enabling teachers to focus on pedagogical design (Tzirides et al., 2024). The involvement of 35 master's students in designing and delivering interdisciplinary lessons also highlights the framework's contribution to teacher preparation, showing that future teachers can successfully integrate AI and VR into educational practice when supported by appropriate pedagogical guidance (Lee and Liu, 2025; Tracy and Spantidi, 2025). Overall, the large-scale implementation involving 702 secondary school students and 550 questionnaire respondents demonstrates that the proposed framework is applicable in authentic secondary education settings and represents a promising approach for the digital transformation of education.

6. Conclusion and Future Work

This paper presented a scalable pedagogical framework for integrating Artificial Intelligence-generated educational resources, Virtual Reality, and SmartLab technologies into interdisciplinary secondary education. The framework combines AI-assisted content generation, immersive learning, interdisciplinary instructional design, and authentic classroom implementation within a teacher-centred educational model. The framework was validated through the implementation of 11 interdisciplinary SmartLab lessons involving 702 secondary school students and 35 master's students. The evaluation, based on classroom observations, Kahoot assessments, discussions, and questionnaires completed by 550 students, demonstrated high levels of engagement, motivation, interdisciplinary understanding, and positive perceptions of AI-assisted immersive learning. An additional contribution of this research is the integration of future teacher preparation through the collaborative design and delivery of interdisciplinary SmartLab activities. Although several organisational and technical challenges were identified, they did not prevent the successful implementation of the proposed framework and provide practical recommendations for future applications. Future work will focus on extending the framework to multiple educational institutions, conducting longitudinal studies, integrating adaptive AI techniques, and evaluating the long-term impact of immersive interdisciplinary learning on students' achievement, digital competencies, and teacher professional development.

Ethics Declaration

The study complied with institutional educational regulations and the General Data Protection Regulation (GDPR). Participation in the questionnaire was voluntary and anonymous, and no personally identifiable information was collected.

AI Declaration

Artificial Intelligence tools were used to support language editing, grammar refinement, manuscript organisation, and the generation of illustrative educational resources described in this paper. All research design, data collection, educational implementation, statistical interpretation, scientific analysis, and final conclusions were performed and validated exclusively by the authors, who assume full responsibility for the content of this manuscript.

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