Table S1. Summary of included studies in systematic review detailing article, year, country, discipline, education level, study design, sample size, used multimedia component(s), and learning outcomes.

Article	Author	Year	Country	Discipline	Education level	Study design	Sample size	Multimedia component (s)	Learning outcomes	Limitations
Improving senior-level students' performance in Traffic Systems Management using multimedia contents	Abu-Eisheh & Ghanim	2022	Palestine	N/A	Undergraduate	Quasi-experimental and survey	46	Animation, Text, Images/other non-interactive visuals, Audio, Interactive learning media, Text, Web-based and mobile-based delivery tools	Multimedia use improved performance by 14-30% and ABET outcomes by 10-25%	N/A
Impact of multimedia technology on university students learning agility and creativity	Alhulail & Singh	2023	Saudi Arabia	Various disciplines	Undergraduate	Survey	318	N/A	Multimedia technology enhances learning agility and creativity	The focus on a single Saudi Arabian public institution limits generalizability;
Examining the user experience of learning with a hologram tutor in the form of a 3D cartoon character	Ali & Ramlie	2021	Malaysia	N/A	Undergraduate	Survey	30	VR/AR/hologram, Animation	Positive UX, increased interest and motivation	Focusing solely on the UX of 3D cartoon tutor, ignoring the complexity of the content and the duration of the teaching session.
The Effect of Game-Based Technology on Students' Learning Anxiety, Motivation, Engagement and Learning Experience: Case Study Kahoot!	Alsswey et al.	2024	Jordan	Various disciplines	Undergraduate	Case study	21	Gamification	Kahoot! reduces anxiety, enhances learning experience, and promotes retention	Sample size constraints; potential biases in participant responses; the specificity of the study context.
Challenges faced by teachers to use multimedia in classroom and students' perception from it: a case study	Azad	2024	Bangladesh	N/A	Undergraduate	Case study	18	Video, Audio, Images/other non-interactive visuals, Text	MMCs are more effective than traditional classes	Purposive sampling; context of a single college in Bangladesh; limited time and budget.

on a selected college in Bangladesh										
Teaching Business English to Future Economists Using a Multimedia Textbook.	Bykonia et al.	2019	Ukraine	English (special purpose)	Undergraduate	Survey	87	Text	Improved educational gains compared to traditional methods	Single institution; first- and second-year students only; Economics major only; researcher involvement in course design.
WordTrek: A Digital Educational Material that Contributes to Vocabulary Learning in Higher Education.	Boude et al.	2023	Columbia	English as foreign language (EFL)	Undergraduate	Case study	21	Games	48% improved vocabulary acquisition	N/A
Effect of Virtual Simulation Teaching System on Learning of Students Majoring in Engineering Technology.	Cao et al.	2022	China	Engineering	Undergraduate	Survey	285	Interactive learning media	The virtual simulation teaching method, resources, and the learner experience improve learning	N/A
Gamification and mobile learning: innovative experiences to motivate and optimise music content within university contexts	Carrión Candel & Colmenero	2022	Spain	N/A	Undergraduate	Quasi-experimental and survey	62	Gamification	Multimedia tools improved learning outcomes	Focus is only on gamification in a specific didactic proposal.
Investigating the challenges of Iranian ESP teachers at medical schools: The role of video presentation on subject related critical incidents	Cheraghi & Motaharinejad	2023	Iran	English (special purpose)	Undergraduate	Survey	118	Video	Video boosts motivation and understanding	N/A
Online Computer-Based Clinical Simulations:The Role of Visualizations	Dubovi	2019	Israel	Healthcare	Undergraduate	Quasi-experimental	97	Video, Animation	Agent-based visualizations resulted in higher learning gains	N/A

Developing skills of fashion design by augmented reality technology in higher education	Elfeky & Elbyaly	2021	Saudi Arabia	Fashion design	Undergraduate	Experimental	54	VR/AR/hologram, Animation	Higher success and acceptance in all aspects	Focuses only on fashion design skills; limited to female students; involved only university-level participants; used data from a single institution.
Web-based adaptive presentation techniques to enhance learning outcomes in higher education	Elmabaredy et al.	2020	Egypt	Pedagogy	Undergraduate	Experimental	70	Text, Images/other non-interactive visuals, Video	Multimedia use significantly improved achievement and performance	Applied only to third-year students in the Faculty of Education specific departments.
Immersive virtual reality to enforce teaching in engineering education	Halabi	2020	China	Design, Engineering	Undergraduate	Quasi-experimental	35	VR/AR/hologram, Interactive learning media	VR improved the grade of the project and course outcomes related to the project design	N/A
Using mobile applications in the study of vocal skills	Han	2023	China	Music	Undergraduate	Quasi-experimental	180	Web-based and mobile-based delivery tools	Higher scores with multimedia use	Conducted at three institutions, not generalizable nationwide; study involved only two mobile apps; study did not involve the use of analysis of variance depending on the distribution of the variables; participants were randomly selected.
Gamified Collaborative Environment in Moodle	Hasan et al.	2019	Cyprus	N/A	Postgraduate	Quasi-experimental	41	Gamification	N/A	Small sample size; applied in one module for one semester of one academic year.
The effect of gamified assessment on student's achievement, motivation and engagement in database design course	Yusof	2019	Malaysia	N/A	Undergraduate	Quasi-experimental	80	Gamification	Gamified assessment improved achievement	N/A

Using Virtual Reality as Support to the Learning Process of Forensic Scenarios	Khalilia et al.	2022	Palestine	Crime scene investigation, LAW	Undergraduate	Case study	25	VR/AR/hologram	VR supports the learning process and improves forensic science knowledge	N/A
Interactive study of multimedia and virtual technology in art education	Liu et al.	2021	China	N/A	Undergraduate	Quasi-experimental	60	VR/AR/hologram	No significant differences in learning outcomes	N/A
Learning and Motivational Impact of Game-Based Learning: Comparing Face-to-Face and Online Formats on Computer Science Education	López-Fernández et.al.	2023	Spain	N/A	Undergraduate	Quasi-experimental	321	Video	Similar effectiveness in knowledge acquisition and motivation in both formats	Quasi-experimental design with groups of different years; focused on one educational game
Comparing Traditional Teaching and Game-Based Learning Using Teacher-Authored Games on Computer Science Education	López-Fernández et al.	2021	Spain	N/A	Undergraduate	Case study	124	Games	Similar effectiveness in knowledge acquisition	N/A
Effect of using gamification of "Kahoot!" as a learning method on stress symptoms, anxiety symptoms, self-efficacy, and academic achievement among university students	Malak	2024	Jordan	N/A	Undergraduate	Experimental	176	Gamification	Reduced stress and anxiety; improved self-efficacy and academic achievement	Conducted at a single location with a homogeneous sample; focused on HCI students studying at a private university; results are assessed by overall course grade; data were collected using a self-administered questionnaire.
Digitisation of English language education: Instagram and TikTok online educational blogs and courses vs. traditional	Meirbekov et al.	2024	Turkey	English as foreign language (EFL)	Undergraduate	Quasi-experimental	187	Communication platforms	N/A	Small sample size; limited experimental data on TikTok's effects; findings based on student opinions, not performance metrics.

academic education. How to increase student motivation?										
Using Mobile gamified quizzing for active learning: the effect of reflective class feedback on undergraduates' achievement	Mimouni	2022	Morocco	N/A	Undergraduate	Quasi-experimental	98	Gamification	Gamified quizzing with reflective class feedback increases achievement scores	Retesting with the same test may affect post-test results; convenience sampling limits generalizability; limited prior literature on game use and cognitive engagement; no national-level studies have been provided for comparison.
An educational tool for enhanced mobile eLearning for technical higher education using mobile devices for augmented reality	Nefatti et al.	2021	Malaysia	N/A	Undergraduate	Survey	500	VR/AR/hologram, Web-based and mobile-based delivery tools	Improved understanding with visual data	N/A
Assessing the impact of multimedia application on student conceptual understanding in Quantum Physics at the Rwanda College of Education	Nyirahabimana et al.	2024	Rwanda	Quantum Physics	Undergraduate	Quasi-experimental	385	Interactive learning media, Animation, Video	Multimedia use significantly increased conceptual understanding of quantum physics	Focus was only on pre-service teachers from public institutions; other categories of students and private institutions were not included; limited only to quantum physics module; factors such as gender, school environment or student motivation were not taken into account.
Game-Based Digital Quiz as a Tool for Improving Students' Engagement and Learning in Online Lectures	Nuci et al.	2021	Kosovo	N/A	Postgraduate	Quasi-experimental	257 and 243	Gamification	73% vs. 57.5% correct answers with quizzes	Non-randomized groups in the first experiment; no control group in the second experiment; repeated use of the same questions; limited generalizability beyond gamification platforms like Kahoot!; lack of observation for data triangulation due to online setting.

Study on the Impact of Gamified Teaching Using Mobile Technology on College Students' Learning Engagement.	Pan & Mow	2023	China	N/A	Undergraduate	Experimental	124	Games	Gamified teaching significantly improved test scores	N/A
The Pedagogical Use of Gamification in English Vocabulary Training and Learning in Higher Education	Panmei & Waluyo	2022	Thailand	English as foreign language (EFL)	Undergraduate	Quasi-experimental	100	Gamification	No significant difference in overall vocabulary scores	No qualitative data were collected; quasi-experimental design limits generalizability; short intervention duration may have influenced results.
Adoption of multimedia technology for learning and gender difference	Park et al.	2019	United states	N/A	Undergraduate	Survey	120	Video	N/A	Only one individual characteristic (prior experience) and one multimedia type (video) were tested; technology characteristics were limited to data quality; gender effects were examined post hoc without a comprehensive theoretical framework; actual behavior was self-reported rather than objectively measured.
The effectiveness of interactive multimedia in learning Indonesian language skills in higher education	Praheto et al.	2020	Indonesia	N/A	Undergraduate	Experimental	118	Interactive learning media, Video, Gamification	Interactive multimedia improves learning outcomes	N/A
Pedagogical innovation on interactive graphic animations: Case study of synaptic transmission 1st year baccalaureate degree, life and earth sciences, Morocco	Rajae et.al.	2021	Morocco	Biology	Undergraduate	Case study	60	Animation	Students using animation performed significantly better in understanding synaptic transmission	N/A

Gamification during Covid-19: Promoting active learning and motivation in higher education	Rincon-Flores & Santos-Guevara	2021	Mexico	N/A	Undergraduate	Survey	57	Gamification	Gamification improved academic performance	N/A
The Effect of Mobile-based Interactive Multimedia on Thinking Engagement and Cooperation	Rogti	2024	Algeria	English as foreign language (EFL)	Undergraduate	Quasi-experimental	60	Interactive learning media	Engagement and cooperation increased. Positive attitudes towards multimedia use	N/A
Mobile Learning in Higher Education: Structural Equation Model for Good Teaching Practices	Romero-Rodríguez et.al.	2020	Spain	N/A	N/A	Survey	1544	Web-based and mobile-based delivery tools	N/A	Transversality of the data; limited sample size in some sociodemographic factors.
Production and uses of e-learning tools for animal biology education at university	Sautière et al.	2019	France	Biology	Undergraduate	Survey	170	Interactive learning media, Video	The learning feedback on animal anatomy was slightly increased	N/A
The Use of Trailer Film to Increase English Essay Writing	Setianingrum et. al.	2021	Indonesia	English (special purpose)	Undergraduate	Quasi-experimental	50	Video	80% improved in English essay writing	Limited to video-based learning tool; shortcomings in monitoring online tests.
3D learning spaces and activities fostering users' learning, acceptance, and creativity	Shin & Park	2019	Korea	N/A	Undergraduate	Experimental	32	Animation	No significant differences in learning outcomes	Small sample size and individual differences in visuospatial abilities may have obscured the effect of visual cues; a within-subject study design may have been more effective.
Investigating the effects of low-cost head-mounted display based virtual reality environments on learning and presence	Tepe & Tüzün	2023	United states	Healthcare	Undergraduate	Experimental	96	VR/AR/hologram	VR increased the academic achievement of the students	Long-term use of MHD can cause fatigue and simulation sickness; high-quality VR devices are expensive and have limited availability; low-cost VR solutions are still underdeveloped and not widely tested.

Preliminary results of the impact of 3D-visualization resources in the area of graphic expression on the motivation of university students	Triviño-Tarradas et al.	2022	Argentina	Engineering	Undergraduate and postgraduate	Survey	134	Interactive learning media	Motivation improved significantly, especially relevance (M = 4.01)	N/A
Representation of machines and mechanisms in augmented reality for educative use	Urbina Coronado et al.	2022	Mexico	Engineering	Undergraduate	Quasi-experimental	59	VR/AR/hologram, Web-based and mobile-based delivery tools	Improved understanding of mechanical components	Novelty effect was not studied; AR was not compared to physical models or prototypes.
Multimedia in Education: What do the Students Think?	Vagg et al.	2020	Ireland	N/A	Undergraduate	Survey	153	N/A	Multimedia enhances the understanding of the topics covered in the class	Potential gender bias due to predominantly female respondents; limited to first and second year healthcare students; small sample from a single institution; unclear or varying definition of virtual practice (VR); not examining changes in perceptions over academic years or during clinical training.
Effectiveness Associated With Learning With Video and Multimedia Content in Engineering Students' Classroom Sessions	Valencia et al.	2023	Peru	Engineering	N/A or undergraduate	Quasi-experimental	183	Video, Communication platforms	Improved student performance and understanding of the sequence and modularity	N/A
Impacts of cues on learning: Using eye-tracking technologies to examine the functions and designs of added cues in short instructional videos	Wang et al.	2020	China	Pedagogy	Undergraduate	Experimental	120	Video, Text, Images/other non-interactive visuals	Cues improved retention and transfer test scores	Short video on fatigue issues; limited to the subject area of geography; relied solely on eye movement and test scores without qualitative data; not tested with diverse populations or in educational contexts.

Innovation of Digital Multimedia VR Technology in Music Education Curriculum in Colleges and Universities	Xiao	2022	China	N/A	Postgraduate	Survey	40	VR/AR/hologram	N/A	Insufficient curriculum resources; slow implementation; gap between development and implementation; low teacher proficiency; regional disparities.
Integrating ease of use and affordable gamification-based instruction into a remote learning environment	Zainuddin	2024	Indonesia	N/A	Undergraduate	Survey	68	Gamification, Communication platforms	Gamification-based quizzes significantly improved learning outcomes	Small sample size; possible bias due to questionnaires and interviews.
Multimedia based Teaching Platform for English Listening in Universities	Zhao et al.	2019	China	English as foreign language (EFL)	Undergraduate	Survey and experimental	318 and 68	Audio, Video, Text, Images/other non-interactive visuals	Multimedia-based teaching increased scores by 6.9% and 9.2%	Limited content variety in test material.
Game-Based Learning: Enhancing Student Experience, Knowledge Gain, and Usability in Higher Education Programming Courses	Zhao et al.	2022	Ireland, Slovakia	N/A	Undergraduate	Survey	231	Games	Games improved understanding and results. Significant differences in knowledge acquisition by location	N/A

Note: N/A – information not reported in the article.