

Trend Analysis of VR- and AR-Based Learning Media Development in Physics Education in the 2015–2025 Period

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Abstrak

This study analyzes trends in the development of Virtual Reality (VR) and Augmented Reality (AR)-based learning media in physics education from 2015 to 2025. A systematic literature review (SLR) following the PRISMA framework was conducted, resulting in 103 selected articles. The analysis focuses on the distribution of physics topics, learning activities, instructional stages, and learning actors. The results show that VR/AR is predominantly used in mechanics and electromagnetism, while solid-state physics is least represented. Learning activities are mainly dominated by visualization/animation and experimental activities, highlighting the role of VR/AR in supporting interactive and experiential learning. These technologies are most frequently applied in the exploration stage, with limited use in the introduction stage. In addition, individual students are the primary users, indicating a strong emphasis on self-directed learning. Overall, VR and AR demonstrate strong potential to enhance conceptual understanding and engagement in physics learning, although their implementation remains uneven across topics and instructional contexts. The findings provide insights for educators, instructional designers, and researchers in developing more pedagogically integrated VR/AR-based learning environments. Future studies are recommended to expand VR/AR applications to underrepresented physics topics, assessment activities, and collaborative learning settings to maximize their educational impact.

Keyword: *virtual reality, augmented reality, physics education, systematic literature review, learning media*

Penelitian ini bertujuan untuk menganalisis tren pengembangan media pembelajaran berbasis Virtual Reality (VR) dan Augmented Reality (AR) dalam pendidikan fisika selama periode 2015–2025. Metode yang digunakan adalah systematic literature review (SLR) dengan pendekatan PRISMA, yang menghasilkan 103 artikel terpilih. Analisis difokuskan pada distribusi materi fisika, aktivitas pembelajaran, tahapan pembelajaran, serta aktor pembelajaran. Hasil penelitian menunjukkan bahwa VR/AR paling banyak digunakan pada materi mekanika dan elektromagnetisme, sedangkan fisika zat padat paling sedikit. Aktivitas pembelajaran didominasi oleh visualisasi/animasi dan eksperimen, yang menegaskan peran VR/AR dalam mendukung pembelajaran interaktif dan berbasis pengalaman. Penggunaan VR/AR paling banyak terjadi pada tahap eksplorasi dan relatif rendah pada tahap pengenalan. Selain itu, siswa secara individual menjadi aktor utama dalam pembelajaran. Secara keseluruhan, VR dan AR memiliki potensi besar dalam meningkatkan pemahaman konsep dan keterlibatan siswa, meskipun penerapannya masih belum merata pada berbagai topik dan konteks pembelajaran. Temuan ini memberikan acuan bagi pendidik dan pengembang media dalam mengintegrasikan VR/AR secara lebih efektif pada pembelajaran fisika. Penelitian selanjutnya disarankan untuk mengembangkan VR/AR pada topik fisika yang masih kurang terwakili, aktivitas asesmen, serta lingkungan pembelajaran kolaboratif agar implementasinya lebih merata dan komprehensif.

Keywords: *virtual reality, augmented reality, pembelajaran fisika, systematic literature review*

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INTRODUCTION

Physics, as a foundational science, inherently poses significant pedagogical challenges due to its abstract concepts such as electromagnetism, quantum mechanics, and natural phenomena expressed through mathematical equations and the intricate mathematical frameworks required for their comprehension, often resulting in student difficulties in problem-solving and conceptual understanding (Prahani, Jatmiko, Saphira, & Amelia, 2022). Traditional teaching methodologies often struggle to bridge the gap between theoretical physics and real-world phenomena, leading to student disengagement and suboptimal learning outcomes (Bao & Koenig, 2019; Musengimana, Yadav, Uwamahoro, & Nizeyimana, 2025). This challenge is exacerbated by the limited opportunities for students to visualize inherently unobservable complex physical interactions, such as electromagnetic fields or quantum mechanical phenomena, which are not readily perceptible in everyday life (Evagorou, Erduran, & Mäntylä, 2015; Lin & Wu, 2021). This limitation consistently hampers students' ability to develop robust mental models of physical systems, thereby impeding deeper conceptual understanding and application (Ubben & Bitzenbauer, 2023).

To address challenges in physics learning, digital transformation improves instructional quality and effectiveness. It systematically integrates digital technologies into education to create interactive, flexible, learner-centered environments. In physics, these tools provide dynamic, visual, interactive representations of abstract concepts that traditional methods cannot achieve (Chen & Singh, 2025; Wijaya, 2025). Within this context, Virtual Reality and Augmented Reality have emerged as key technologies in education's digital transformation. VR provides a fully immersive, computer-generated 3D environment for interacting with simulated physical phenomena (Jantanukul, 2024; Schwaiger, Krajnčan, Vukovič, Jenko, & Doz, 2024). AR overlays digital elements such as 3D models, animations, or data onto the real world in real time, enhancing perception without replacing it (Jantanukul, 2024; Schwaiger et al., 2024). Both enable visualization of abstract physical processes, experiential learning, and greater student engagement, addressing physics education challenges in abstraction, visualization, and meaningful learning (Venkatesan et al., 2021). The growing adoption of virtual reality and augmented reality in education shows increasing interest in their value as effective learning media, beyond mere technological novelties (Sakr & Abdullah, 2024). In physics education, VR and AR support instructional activities like concept introduction, exploration, experimentation, and practice by letting students interact directly with simulated or augmented phenomena (Girwidz & Thoms, 2021). As learning media, they feature structured integration into lesson designs, alignment with objectives, and involvement of teachers and students in individual or collaborative settings. Thus, VR and AR serve as key tools for physics learning across various contexts (Tene, Guevara, Moreano, Vera, & Gómez, 2024). As learning media, VR and AR provide key educational benefits for physics education. They improve conceptual understanding through immersive, interactive visualizations of abstract phenomena hard to observe directly (B Arymbekov & Turekhanova, 2025). These technologies promote active, experiential learning by letting students manipulate variables, explore from multiple views, and receive instant feedback (Sakr & Abdullah, 2024). They also increase engagement, motivation, and meaningful learning by shifting students from passive recipients to active participants (Tene, Guevara, et al., 2024).

In physics learning, the implementation of VR and AR can be systematically examined through the physics materials addressed, the learning activities conducted, the instructional stages involved, and the roles assumed by different learning actors (Gillies, 2023; Girwidz & Thoms, 2021). The physics materials discussed in the reviewed studies cover a wide spectrum of content, ranging from classical physics topics such as mechanics, electricity and magnetism, optics, acoustics, and thermodynamics to modern physics areas including quantum mechanics, solid-state physics, nuclear and particle physics, astrophysics, relativity, and atomic and molecular physics. In addition, several studies address integrated topics that combine multiple physics domains, reflecting the interconnected nature of physical concepts across different levels of

education (Girwidz & Thoms, 2021; Oral, 2017). Across physics topics, learning activities aim to develop conceptual understanding and skills (Al-Kamzari & Alias, 2025). These activities include experiments, data collection and analysis, use of graphs, equations, and diagrams, problem solving, modeling and simulations, as well as practice, evaluation, and reflection (Girwidz & Thoms, 2021). Learning activities are organized into instructional stages commonly used in physics teaching (Mesquita, Brockington, Testoni, & Studart, 2021). These stages include introducing concepts, exploring physical phenomena, explaining theory, practicing to strengthen understanding, expanding knowledge beyond core material, and assessing students' conceptual mastery (Girwidz & Thoms, 2021). Learning actors are the individuals or group that involved in the learning process (Zulfatunnisa, 2022). Learning participants in the classroom include both teachers and students, engaging either individually or collaboratively in groups (Gillies, 2023). Each actor has specific roles at different stages of learning, with some stages being teacher-dominant and others student-dominant, including in the use of learning media (Girwidz & Thoms, 2021).

Research on virtual reality (VR) and augmented reality (AR) in education has increased markedly during the 2015–2025 period, with a clear surge since 2017 and further acceleration during the COVID-19 pandemic (Al-Ansi, Jaboob, Garad, & Al-Ansi, 2023; Jiang, Zhu, Chugh, Turnbull, & Jin, 2025). Existing review studies predominantly focus on general publication trends, technological features, and overall learning outcomes, particularly in science and STEM education, including physics (Jiang et al., 2025; Lai & Cheong, 2022). Although positive impacts on engagement, motivation, and conceptual understanding are widely reported, prior reviews tend to remain at a macro level and do not systematically examine how physics learning materials are distributed, what forms of learning activities are employed, or how these activities align with specific stages of the physics learning process (Huang & Tseng, 2025; Zhang & Wang, 2021). In addition, the roles and distributions of learning actors teachers, individual students, and student groups are rarely mapped in relation to instructional stages within VR and AR based physics learning. Given these gaps, a comprehensive literature-based trend analysis is essential to systematically categorize and analyze the integration of VR and AR in physics education across different physics content, learning activities, instructional stages, and learning actor roles (Menchafou, Aaboud, & Chekour, 2023; Tene, Tixi, et al., 2024).

To fill these gaps, this study conducts a systematic literature review (SLR) focusing on the use of virtual reality (VR) and augmented reality (AR) in physics education from 2015 to 2025. The period was selected because it represents a decade of rapid growth and increasing maturity in the educational application of Virtual Reality (VR) and Augmented Reality (AR). Previous bibliometric and review studies have reported a substantial increase in AR/VR-related educational publications, particularly during the last decade and the COVID-19 pandemic period, accompanied by broader adoption across educational contexts. Therefore, this timeframe provides a comprehensive basis for examining recent trends and developments in VR- and AR-based physics education (Fortuna et al., 2024; Karakus, Ersozlu, & Clark, 2019; Rojas-Sánchez, Palos-Sánchez, & Folgado-Fernández, 2023; Zhao, Ren, & Cheah, 2023). This review goes beyond general trend and outcome analyses by systematically examining what physics content is taught, what learning activities are used, at which instructional stages they occur, and who is involved in VR and AR based physics learning. Accordingly, this SLR aims to provide a structured and comparable overview of how VR and AR are implemented in physics education by addressing a set of predetermined research questions (RQs) that capture the distribution of learning materials, instructional activities, learning stages, and the roles of learning actors within this field. The following RQs therefore guide this review.

1. What is the distribution of physics learning materials developed using VR and AR during the period 2015–2025? *(To identify which physics topics are most and least represented, revealing content concentration and potential gaps in VR and AR based physics learning.)*
2. What forms of learning activities are associated with VR- and AR-based physics learning materials during the period 2015–2025? *(To understand how immersive technologies are used pedagogically, such as for visualization, experimentation, inquiry, or collaborative learning.)*
3. How are VR- and AR-based learning activities mapped to the stages of physics learning during the period 2015–2025? *(To determine which phases of instruction—introduction, concept development, practice, or assessment—are most frequently supported by VR and AR.)*
4. How are learning actors (teachers, individual students, and student groups) distributed in VR- and AR-based physics learning during the period 2015–2025? *(To identify who primarily engages with VR and AR in physics learning and to reveal patterns of teacher-centered, individual, or collaborative use.)*

5. What roles do learning actors (teachers, individual students, and student groups) play across the stages of VR- and AR-based physics learning during the period 2015–2025? (To examine how responsibilities and interactions shift across instructional stages, such as guidance by teachers, independent exploration by students, or collaborative problem solving.)

This study is expected to provide a systematic and pedagogically grounded overview of how VR and AR are used in physics education by mapping physics content, learning activities, instructional stages, and learning actors. The findings will help identify dominant patterns, underrepresented areas, and pedagogical gaps, thereby supporting better instructional design, teacher practice, and future research in VR- and AR-based physics learning.

METHOD

This study uses a systematic review approach, which is designed to identify, evaluate, and synthesize all relevant evidence available regarding the use of VR and AR media in physics learning from reputable journals within the 2015-2025 time frame. A systematic review follows explicit methodology to answer a well-defined research question by comprehensively searching the literature, rigorously evaluating the quantity and quality of research evidence, and analyzing the evidence to synthesize an answer to the research question (Sataloff et al., 2021).

Research Design

This study adopted a qualitative systematic literature review methodology to methodically investigate and synthesize peer-reviewed literature on the development of VR and AR based learning media in physics education. The review process adhered to the PRISMA framework across four stages identification, screening, eligibility assessment, and inclusion as depicted in (Haddaway et al., 2022). The principal aim was to delineate research trends, key influencing factors, and pedagogical strategies pertinent to VR and AR integration in physics education for the 2015–2025 period.

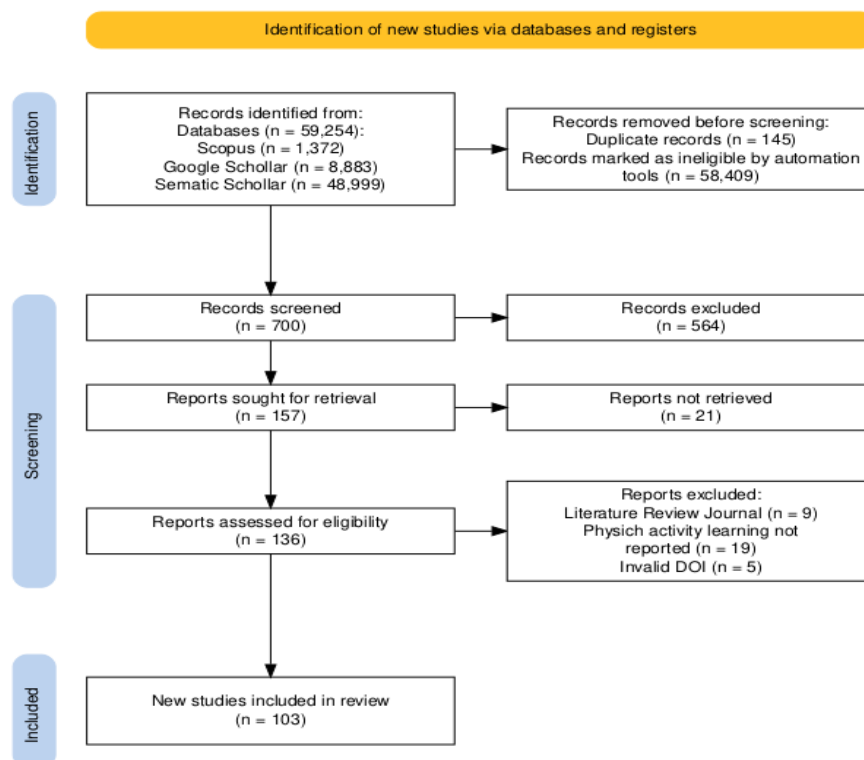


Figure 1. PRISMA flowchart

Search Strategy

Searches were conducted using the Harzing’s Publish or Perish application to improve the efficiency and accuracy of literature retrieval. The application offers significant advantages to researchers by automatically retrieving and analyzing academic citations from various data sources, thus saving time and effort in calculating important citation metrics such as the number of publications, total citations, and the h-

index. Its ability to search across multiple databases and present detailed metrics including publication and citation years, hI norm, hI annual, hA-index, and annual citation counts provides a comprehensive view of a researcher's academic impact. Although users may need to clean the results due to occasional data errors or ambiguities, the wealth of analytical information greatly enhances the evaluation process for academic performance and influence (Baiget, 2023).

To ensure a rigorous and reproducible search process, a set of keywords commonly used in the literature on immersive learning and physics education was applied. The search terms included “Virtual Reality”, “Augmented Reality”, “VR”, “AR”, “Physics Learning”, “Pembelajaran Fisika”, “Media Development”, and “Pengembangan Media”. These keywords were systematically combined using Boolean operators and were applied to titles, abstracts, and keywords in the databases to maximize coverage of relevant studies in both English and Indonesian publications.

The systematic search process produced a large and diverse set of records across multiple databases. As illustrated in Figure 1, a total of 59,254 records were initially identified, including 1,372 records from Scopus, 8,883 from Google Scholar, and 48,999 from Semantic Scholar. Prior to screening, 145 duplicate records and 58,409 records identified as ineligible by automated filtering tools were removed. The remaining 700 records were screened based on titles and abstracts, resulting in 564 records being excluded due to irrelevance. Subsequently, 157 full-text reports were sought for retrieval, of which 21 reports could not be retrieved. After eligibility assessment, 136 reports were evaluated in full text, leading to the exclusion of 33 studies due to being review articles, not involving physics learning activities, or lacking accessible DOI information. Finally, 103 studies met all inclusion criteria and were included in the systematic review.

**Inclusion and Exclusion Criteria
Screening Stage**

Table 1. Screening inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Year of publication	Articles published between January 2015 and November 2025	Articles published before 2015 or after November 2025
Field of Study	Physics	Non-Physics
Topic	VR or AR on physics learning media	VR or AR on Non-physics learning media

Eligibility Stage

Table 2. Eligibility inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Journal Type	Primary research	Non-primary research such as literature review
Activity reported	Report the activity at least the result of learning activity	Has no activity report
Valid DOI	Has a valid DOI that can be accessed	Has a file but the DOI is not valid (expired/website has a problem)

RESULTS AND DISCUSSION

Following the screening and eligibility assessment stages, a total of 103 studies met all inclusion criteria and were selected for further analysis. These studies represent the final dataset used in this systematic literature review and encompass various applications of Virtual Reality (VR) and Augmented Reality (AR) in physics education. Table 3 presents the list of eligible articles, including their titles, authors, and publication years, which served as the primary sources for identifying trends in physics content, learning activities, instructional stages, and learning actors during the 2015–2025 period.

Table 3. Eligible journal

ID	Title	Author (year)
1	Design and validation of a multi-interaction-based Augmented Reality learning model to overcome abstractness in physics concepts at the secondary education level	Karuru and Pakanan (2025)
2	A teaching concept for school experiments on radioactivity using augmented reality methods	Schuette,Streuber,Pottgiesser,Preim,Saalfeld ,Vahlbruch, Walther (2023)
3	Adventuring Physics: Integration of adventure game and Augmented Reality based on android in physics learning	Rizki, Shapira, Alfarizy, Saputri, Ramadani, Suprpto (2023)
4	AI support meets AR visualization for Alice and Bob: personalized learning based on individual ChatGPT feedback in an AR quantum cryptography experiment for physics lab courses	Coban, Dzsojan, KÜchemann, Durst, Kuhn, Hoyer (2025)
5	An evaluation of the “PicsAR” research project: An augmented reality in physics learning	Suprpto, Nandyansah, Mubarook (2020)
6	Analysis of students’ self regulated learning using augmented reality media on solar system material at class VII SMP	Supriasih, Fathurohman, Sriyanti (2022)
7	Analyzing the effective use of augmented reality glasses in university physics laboratory courses for the example topic of optical polarization	Laumann, Schlummer, Abazi, Borkamp, Lauströer, Pernice, Schuck, Schulz-Schaeffer, Heusler (2024)
8	Application of augmented reality (AR) in the laboratory for experimental physics	Lyrath, Stechert, Ahmed (2023)
9	Argumentação em ambiente de realidade virtual: uma aproximação com futuros professores de Física	Ferreira, Lourenço, Alves Da Cruz, Paza, Botero, Rocha (2020)
10	Augmented Reality Geometrical Optics (AR-GiOs) for physics learning in high schools	Kencana, Iswanto, Wibowo (2021)
11	Augmented reality water rocket: develop an enrichment book of physics	Anisah, Astra, Delina (2019)
12	Augmented reality-problem solving lab: Does it foster elementary students’ understanding of submicroscopic phenomena in physics?	Ismail, Isrokatun, Bhakti, Kemalia (2025)
13	Augmenting the thermal flux experiment: A mixed reality approach with the HoloLens	Strzys, Kapp, Thees, Lukowicz, Knierim, Schmidt, Kuhn (2017)
14	Changing physics instruction by synergizing vygotskian educational theory and virtual reality	Vanderburg, Mann, Cowling (2021)
15	Comparison of student achievement in electricity using augmented reality between offline and online classes	Ropawandi, Husnin, Halim (2023)
16	Design and analysis of multimedia mobile learning based on Augmented Reality to improve achievement in physics learning	Nasir and Z (2023)
17	Diseño e implementación de un simulador basado en realidad aumentada móvil para la enseñanza de la física en la educación superior	Aguilar Acevedo, Flores Cruz, Hernández Aguilar, Pacheco Bautista (2022)
18	Designing interactive learning media using mobile Augmented Reality for electrical circuit education	Luthfi, Muskhir, Effendi, Jalinus (2024)
19	Developing a virtual reality simulation of the Michelson-Morley experiment for physics education: Design, validation, and educational	Alka (2024)
20	Developing an Augmented Reality application as instruction media to help in learning the solar system	Sholeh, Fatkhiyah, Aprianto (2023)
21	Developing an augmented reality-assisted E-module based on local wisdom of pedicabs for physics teaching	Dewi & Kuswanto (2023)

22	Developing physics experiments using augmented reality game-based learning approach: A pilot study in primary school	Zafeiropoulou, Volioti, Keramopoulos, Sapounidis (2021)
23	Development of 2-D augmented reality integrated physics e-book to improve students' problem-solving skills	Nugraheni & Mundilarto (2022)
24	Development of 3D physics learning media using Augmented Reality for first-year junior high school students	Azhar, Herfana, Nasir, Irawan, Islami (2021)
25	Development of an app and teaching concept for implementation of hyperspectral remote sensing data into school lessons using augmented reality	Lindner, Rienow, Otto, Juergens (2022)
26	Development of android-based augmented reality learning media on atomic matter	Kumalasari & Fikroh (2023)
27	Artificial Intelligence and Applications	Long, Chen, Zhou (2022)
28	Development of augmented reality application in physics through newton's laws and object interaction	Ferdiman, Akbar, Faturrahman, Maulana (2023)
29	Development of augmented reality as physics learning media on electric concepts	Ismail, Rahayu, Putera, Aghniya, Gumilar (2021)
30	Development of augmented reality in the basic physics practicum module	Firmansyah, Suhandi, Setiawan, Permanasari (2020)
31	Development of augmented reality integrated physics e-worksheet to improve students' problem-solving skills	Suryanto Dewi, Rosana (2022)
32	Development of Augmented Reality-based digital teaching materials on optical instruments to enhance conceptual understanding and project skills	Saputri, Asrizal, Ulmi, N, Zan, Ashel (2025)
33	Development of augmented reality-based physics learning media on magnetic field	Sholeh, Haryanto, Zulkarnaen (2024)
34	Development of augmented-reality-based magnetic field visualization system as an educational tool	Nakamura & Mizuno (2022)
35	Development of BD F-AR 2 (physics digital book based augmented reality) to train students' scientific literacy on global warming material	Kholiq (2020)
36	Development of E-book integrated Augmented Reality based on STEM approaches to improve critical thinking and multiple representation skills in learning physics	Rahmayani, Kuswanto, Rahmat (2024)
37	Development of e-Modules using Augmented Reality in physics teaching at high school of Manokwari Regency	Allo and Suhendra (2022)
38	Development of E-physics teaching material integrated with augmented reality and ethno-meaningful learning to promote students' 21st century skills	Putri, Asrizal, Fitri (2025)
39	Development of Pascal's Law Learning Media Using Augmented Reality Based on the Marker Based Tracking	Sukmawati and Nasir (2025)
40	Development of physics education content using AR-HMD: Focusing on image formation by convex lenses	Park (2025)
41	Development of physics learning media based on self-efficacy use mobile augmented reality for senior high school	Nasir, Z, Prastowo (2019)
42	Development of physics learning media PHY-ART (physics with Augmented Reality technology) to empower student's laboratory skills	Prastya, Budiawanti, Wahyuningsih (2023)
43	Development of Virtual Reality Endogen Energy (VREE) media for Physics learning mechanical wave on class XI	Kartikasari and Anggaryani (2022)
44	Development of virtual reality on material: Archimedes' Law (VIRMA) to improve student learning outcomes	Prillyanti and Anggaryani (2023)

45	Education-based augmented reality applications for heat learning media content lesson in physics	Suryadi, Rahayu, Amalia, Hamdani, Nuraeni (2019)
46	Effectiveness of augmented reality-based learning media for engineering-physics teaching	Sriadhi, Hamid, Sitompul, Restu (2022)
47	Effects of augmented reality on learning and cognitive load in university physics laboratory courses	Thees, Kapp, Strzys, Beil, Lukowicz, Kuhn (2020)
48	Effects of learning physics using Augmented Reality on students' self-efficacy and conceptions of learning	Cai, Liu, Wang, Liu, Liang (2021)
49	Enhancing Physics Experience: VIRRE (Virtual Reality of Renewable Energy) to Increasing Concept Understanding and Learning Motivation in Secondary Education	Anggaryani and Citra (2024)
50	Enhancing students' conceptual understanding of electricity using learning media-based augmented reality	Ismail, Festiana, Hartini, Yusal, Malik (2019)
51	Experiments for students with built-in theory: 'PUMA: Spannungslabor' – an augmented reality app for studying electricity	Stolzenberger, Frank, Trefzger (2022)
52	FizaAR: An Augmented Reality learning kit integrating Social Cognitive Theory in learning physics	Karim, Karim, Kasmin (2024)
53	How augmented reality enhances typical classroom experiments: examples from mechanics, electricity and optics	Teichrew and Erb (2020)
54	Impact of virtual reality instruction on secondary school students' conceptual understanding of physics concepts in Dutsin-ma, Katsina state Nigeria	Salihu and Sabitu (2024)
55	Impact of VR technology in physics teaching on students' knowledge: a study on body acceleration	Kurbanbekov, Ramankulov, Nurizinova, Asanbek (2025)
56	Implementation of Augmented Reality (AR) using assembler in high school applied physics education with the ADDIE model approach	Soraya (2022)
57	Implementation of augmented reality applications in developing flashcard learning media for the solar system	Sirti, Rosmawarni, Prada, Arianti, Widyaningrum (2025)
58	Implementation of mobile augmented reality on physics learning in junior high school students	Rahmat, Kuswanto, Wilujeng, Perdana (2023)
59	Interactive Book Augmented Reality (IBAR) for Lesson Physics on STEM	Wibowo, Nasbey, Sanjaya, Darman, Ahmad (2021)
60	Monopoly-based augmented reality game design as a practice media in learning the Physics of magnetism concepts	Permana and Nugroho (2023)
61	On the suitability of augmented reality for safe experiments on radioactive materials in physics educational applications	Schiano Lo Moriello, Liccardo, Bonavolonta, Caputo, Gloria, De Alteriis (2022)
62	Optimization of 3D virtual reality technology in high school physics direct-type teaching	Guan, Li, Fang, Wu (2022)
63	Pengembangan E-Bahan Ajar Berbantuan Augmented Reality Pada Mata Pelajaran IPAS Materi Mengubah Bentuk Energi Untuk Meningkatkan Hasil Belajar Peserta Didik Sekolah Dasar	Lestari and Setyasto (2025)
64	Pengembangan media pembelajaran fisika pada materi optik geometri berbasis augmented reality dengan unity dan vuforia	Affriyenni, Swalaganata, Mustikasari, Fitriyah (2025)
65	Pengembangan Media Pembelajaran Fisika SMA Augmented Reality Video Berbasis Android pada Materi Pemanasan Global di Kelas XI SMA N 1 Gemolong	Ali, Wahyuningsih, Supurwoko (2021)
66	Pengembangan Modul Fisika Berbantuan Teknologi Augmented Reality pada Materi Gelombang Bunyi untuk SMA/MA Kelas XI	Khunaeni, Yuniarti, Khalif (2020)
67	Pengembangan Modul Fisika Berbasis Augmented Reality (AR) Materi Rangkaian Arus Searah Untuk Siswa SMA	Ilhamsyah and Bektiasro (2022)

68	Physics E-book with augmented reality to improve students' interest in physics	Novita (2023)
69	Physics learning media based Augmented Reality (AR) for electricity concepts	Ismail, Gumilar, Amalia, Bhakti, Nugraha (2019)
70	Physics textbook enriched augmented reality: Easy way to understand the physical concept	Muliyati, Baiti, Bakri, Permana (2020)
71	Physics textbook enriched with videos based on augmented reality technology: Practice in problem solving skill in dynamics of rotation concept for senior high school students	Bakri and Dwijayanti (2022)
72	Picsar (Physics Augmented Reality) as a learning media to practice abstract thinking skills in atomic model	Nandyansah, Suprpto, Mubarok (2020)
73	PicsAR: A physics visualisation to enhance students' thinking skills in abstract concepts	Suprpto and Nandyansah (2021)
74	Practice the higher-order thinking skills in optic topic through physics worksheet equipped with augmented reality	Bakri, Ervina, Muliyati (2019)
75	Revolutionizing physics learning: Augmented reality changes the way students learn momentum and impulse	Angraini, Siahaan, Fathurohman (2025)
76	Smart teaching materials with real-time augmented reality support for introductory physics education	Javaheri, Lauer, Altmeyer, Brünken, Peschel, Wehn, Lukowicz (2022)
77	Student worksheet with AR videos: Physics learning media in laboratory for senior high school students	Bakri, Permana, Wulandari, Muliyati (2020)
78	Technology deployment in physics lessons: Understanding optics better with Augmented Reality	Stolzenberger, Wolf, Trefzger (2021)
79	Textbooks equipped with Augmented Reality technology for physics topic in high-school	Bakri, Marsal, Muliyati (2019)
80	The application of scaffolding augmented reality (AR) media in the sharing task learning of electrolyte and non-electrolyte solutions	Nurrohmah, Supriatna, Fatimah, Setiaji (2020)
81	The Augmented Laboratory – a mixed reality setup for physics education	Rosi, Onorato, Oss (2019)
82	The augmented reality based flashcards for learning heat and thermodynamics in high school	Siahaan and Putri (2024)
83	The design of sound wave and optic marker for physics learning based-on augmented reality technology	Muliyati, Bakri, Ambarwulan (2019)
84	The development of a physics knowledge enrichment book “optical instrument equipped with augmented reality” to improve students' learning outcomes	Astra and Saputra (2018)
85	The effect of Augmented Reality (AR) supported teaching activities on academic success and motivation to learn Nuclear Physics among high school pupils	Arymbekov, Turekhanova, Turdalyuly (2024)
86	The effectiveness of a 3D-Virtual Reality Learning Environment (3D-VRLE) on the Omani eighth grade students' achievement and motivation towards physics learning	Al Amr, Osman, Al Musawi (2020)
87	The effectiveness of augmented reality as a learning medium in enhancing students' motivation and their ability to analyze physics concepts	Egista, Haryanto, Mustofa (2025)
88	The effectiveness of Problem-Based Learning physics pocketbook integrating Augmented Reality with the local wisdom of catapults in improving mathematical and graphical representation abilities	Rahmasari and Kuswanto (2023)
89	The effectiveness of the use of augmented reality-assisted physics e-module based on pedicab to improve mathematical communication and critical thinking abilities	Dewi and Kuswanto (2023)

90	The effectiveness use of virtual reality media in physics education of solar system towards cognitive learning outcomes	Saputro and Setyawan (2020)
91	The effects of AR-based physics homework on learning circular motion	Vidak, Movre Šapić, Simić, Mešić (2024)
92	The effects of augmented reality: A comparative study in an undergraduate physics laboratory course	Kapp, Thees, Beil, Weatherby, Burde, Wilhelm, Kuhn (2020)
93	The influence of using physics student worksheets assisted by augmented reality toward students' creative thinking ability	Apriani, Kuswanto, Nuha (2021)
94	The integration of scaffolding and augmented reality in physics learning	Karim, Karim, Khalid (2025)
95	The TPACK implementation in physics textbook with Augmented Reality: Enhance the 4C skills at mechanics wave concept	Bakri and Sunardi (2022)
96	The use of augmented reality for teaching kazakhstan students physics lessons	Mukhtarkyzy, Abildinova, Sayakov (2022)
97	The use of physics pocketbook based on augmented reality on planetary motion to improve students' learning achievement	Suprpto, Ibisono, Mubarak (2021)
98	TPACK and augmented reality in kinematics practicum module: Forming HOTS physics education students	Bakri, Kusuma, Permana (2021)
99	Using immersive augmented reality to teach Physics to students with Intellectual Disabilities	Iatraki and Mikropoulos (2025)
100	Using virtual Reality for teaching kinematics	Kortemeyer (2024)
101	Validity of E-module based on cognitive conflict integrated augmented reality for improving students physics science literacy	Emilya and Mufit (2023)
102	Virtual reality applied to physics teaching	Rivas, Alvarez, Guerrero, Grijalva, Loor (2017)
103	Virtual reality physics lab	Munoz, Lewis, Bolling, Zandbergen, Scully-Allison, Le, Dascalu (2019)

QR 1. What is the distribution of physics learning materials developed using VR and AR during the period 2015–2025?

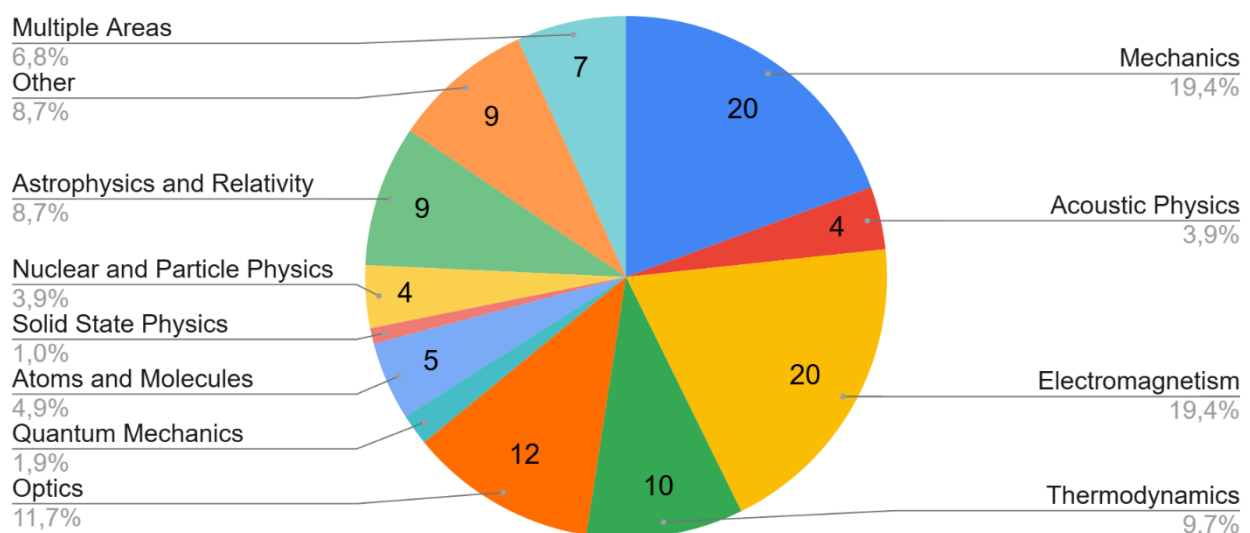


Figure 2. Distribution of physics learning material using VR and AR

In Figure 2, twelve classifications of physics topics are presented, namely Mechanics, Acoustics, Electromagnetism, Thermodynamics, Optics, Quantum Mechanics, Atoms and Molecules, Solid State Physics, Nuclear and Particle Physics, Astrophysics and Relativity, and Other Multiple Areas. Among these, Mechanics and Electromagnetism exhibit the highest use of VR and AR media.

According to (A Ismail, Rahayu, Putera, Aghniya, & Gumilar, 2021), physics concepts can be categorized into tangible and intangible forms. One example of an intangible concept is Electromagnetism. With the integration of VR and AR, electromagnetism materials can be more easily understood by students, as evidenced by the improvement in student comprehension following learning activities utilizing these technologies. This is further supported by research conducted by (Rizki et al., 2023), which found that the use of AR media in electromagnetism significantly enhances students' learning motivation.

In the context of Mechanics, states that a key limitation of conventional media is the lack of visualization of force direction, which often leads to misconceptions. The implementation of VR and AR effectively addresses this issue by providing clearer visual representations, thereby minimizing misconceptions (Vidak, Movre Šapić, Simić, & Mešić, 2024). This finding is reinforced by a study conducted by (Rivas et al., 2017), which indicates that the use of VR media can reduce human error commonly encountered in conventional mechanics experiments, allowing students to develop a deeper understanding of theoretical concepts.

On the other hand, Solid State Physics is identified as the topic with the least use of VR and AR media. In a study conducted by (Rahmasari & Kuswanto, 2023), the material focused on elasticity, where VR and AR were utilized to enhance students' understanding of stress, strain, and Young's modulus through visual representation. In conclusion, both highly and minimally represented topics indicate that VR and AR media are primarily utilized for physics materials that require the visualization of abstract concepts.

QR 2. What forms of learning activities are associated with VR- and AR-based physics learning materials during the period 2015–2025?

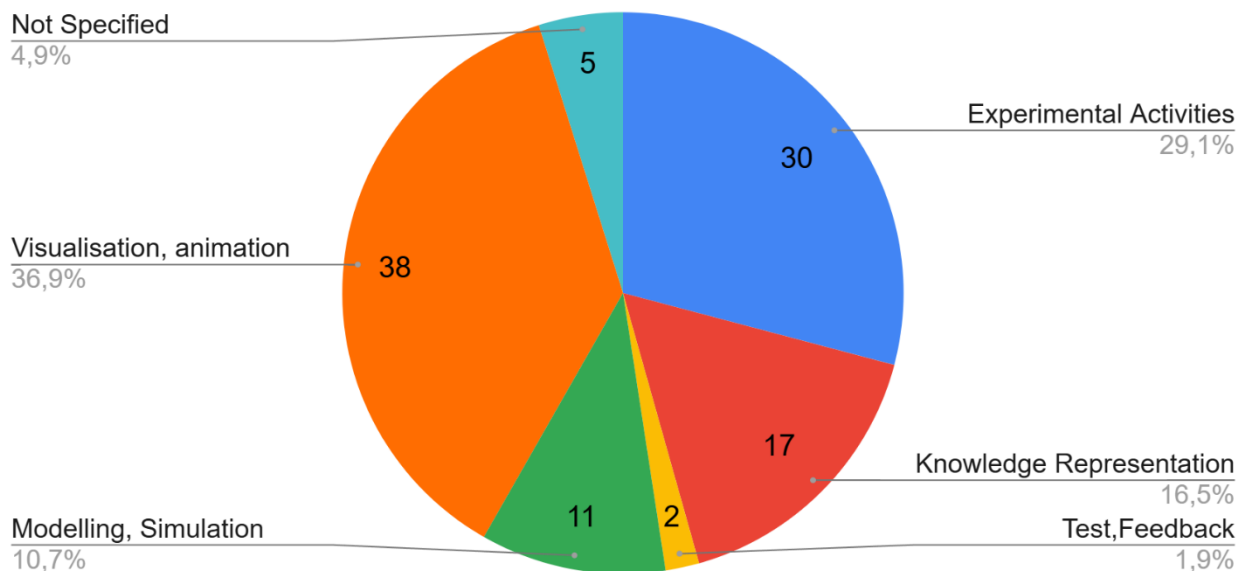


Figure 3. Distribution of learning activity of VR and AR learning media

There are six classifications of learning activities identified in the eligible research journals: Experimental Activities, Knowledge Representation, Test, Feedback, Modelling and Simulation, Visualization and Animation, and Not Specified. In more detail, 36 journals use VR and AR for visualization and animation, 30 for experimental activities, 17 for knowledge representation, 11 for modelling and simulation, 2 for test and feedback, and 5 are not explicitly specified, although the learning outcomes indicate that certain activities were conducted using VR and AR. The following section presents these findings in the form of a table, along with the underlying rationales for the use of VR and AR in each learning activity.

Table 4. Background of use of VR/AR on specific learning activity

Learning Activity	Journal ID	Reason
Experimental Activities	100	VR/AR makes abstract physics concepts tangible through immersive interaction while remaining safe, scalable, and increasingly affordable to develop, with added benefits of precise 3D tracking and support for exploratory and student-created simulations(Kortemeyer, 2024).
	37	VR/AR makes abstract experimental concepts and activities more accessible, interactive, and three-dimensional via mobile devices overcoming outdated printed modules, student boredom, cost and storage issues, and enabling virtual experiments, videos, and simulations to improve learning outcomes(Allo & Suhendra, 2022).
Knowledge Representation	33	VR/AR solve overcome the limitations of conventional representations in explaining abstract physics concepts by providing visual, interactive, and dynamic forms that are easier for students to understand(Sholeh et al., 2024).
	93	VR/AR interactive 3D visual representations enrich students' conceptual understanding while encouraging idea exploration, thereby enhancing creative thinking skills(Apriani, Kuswanto, & Nuha, 2021).
Test,Feedback	89	VR/AR supports the evaluation of higher-order understanding through direct interaction that provides immediate and more meaningful feedback compared to conventional methods(Dewi & Kuswanto, 2023a).
	4	VR/AR is used as a test and feedback tool is driven by the need to provide contextual, real-time, and personalized evaluation that not only assesses understanding but also actively guides students' cognitive processes during learning(Coban et al., 2025).
Modelling, Simulation	103	VR/AR makes it enables abstract and unobservable physics concepts to be represented as interactive and manipulable visual models, thereby enhancing conceptual understanding and linking theory to observable phenomena(Munoz et al., 2019).
	19	VR/AR is used as modeling or simulation tools is motivated by their ability to transform abstract physics concepts into interactive 3D experiences that enhance understanding, engagement, and learning effectiveness(Alka, 2024).
Visualisation, animation	3	The use of VR and AR as visualization animation in this study is motivated by the need to represent abstract and invisible physics concepts through interactive 3D animations, making them more concrete, engaging, and easier for students to understand(Rizki et al., 2023).
	6	VR /AR as visualization animation in this study is driven by the need to overcome students' difficulties in understanding abstract concepts (such as the solar system) by providing interactive 3D visualizations that make learning more engaging, concrete, and easier to comprehend(Supriasih, Fathurohman, & Sriyanti, 2022).

Overall, the analysis of the table shows that the reasons for using VR and AR across different learning activities are strongly centered on their ability to address the limitations of traditional learning methods, particularly in dealing with abstract physics concepts. In Visualization and Animation, VR/AR is mainly used to transform abstract and invisible phenomena into interactive 3D representations, making concepts more concrete, engaging, and easier for students to understand. In Experimental Activities, the primary reason is to provide accessible, safe, and cost-effective virtual experiments, allowing students to explore and interact with phenomena that are difficult to conduct in real laboratories.

For Knowledge Representation, VR/AR is utilized to present information in more dynamic, visual, and interactive forms, helping students build deeper conceptual understanding and supporting creative and critical thinking. In Modelling and Simulation, the key reason lies in enabling the manipulation of virtual models that link theoretical concepts to observable phenomena, thereby enhancing comprehension through experiential learning.

Meanwhile, in Test and Feedback, although limited in number, VR/AR is used to deliver more interactive, real-time, and personalized assessment, supporting higher-order thinking and providing more meaningful feedback compared to conventional methods. Overall, these reasons highlight that VR and AR are

primarily adopted to enhance interactivity, visualization, accessibility, and student engagement in learning processes. The complete detailed distribution can be seen on Table 5 and Table 6 below

Table 5. Distribution physics material and learning activity (ID)

	Experimental Activities	Knowledge Representation	Test,Feedback	Modelling, Simulation	Visualisation, animation	Not Specified
Mechanics	31;37;55;91;98;100;102	21;39;71	89	9;17;28;103	11;44;70;75	87
Acoustic Physics		66		16	43;95	
Electromagnetism	8;25;51;92	29;33;50;67		14;15;46;96	3;12;18;34;60;62;69;76	
Thermodynamics	13;47	38;82		27	65;68;99	35;45
Optics	7;10;23;42;78	84;93		19	32;40;64;74	
Quantum Mechanics	48		4			
Atoms and Molecules	5;80				26;72;73	
Solid State Physics		88				
Nuclear and Particle Physics	61;85				2;59	
Astrophysics and Relativity	90	41			6;20;24;52;58;94;97	
Other	22;54;77	49;57;79			36;63	101
Multiple Areas	1;81;86				30;53;83	56

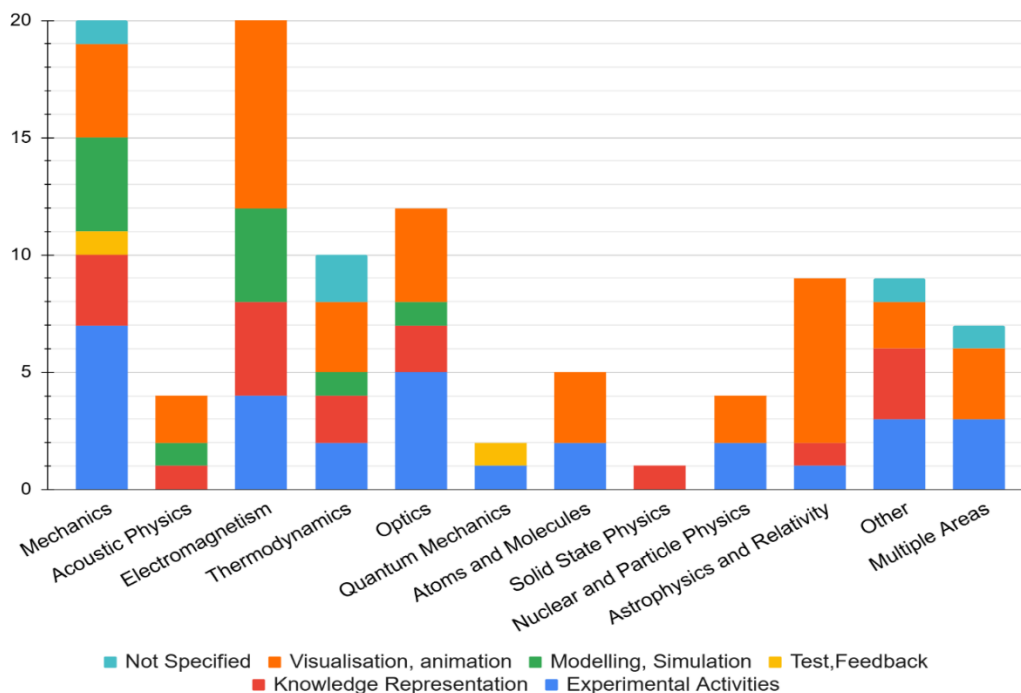


Figure 4. Diagram of distribution physics material and learning activity (Count)

The dominance of Experimental Activities and Visualization & Animation in the journals is mainly driven by the inherent strengths of VR and AR technologies in addressing the limitations of traditional learning. VR/AR enables the visualization of abstract and invisible phenomena through interactive 3D representations, making complex concepts more concrete and easier to understand. At the same time, these technologies support experimental activities by providing virtual simulations that are safer, more cost-effective, and more accessible than real laboratory experiments, while still allowing students to manipulate variables and observe results in real time. Therefore, the combination of strong visualization capabilities and the ability to simulate practical experiences explains why these two categories are the most frequently used in VR/AR-based learning (Vidak et al., 2024).

QR 3. How are VR- and AR-based learning activities mapped to the stages of physics learning during the period 2015–2025?

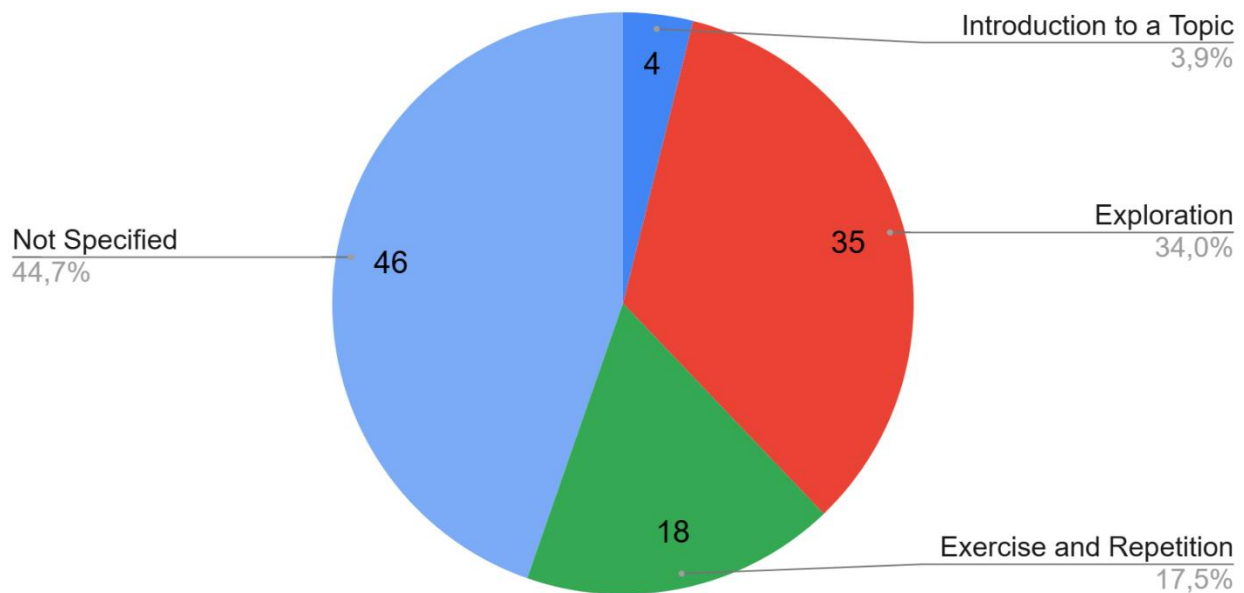


Figure 5. Distribution VR/AR learning media on stage of learning

There are four classification of stage of learning of eligible journal reported.

1. Introduction to the topic: This stage involves presenting the material by introducing key concepts through various teaching methods (V. W. Putri & Gazali, 2021).
2. Exploration: At this stage, students actively engage with new concepts, conduct independent investigations, and test hypotheses through a series of activities designed to facilitate inductive knowledge discovery (Monalisa, Noviana, & Alpusari, 2022).
3. Exercise and repetition: This is a crucial process for consolidating understanding and improving skills through repeated application of learned concepts, often involving various exercises and problem-solving scenarios (Baidi, 2022).
4. Not Specified : mean journal has not giving any information about stage of learning when the VR/AR used

The relatively low use of VR and AR in the introduction stage can be explained by the nature of this phase, which primarily focuses on delivering basic information and initial concept exposure. At this stage, simpler and more efficient instructional methods such as text, images, or brief explanations are often sufficient, making the use of immersive technologies like VR/AR less necessary and sometimes inefficient in terms of time and resources. VR/AR tends to be more beneficial when deeper interaction and engagement are required, rather than for straightforward content delivery. In contrast, the use of VR and AR in practice and repetition falls within a moderate range because, although these technologies can support interactive exercises and reinforce learning through repeated engagement, they are not always the most practical choice for routine practice. Traditional methods such as worksheets or standard problem-solving activities are often more accessible, quicker to implement, and easier to scale. However, VR/AR is still utilized in some cases to enhance

motivation and provide varied practice experiences, particularly when repetition involves spatial or experiential elements (Radianti, Majchrzak, Fromm, & Wohlgenannt, 2020).

Overall, this distribution reflects that VR and AR are most effective when used in stages that require high levels of interaction and experiential learning, while their use is less prominent in stages that prioritize efficiency and routine reinforcement. The detailed Distribution can be seen on Table 7 and Table 8 below

Table 6. Distribution learning activity and stage of learning (ID)

	Experimental Activities	Knowledge Representation	Test,Feedback	Modelling, Simulation	Visualisation, animation	Not Specified
Introduction to a Topic		79			20;65;76	
Exploration	5;7;8;10;25;42;51;55;61;77;78;80;81;92	66	4	9;27;28;96;103	2;6;12;34;36;40;43;53;59;60;62;63;64;95	
Exercise and Repetition	1;31;54;85;86;90;91;102	33;57;71;82;93	89		32;44;74;94	
Not Specified	13;22;23;37;47;48;98;100	21;29;38;39;41;49;50;67;84;88		14;15;16;17;19;46	3;11;18;24;26;30;52;58;68;69;70;72;73;75;83;97;99	35;45;56;87;101

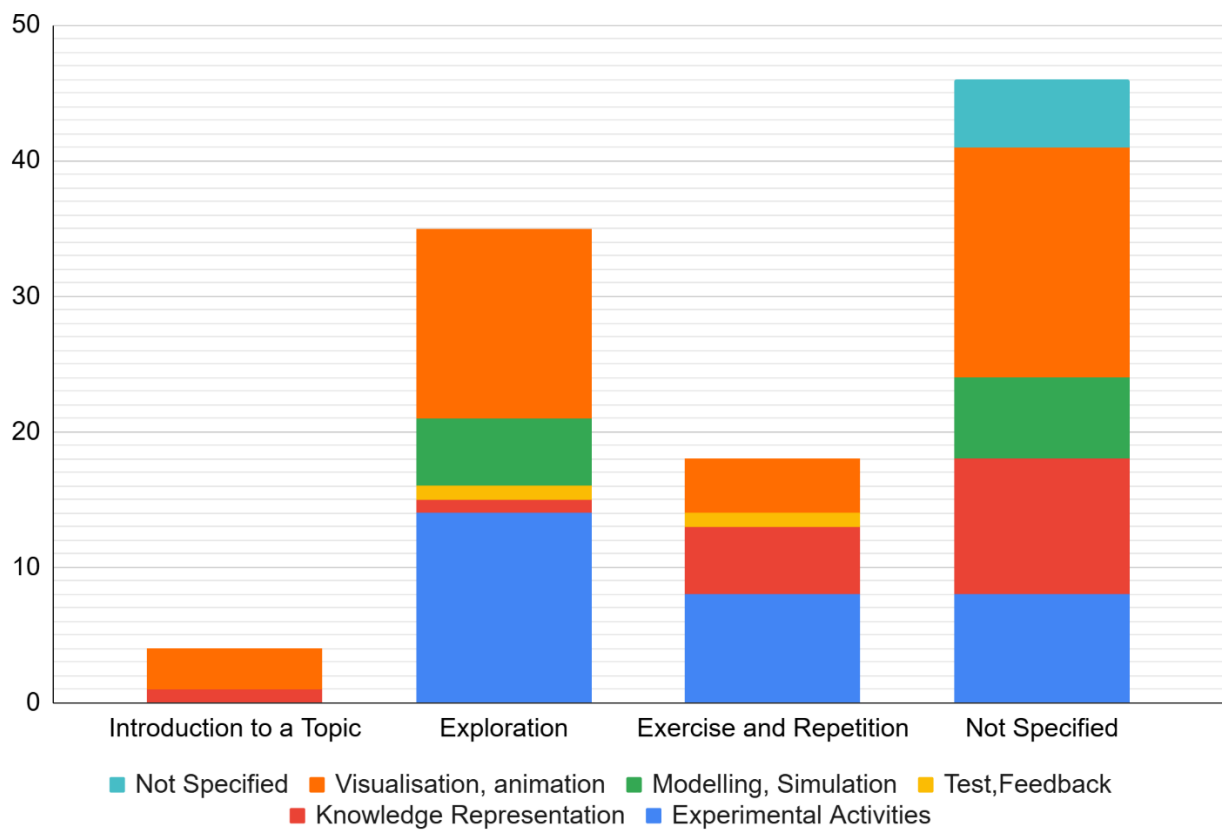


Figure 6. Diagram of distribution learning activity and stage of learning (Count)

Based on Table 7 and Figure 6 experimental activity and visualization has same number of journal on stage of exploration, this data was supported by constructivism learning theory that highly support about exploration by the student that also one of the power of VR/AR that can be used interactively(Masgumelar & Mustafa, 2021)

QR 4. How are learning actors (teachers, individual students, and student groups) distributed in VR- and AR-based physics learning during the period 2015–2025?

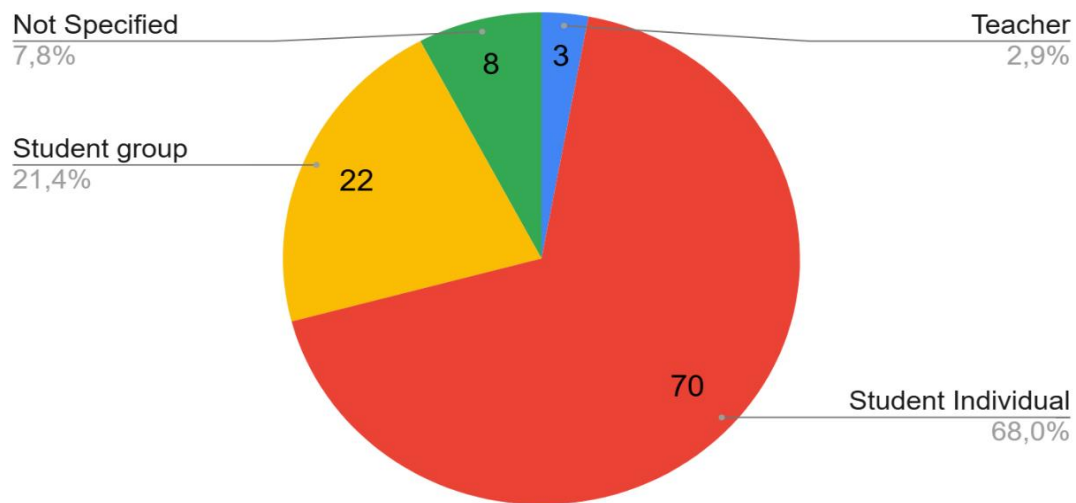


Figure 7. Distribution VR/AR learning media on learning actor

Actors in learning refer to individuals or groups who are directly involved in the educational process, such as students, teachers, or learning groups, each of whom plays a crucial role in shaping the learning experience(Girwidz & Thoms, 2021). Based on Figure 7,The dominance of individual learners as the primary learning actors in VR/AR-based learning can be explained by the inherent characteristics of these technologies, which strongly support personalized and self-regulated learning. VR/AR environments allow students to interact directly with virtual objects, control their own pace of learning, and explore content independently, which naturally aligns with individual learning settings. Studies show that AR enhances motivation, engagement, concentration, and knowledge retention at the individual level, making it highly effective for self-directed learning(Vidak et al., 2024).

QR 5 What roles do learning actors (teachers, individual students, and student groups) play across the stages of VR- and AR-based physics learning during the period 2015–2025?

Table 7. Distribution learning actor and stage of learning (ID)

	Teacher	Student Individual	Student group	Not Specified
Introduction to a Topic		20;65;76;79		
Exploration	27	6;7;8;10;28;34;36;40;42;51;59;60;61;62;63;64;66;77;95;96;103	2;4;5;9;12;25;43;55;78;80;81;92	53
Exercise and Repetition		31;32;33;54;57;71;74;82;86;89;90;91;93;94;102	1;44;85	
Not Specified	14;21	11;18;23;24;26;29;30;35;37;39;41;45;46;48;49;50;58;67;68;69;70;72;73;75;84;87;88;97;98;99	13;15;16;17;22;47;52	3;19;38;56;83;100;101

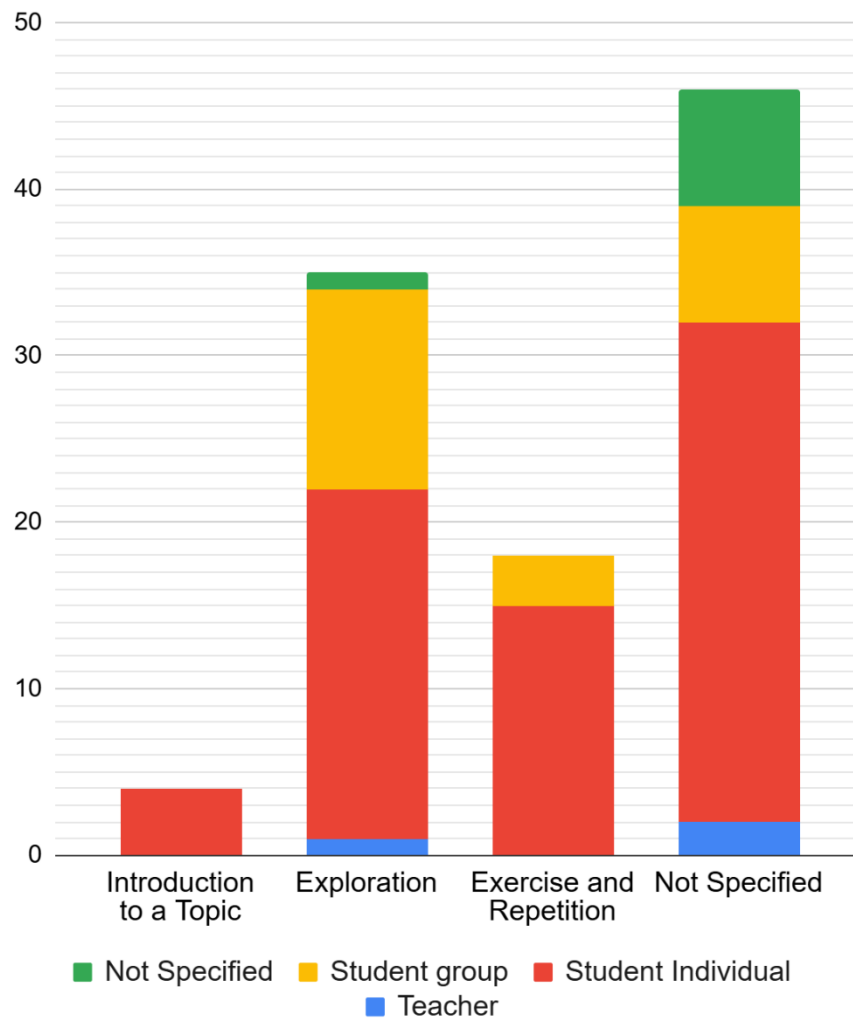


Figure 8. Diagram of distribution learning actor and stage of learning (Count)

The distribution in Figure 8 where individual students dominate across learning stages, can be explained by the pedagogical characteristics of VR/AR supported by existing research. VR/AR technologies are fundamentally designed to support active, immersive, and learner-centered experiences, which align strongly with constructivist learning principles. Studies show that VR enables learners to explore virtual environments, manipulate objects, and engage in inquiry-based activities, thereby facilitating experiential and self-directed learning (Jiang et al., 2025). This explains why the number of individual learners is highest, particularly in the exploration stage (21), as students interact directly with the virtual environment at their own pace.

Furthermore, the moderate dominance of individual learners in exercise and repetition (15) can be linked to the ability of VR/AR to provide adaptive environments, immediate feedback, and repeated practice opportunities, which are key elements of behaviorist and self-regulated learning approaches (Jiang et al., 2025). These features allow students to practice independently without heavy reliance on teachers or group collaboration.

On the other hand, the lower representation of teachers and groups can be explained by the fact that most VR/AR systems are designed for single-user interaction, emphasizing immersion, agency, and personal experience rather than collaborative learning. The Cognitive Affective Model of Immersive Learning (CAMIL) also highlights that VR enhances learning through factors such as presence, motivation, and self-regulation, which are inherently individual processes (Botkin & Trespalacios, 2026).

CONCLUSION

This study provides a comprehensive analysis of the trends in the development and implementation of Virtual Reality (VR) and Augmented Reality (AR) in physics education during the 2015–2025 period. The findings reveal that the use of VR and AR is predominantly concentrated in physics topics that require strong visualization, such as mechanics and electromagnetism, indicating that these technologies are primarily utilized to address abstract and difficult-to-observe concepts.

In terms of learning activities, VR and AR are most frequently employed for visualization and animation as well as experimental activities. This reflects their capability to transform abstract concepts into interactive and immersive experiences while also providing safe and accessible alternatives to real laboratory experiments. Regarding instructional stages, VR and AR are mainly integrated into the exploration phase, where active interaction and experiential learning are essential, while their use in the introduction stage remains limited due to efficiency considerations.

Furthermore, the analysis of learning actors shows that individual students dominate the use of VR and AR, highlighting the strong alignment of these technologies with self-directed and learner-centered approaches. The roles of teachers and student groups are comparatively less prominent, indicating that most VR/AR applications are designed for individual interaction rather than collaborative learning.

Overall, this study concludes that VR and AR have significant potential to enhance physics learning by improving conceptual understanding, engagement, and interactivity. However, their implementation is still uneven across topics, learning stages, and instructional approaches, suggesting the need for more balanced and pedagogically integrated use in future developments.

Based on the findings of this study, several recommendations can be proposed for future research and educational practice. (1) future studies should focus on underrepresented physics topics, such as solid-state physics and modern physics, to ensure a more balanced development of VR- and AR-based learning media across all areas of physics (2) there is a need to expand the use of VR and AR beyond visualization and experimental activities by integrating them into assessment, feedback, and higher-order thinking activities. This would allow these technologies to support a wider range of pedagogical functions, including evaluation and critical thinking development. (3) future developments should explore collaborative and multi-user VR/AR environments to increase the involvement of student groups and teachers, thereby supporting social interaction and cooperative learning, which are currently underrepresented (4) educators and instructional designers are encouraged to integrate VR and AR more systematically across all stages of learning, including the introduction and reinforcement stages, to maximize their pedagogical potential.

AUTHOR CONTRIBUTIONS

Handoko Bintoro : Conceptualization, Methodology, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing; **Mita Anggaryani** : Conceptualization, Methodology, Validation, Supervision; **Mohd Zaidi Bin Amiruddin** : Data Curation. All authors have read and approved the final version of this manuscript.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known financial conflicts of interest or personal relationships that could have appeared to influence the work reported in this manuscript.

DECLARATION OF ETHICS

The authors declare that this research and the preparation of this manuscript have been conducted in accordance with established research and publication ethics standards, adhere to scientific principles, and are free from plagiarism.

DECLARATION OF ASSISTIVE TECHNOLOGIES IN THE WRITING PROCESS

The authors declare that Generative Artificial Intelligence (AI) tools were used solely as assistive instruments during the preparation of this manuscript. ChatGPT was employed to improve language quality, grammar, and academic writing style, while MaxAI was used to facilitate the review and navigation of PDF documents. All outputs generated with AI assistance were critically evaluated, verified, and revised by the authors. The authors assume full responsibility for the accuracy, integrity, and originality of the final manuscript.

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