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Bibliometric Analysis of 3D Media Research Trends in Science Education from 2020 to 2025: A Literature Review

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Abstract

Advances in digital technology have triggered a major transformation in the world of education, particularly through the use of technology-based learning media. One innovation that has attracted a lot of attention in recent years is the use of three-dimensional (3D) media in the science learning process. This literature review aims to (1) identify developments in research publications related to the use of 3D media in science education during the period 2020-2025; (2) analyse trends in 3D research in science education based on the number of publications, citations, authors, countries, and contributing journals; (3) Analyse the 3D tools used in the research, and (4) Provide an overview of opportunities and future research directions related to the application of 3D media in science education. The research method used was bibliometric analysis of a literature review assisted by Bibliloshiny software and Microsoft Excel for data tabulation. The database used was Scopus. The analysis resulted in a total of 50 documents analysed from the Scopus database. The results of the study show that (1) publications related to virtual reality in learning have increased, although they are not yet stable; (2) China and the United States have made the largest contributions related to 3D media, with the article with the highest number of citations being by Burley S.K. (2021). Burley S.K. is the author who has contributed the most to 3D media, with Applied Sciences (Switzerland) being the journal with the largest contribution; (3) The results show that 3D printing is the most discussed tool in research; (4) In addition, the study also shows that 3D media has the potential to be an innovation in learning in the future and continues to increase in its development.

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INTRODUCTION

Advances in digital technology have triggered a major transformation in the world of education, particularly through the use of technology-based learning media. One innovation that has attracted a lot of attention in recent years is the use of three-dimensional (3D) media in the science learning process. 3D media, whether in the form of interactive models, digital simulations, or 3D prints, provide opportunities for students to understand scientific phenomena in a more concrete and contextual manner. The use of this visual technology not only enhances the appeal of learning but also deepens understanding of abstract concepts that are difficult to visualise through two-dimensional images (Wahidin, 2025).

In science education, concepts such as cell structure, organ systems, chemical reactions, and physical phenomena often require a high level of abstract thinking. 3D media provides a solution to bridge the gap between abstract representations and students' concrete understanding (Fariqoh et al., 2025). Several international studies indicate that the application of 3D models can enhance student engagement, concept retention, and spatial thinking skills (Abdo et al., 2024). Furthermore, the integration of 3D media with immersive technologies such as Virtual Reality (VR) and Augmented Reality (AR) has been proven to provide a more interactive and in-depth learning experience, encouraging exploration-based learning (Muti et al., 2024).

In line with these developments, the number of scientific publications related to 3D media in learning has increased significantly over the past five years. Researchers have not only focused on the creation and application of media, but also on evaluating its effectiveness, pedagogical integration, and implications for 21st-century curriculum design (Tejera et al., 2025). These studies indicate a paradigm shift in education from text-based learning to visual and interactive learning that emphasises direct experience and meaning construction by learners. This trend confirms the importance of scientific mapping to understand the direction of research development in the field of 3D media, in terms of research themes, author collaboration, and institutional and national contributions.

However, to date, there are still limited studies that systematically analyse the research map related to 3D media in science education through a bibliometric approach. Most studies focus on aspects of development or effectiveness of media use, rather than quantitative analysis of research networks and themes developing at the global level (Rojas-Sánchez et al., 2022). As a result, a comprehensive picture of publication trends, author productivity, and future research directions has not been fully identified..

Against this backdrop, this study attempts to fill the gap by focusing on a bibliometric analysis of trends in 3D research in science education during the period 2020–2025. This approach will provide a quantitative and visual overview of the number of publications, citations, authors, countries, and contributing journals, thereby indicating the direction of research development and identifying gaps in research that remain open. Therefore, this study not only describes the academic landscape but also provides strategic recommendations for research development and practical implementation of 3D in science education. More specifically, the objectives of this article are (1) to identify the development of research publications related to the use of 3D media in science education during the period 2020–2025. (2) To analyse trends in 3D media research in science education based on the number of publications, citations, authors, countries, and contributing journals. (3) To analyse the forms of virtual reality media discussed in the research. (4) To provide an overview of future research opportunities and directions related to the application of 3D media in science education based on the results of bibliometric analysis. The benefits of this research provide a theoretical contribution in the form of mapping publication trends, authors, countries, and journals related to the use of virtual reality in science education for the 2020–2025 period. In practical terms, the results of this study can be used as a reference for educators and media developers in designing interactive 3D-based learning innovations that are relevant to the needs of the 21st century.

RESEARCH METHOD

This study uses a bibliometric approach with a literature review to analyse publication trends regarding the application of 3D learning media in science education during the period 2020-2025. The main data source used was Scopus, given that this database has extensive international literature coverage and provides metadata that can be exported for bibliometric analysis purposes. The search strategy was carried out using a combination of the keywords ‘3D’ AND “Science” AND ‘Education’, with publication years restricted to 2020–2025. The search results were filtered by document type, namely journal articles and accessible documents. The data

obtained was then converted into BibTeX format for further analysis using Biblioshiny software and Microsoft Excel for data tabulation and descriptive analysis. The results of this quantitative analysis were then combined with qualitative interpretations in the form of a literature review, providing a comprehensive overview of the development, contributions, and future research directions related to the use of 3D media in science education. The investigation was conducted on 1 October 2025. The search results yielded 50 documents in the Scopus database.

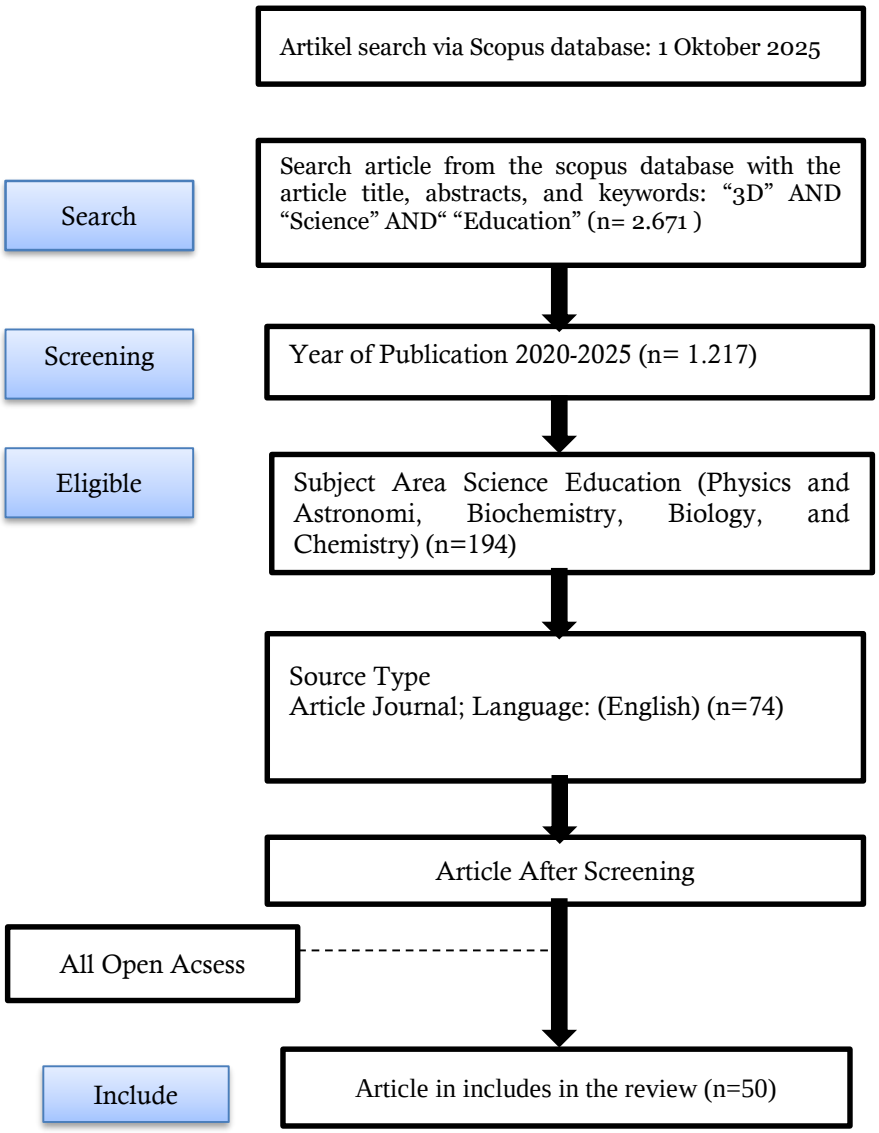

Figure 1. Prism Diagram

RESULTS AND DISCUSSION

Science education requires students to understand concepts that are often abstract and difficult to observe directly. Therefore, the presence of technology-based learning media, such as 3D media, is one solution to help visualise concepts and improve student understanding. In recent years, the use of 3D media has been increasingly studied by researchers because it is considered capable of creating a more interactive learning experience. Through a bibliometric approach, this study analyses various scientific publications from 2020 to 2025 to determine the trends, directions, and main focus of research on 3D media in science education. The results of this analysis are expected to provide a comprehensive overview of the extent to which 3D media has been utilised in science education and its future development opportunities. The following is a visualisation of research publication trends related to the use of 3D media in science education for the period 2020–2025.

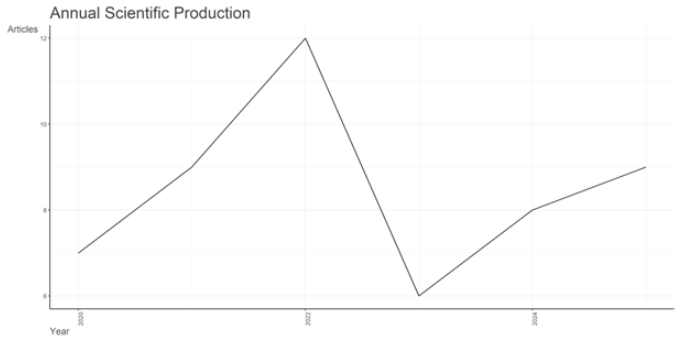

Figure 2 visualisation of trends in the number of research publications related to the use of 3D media in science education for the period 2020-2025

The image shows the annual trend of scientific publications related to the use of 3D media in science education during the period 2020–2025. Based on the graph, the number of studies increased from 2020, peaking in 2022 with a total of 12 articles. This indicates that during this period, researchers' interest in developing 3D media to support science education increased. 3D media is considered capable of helping students understand abstract concepts and microscopic structures in science, making it an interesting and relevant research topic in the development of educational technology. However, in 2023, the number of publications declined sharply, possibly due to a shift in research focus or limited research resources in this field.

Although it had declined, the research trend showed an increase again in 2024 and is expected to continue to grow in the following years. This increase indicates that the use of 3D media in science education is still an important field of study and has great potential for further development. Technological advances such as three-dimensional modelling and interactive visualisation also support future research directions, particularly in creating learning media that is more engaging, contextual, and capable of improving students' understanding of scientific concepts. Thus, the graph illustrates the dynamics of 3D media research productivity, which continues to evolve in line with the need for innovation in science education. Furthermore, Table 1 presents the countries that have contributed to the publication of articles related to 3D media in science education.

Table 1. Countries contributing to 3D media publications in science education

Country	Frequency
China	10
USA	10
Spain	5
Austria	3
France	2
Netherlands	2
Argentina	1
Australia	1
Brazil	1
Czech Republik	1

Table 1 shows the distribution of countries contributing to research publications on 3D media in science education. Based on the data, China and the United States are the two countries with the highest contribution rates, each producing 10 publications. This illustrates that both countries have a strong interest in innovation in 3D technology-based learning. Next, Spain ranks third with 5 publications, followed by Austria with 3 publications, and France and the Netherlands, each contributing 2 publications. The dominance of these countries shows that research on the use of 3D media in science education is still concentrated in countries with advanced technology and research infrastructure.

Meanwhile, several countries such as Argentina, Australia, Brazil, and the Czech Republic only have one publication each. This indicates that research on 3D media in science education is still relatively limited in some parts of the world. However, the diversity of countries involved shows that there is global interest in developing 3D-based learning media. In the future, it is hoped that more international collaborations can be carried out so that research in this field can be more evenly distributed and have a broad impact on improving the quality of science education in various countries. In addition, the most cited documents globally in the field of research related to 3D media are also presented.

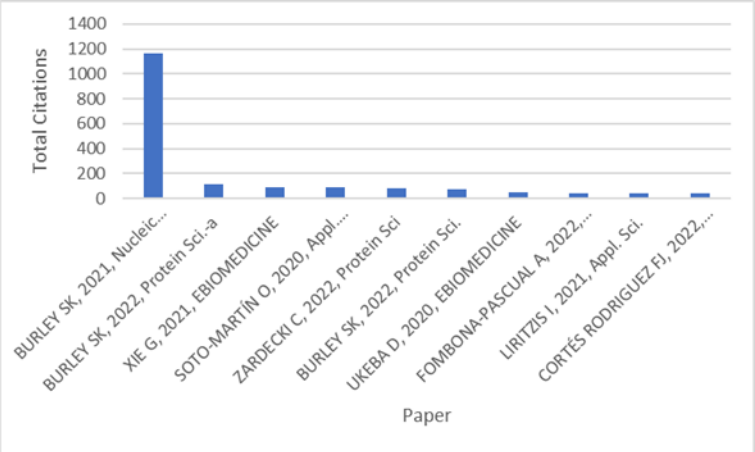

Figure 2 shows a list of publications that received the highest number of citations in research related to 3D media in science education. Based on the graph, the article written by Burley S.K. (2021) in the journal Nucleic Acids Research ranks highest with a significantly higher number of citations than other publications, reaching more than 1,000 citations. This shows that this work has had a significant influence on the development of research in the field of 3D media and science education. Other publications, such as those by Xie G. (2021), Soto-Martín O. (2020), and Zardeck C. (2022), also show important contributions, albeit with lower numbers of citations. The difference in citation rates between articles illustrates the variation in the scientific impact of each study, with some studies becoming key references for other researchers in developing innovations in 3D media-based learning. In addition, the authors who contribute most frequently to research on 3D media are also presented.

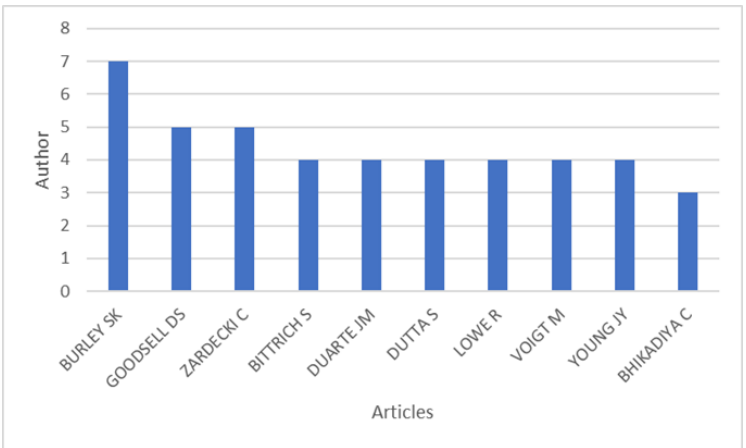

Figure 3. Authors who have contributed most frequently to research on 3D media

Figure 3 shows a list of the most prolific authors in research publications on 3D media in science education. Based on the graph, Burley S.K. is the author with the highest contribution, with seven articles, demonstrating his important role in the development of research in this field. Other authors such as Goodsell D.S. and Zardecki C. each contributed five publications, followed by Bittrich S., Duarte J.M., Dutta S., Lowe R., Voigt M., and Young J.Y. with four articles. Meanwhile, Bhikadiya C. ranked last with three publications. This data shows that research related to 3D media is still dominated by certain authors who consistently conduct studies and publish in this field, thus serving as a primary reference for the development of similar research in the future. In addition, the distribution of articles based on the publication sources used in research related to 3D media is also presented.

Table 2. Distribution of articles based on publication sources used in research related to 3D media

Sources	Articles
Applied Sciences (Switzerland)	6
Biochemistry And Molecular Biology Education; Protein Science	3
Annals Of Anatomy; Ebiomedicine; Frontiers In Bioengineering And Biotechnology; Hardwarex; Journal Of Chemical Education; Journal Of Molecular Graphics And Modelling; School Science And Mathematics; Sensors	2
Acta Imeko; Afinidad; Batteries And Supercaps; Biofabrication; Bioinformatics; Bioinformatics Advances; Biomimetics; Biotechniques; Cbe Life Sciences Education; Chemistry - A European Journal; Current Protocols; Frontiers In Genetics; Frontiers In Physiology; International Journal Of Biological Macromolecules; Journal Of Chemical Information And Modeling; Journal Of Cheminformatics; Journal Of The Serbian Chemical Society; Molecular Catalysis; Nucleic Acids Research;Open Astronomy; Peerj; Physics Teacher; Star Protocols	1

Table 2 shows the distribution of publication sources or journals that contain articles on 3D media in science education. Based on the data, the journal Applied Sciences (Switzerland) is the publication source with the highest number of articles, namely six articles, followed by Biochemistry and Molecular Biology Education and Protein Science, each of which contains three articles. Meanwhile, several other journals such as Annals of Anatomy, EBiomedicine, and Frontiers in Bioengineering and Biotechnology have two articles. Most other journals only contain one article, indicating that research on 3D media is spread across various fields of science. These findings illustrate that 3D media studies are not only relevant in science education, but are also widely applied in interdisciplinary research such as biotechnology, chemistry, and engineering, confirming the broad potential of 3D media in supporting visualisation-based learning and scientific experimentation. In addition, a table of 3D media forms/tools discussed in the study is also presented.

The spread of publications across multiple journals also highlights the expanding scope and adaptability of 3D media in various domains of science and education. This trend suggests that researchers from different disciplines recognize the value of 3D visualization in simplifying complex scientific concepts and enhancing experimental analysis. The inclusion of 3D media research in both pedagogical and applied science journals indicates that its use is no longer confined to classroom learning but is also being leveraged to support innovation in laboratory simulations, biomedical modeling, and engineering design. Such diversification emphasizes the transformative role of 3D media in modern scientific inquiry, bridging the gap between theory and real-world application through immersive and interactive digital experiences.

Table 3: 3D media tools discussed in the study.

No	Tools	Frequency	Studies
1	3D Printing	9	Răzvan-Ştefan, B., Laura Nicoleta, P., & Mihăşan, M. (2025). ; Bracco et al., (2025); Hansen et al (2025); Smith et al., (2024); Serôdio (2024); Zang et al., (2023); Han et al (2022); Peerna (2022); Asempapa, R. S., & Love, T. S. (2021)
2	Blender	4	Svatunek (2023); Dosoftei (2023); Serodio et al (2024); Roshndel et al (2023)
2	Molekul WebXR	3	Komalawardhana, N., Euaumpon, N., Song, Z., & Limpanuparb, T. (2025); Rodríguez et al., (2025); Rodríguez et al (2022)
3	Unity	3	Hemme et al (2023); Liritzis et al (2021); Soto-Martin et al (2020)
4	RCSB.org	3	Burley et al (2022); Burley et al (2022); Zardecki et al (2022)
5	Lab 3D	1	Żyła, K., Kęsik, J., & Dakowicz, A. L. (2025).
6	IndagApp	1	Yánez et al (2025)
7	3D Zernike	1	Lai et al (2024)
8	Glow Script	1	Kubsch, M., & Hamerski, P. C. (2022).
9	QR Chem	1	Fambona et al (2022)
10	Laborem Box	1	Lavayssièr et al (2022)
11	Holographic 3D displays	1	He & Cao (2021)
12	MiniCERNBot	1	Marín Garcés et al (2021)
13	CAVE21	1	Reinke et al (2021)
14	Crystal VR	1	Franco et al (2020)
15	3DStryuctGen	1	Chen et al (2020)

Table 3 displays various forms or tools of 3D media used in research related to science learning. Based on the data, there are various types of technology and applications used to develop 3D media, such as 3D Printing, Blender, Unity, RCSB.org Lab 3D, 3D Zmolview, Glow Script, and QR Chem. From the overall data, 3D Printing is the most frequently used tool with the highest number of studies, followed by Blender and Unity. This shows that 3D Printing technology is considered effective in helping to visualise scientific concepts in a realistic way, while Blender and Unity are widely used to create interactive virtual models that support exploration-based learning experiences.

The variety of 3D media used in this study illustrates that the development of science learning does not focus on just one form of technology, but encompasses various approaches according to the needs and characteristics of the teaching material. Several studies also utilise new technologies such as Holographic 3D

Displays, Crystal VR, and CAVE3 to create a more immersive learning experience. The diversification of the use of these devices indicates ongoing efforts to integrate visual technology into science learning to make it more interesting, contextual, and easier for students to understand abstract or microscopic phenomena.

Bibliometric analysis and recent research findings indicate that the use of 3D media, whether in the form of dynamic models or interactive animations, has a significant positive impact on students' learning motivation and conceptual understanding in science education, particularly in biology and chemistry. Research by Teplá, Teplý, and Šmejkal (2022) found that 3D visualisations and animations can increase students' interest in learning and facilitate the understanding of abstract concepts in science material. Therefore, further research should focus on longitudinal studies with an experimental approach to assess the long-term effects of 3D media on knowledge retention, concept transfer abilities, and learning outcomes at various levels of education. In addition, adapting 3D media to the local context, taking into account the availability of resources and teacher competencies, is also important for its effective and sustainable implementation.

Future research could focus on integrating 3D media with other technologies such as Virtual Reality (VR) and Augmented Reality (AR) to create a more immersive and contextual learning experience. Several studies have shown that combining 3D visualisation with interactive simulations can significantly improve students' spatial abilities and learning outcomes (Xie et al., 2021; Soto-Martín et al., 2020). Xie et al. (2021) revealed that the use of interactive 3D media in chemistry learning improved students' spatial abilities and molecular understanding. Meanwhile, research by Soto-Martín et al. (2020) proved that 3D-based simulations can strengthen conceptual understanding through exploration-based learning. In addition, technological advances such as smart devices, internet-based learning platforms, and artificial intelligence are also expected to accelerate innovation in the development of 3D media in science education (Hemme et al., 2023). Therefore, future research should not only focus on the visual design of 3D media but also on how such media can be effectively integrated into interactive, adaptive learning processes that align with the demands of 21st-century education.

CONCLUSION

Based on the results of bibliometric analysis of 50 publications from the Scopus database, it can be concluded that research on 3D media in science education shows an upward trend during the period 2020–2025, despite fluctuations in the number of publications each year. The countries that contributed the most to these publications were China and the United States, while the journal Applied Sciences (Switzerland) was the source of publications with the highest contribution. The most prolific author is Burley S.K., who has conducted extensive research on the development of 3D media in the fields of molecular biology and science education. The analysis also shows that 3D printing is the most frequently used tool in the development of learning media, followed by Blender and Unity, which are widely used for the creation of digital-based interactive models.

Overall, 3D media has been proven to have a positive impact on increasing learning motivation, spatial thinking skills, and students' understanding of abstract science concepts. Future research should focus on integrating 3D media with other technologies such as Virtual Reality (VR), Augmented Reality (AR), and artificial intelligence to create a more immersive and adaptive learning experience (Xie et al., 2021; Hemme et al., 2023). In addition, further research also needs to consider aspects of teacher readiness, infrastructure availability, and implementation effectiveness in various educational contexts so that 3D-based innovations can be adopted widely and sustainably. Thus, future research related to 3D media will not only contribute to the development of learning technology but also to improving the quality of science education relevant to the challenges of the 21st century.

REFERENCES

Abdo, S. N., Hsu, J. L., Kapetanakis, C., Newman, D. L., Wright, L. K., & Bailey, J. (2024). An Exploration of Spatial Visualization Skills: Investigating Students' Use of 3D Models in Science Problems during Think-Aloud Interviews. *Journal of chemical education*, *101*(9), 3624-3634.

Asempapa, R. S., & Love, T. S. (2021). Teaching math modeling through 3d-printing: Examining the influence of an integrative professional development. *School science and mathematics*, *121*(2), 85-95.

Burley, S. K., Bhikadiya, C., Bi, C., Bittrich, S., Chao, H., Chen, L., ... & Zardecki, C. (2022). RCSB Protein Data bank: Tools for visualizing and understanding biological macromolecules in 3D. *Protein Science*, *31*(12), e4482.

Bracco, F., Zanderigo, G., Paynabar, K., & Colosimo, B. M. (2025). Leveraging transfer learning for efficient bioprinting. *Biofabrication*.

Burley, S. K., Bhikadiya, C., Bi, C., Bittrich, S., Chen, L., Crichlow, G. V., ... & Zardecki, C. (2022). RCSB Protein Data Bank: Celebrating 50 years of the PDB with new tools for understanding and visualizing biological macromolecules in 3D. *Protein Science*, *31*(1), 187-208.

Chen, P., Wang, Y., Yan, H., Gao, S., Xu, Z., Li, Y., ... & Du, Y. (2020). 3DStructGen: an interactive web-based 3D structure generation for non-periodic molecule and crystal. *Journal of Cheminformatics*, *12*(1), 7.

Dosoftei, C. C. (2023). Simulation power vs. immersive capabilities: enhanced understanding and interaction with digital twin of a mechatronic system. *Applied Sciences*, *13*(11), 6463.

Fariqoh, A., Sutriyani, W., & Zumrotun, E. (2025). Pengaruh Game Based Learning Berbasis Augmented Reality terhadap Pemahaman Konsep Bangun Ruang SD. *Jurnal Pendidikan dan Pembelajaran Indonesia (JPPI)*, *5*(3), 1243-1253.

Fombona-Pascual, A., Fombona, J., & Vicente, R. (2022). Augmented reality, a review of a way to represent and manipulate 3D chemical structures. *Journal of chemical information and modeling*, *62*(8), 1863-1872.

Franco, A. A., Chotard, J. N., Loup-Escande, E., Yin, Y., Zhao, R., Rucci, A., ... & Lelong, R. (2020). Entering the augmented era: Immersive and interactive virtual reality for battery education and research. *Batteries & Supercaps*, *3*(11), 1147-1164.

Han, W., Shin, J., & Shin, J. H. (2022). Low-cost, open-source contact angle analyzer using a mobile phone, commercial tripods and 3D printed parts. *HardwareX*, *12*, e00327.

He, Z., Sui, X., & Cao, L. (2021). Holographic 3D display using depth maps generated by 2D-to-3D rendering approach. *Applied Sciences*, *11*(21), 9889.

Hemme, C. L., Carley, R., Norton, A., Ghumman, M., Nguyen, H., Ivone, R., ... & Cho, B. (2023). Developing virtual and augmented reality applications for science, technology, engineering and math education. *BioTechniques*, *75*(1), 11-20.

Henssen, D., Karstens, J., De Jong, G., Duits, J. D., Boer, L., Brink, M., ... & Peters-Bax, L. (2025). Implementing 3D printing and extended reality in anatomy education: Organization, evolution, and assessment of an innovative teaching program in an undergraduate medical school in the Netherlands. *Annals of Anatomy-Anatomischer Anzeiger*, *257*, 152354.

Komalawardhana, N., Euaumpon, N., Song, Z., & Limpanuparb, T. (2025). The virtual periodic table: Pilot development of open-source VR educational resource. *Molecular Catalysis*, *585*, 115326.

Kubsch, M., & Hamerski, P. C. (2022). Dynamic Energy Transfer Models. *The Physics Teacher*, *60*(7), 583-585.

Lavayssière, C., Larroque, B., & Luthon, F. (2022). Laborem Box: A scalable and open source platform to design remote lab experiments in electronics. *HardwareX*, *11*, e00301.

Lai, J. S., Burley, S. K., & Duarte, J. M. (2024). ZMPY3D: accelerating protein structure volume analysis through vectorized 3D Zernike moments and Python-based GPU integration. *Bioinformatics Advances*, *4*(1), vbae111.

Liritzis, I., Volonakis, P., & Vosinakis, S. (2021). 3d reconstruction of cultural heritage sites as an educational approach. The sanctuary of Delphi. *Applied Sciences*, *11*(8), 3635.

Marín Garcés, J., Veiga Almagro, C., Lunghi, G., Di Castro, M., Buonocore, L. R., Marín Prades, R., & Masi, A. (2021). MiniCERNBot educational platform: Antimatter factory mock-up missions for problem-solving STEM learning. *Sensors*, *21*(4), 1398.

Muti, I., Hasyim, D. M., Ummah, S. S., Anwar, S., & Hilman, C. (2024). Pemanfaatan teknologi pembelajaran berbasis augmented reality sebagai media pembelajaran iteraktif era metaverse. *Innovative: Journal Of Social Science Research*, *4*(6), 5463-5474.

Pernaa, J. (2022). Possibilities and challenges of using educational cheminformatics for STEM education: A SWOT analysis of a molecular visualization engineering project. *Journal of Chemical Education*, *99*(3), 1190-1200.

Răzvan-Ştefan, B., Laura Nicoleta, P., & Mihăşan, M. (2025). Impact of 3D-printed molecular models on student understanding of macromolecular structures: a compensatory research study. *Biochemistry and Molecular Biology Education*, *53*(4), 358-369.

Reinke, N. B., Kynn, M., & Parkinson, A. L. (2021). Immersive 3D experience of osmosis improves learning outcomes of first-year cell biology students. *CBE—life sciences education*, *20*(1), ar1.

Rodríguez, F. J. C., Frattini, G., Phloi-Montri, S., Meireles, F. T. P., Terrien, D. A., Cruz-León, S., ... & Abriata, L. A. (2025). MolecularWebXR: Multiuser discussions in chemistry and biology through immersive and inclusive augmented and virtual reality. *Journal of Molecular Graphics and Modelling*, *135*, 108932.

Rodríguez, F. C., Dal Peraro, M., & Abriata, L. A. (2022). Online tools to easily build virtual molecular models for display in augmented and virtual reality on the web. *Journal of Molecular Graphics and Modelling*, *114*, 108164.

Roshandel, H., Shammami, M., Lin, S., Wong, Y. P., & Diaconescu, P. L. (2023). App-Free Method for Visualization of Polymers in 3D and Augmented Reality. *Journal of chemical education*, *100*(5), 2039-2044.

Rojas-Sánchez, M. Á., Palos-Sánchez, P. R., & Folgado-Fernández, J. A. (2022). *A Bibliometric Analysis of Virtual Reality Research in Education (2010–2021). Education and Information Technologies*, 27(12), 17435–17457.

Serôdio, J., Bastos, A., Frankenbach, S., Frommlet, J. C., Esteves, A. C., & Queiroga, H. (2024). The 'Erlenmeter': a low-cost, open-source turbidimeter for no-sampling phenotyping of microorganism growth. *PeerJ*, *12*, e17659.

Smith, M. M., Ochoa, E., Barannikov, S., Keating, M., Habes, M., Flanagan, M. E., ... & Bieniek, K. F. (2024). Protocol for hybrid structured-light three-dimensional scanning and modeling of human postmortem brains. *STAR*

protocols, *5*(3), 103246.
Soto-Martin, O., Fuentes-Porto, A., & Martin-Gutierrez, J. (2020). A digital reconstruction of a historical building and virtual reintegration of mural paintings to create an interactive and immersive experience in virtual reality. *Applied Sciences*, *10*(2), 597.
Soto-Martín, O., Pérez, M. Á., & Castro, M. (2020). *Immersive 3D environments in science education: A study on motivation and learning outcomes*. *Applied Sciences*, 10(18), 6530.
Svatunek, D. (2023). "Holographic" Autostereoscopic Displays: A Perspective on Their Technology and Potential Impact in Chemistry. *Chemistry–A European Journal*, *29*(61), e202301746.
Tejera, R., Galić, M., & Lavicza, Z. (2025). *3D Modelling and Printing in Teacher Education: A Systematic Literature Review*. *Smart Learning Environments*, 12(1), 45–62.
Teplá, M., Teplý, P., & Šmejkal, P. (2022). *Influence of 3D models and animations on students in natural subjects*. *International Journal of STEM Education*, 9(1), 1–18.
Xie, G., Fang, Y., & Chen, X. (2021). *Exploring 3D interactive visualization tools for chemistry learning: Effects on spatial ability and conceptual understanding*. Frontiers in Psychology, 12, 713280
Yánez-Pérez, I., Toma, R. B., & Meneses-Villagrá, J. Á. (2025). Design and usability evaluation of a mobile app for elementary school inquiry-based science learning. *School Science and Mathematics*, *125*(3), 247-258.
Zangl, H., Anandan, N., & Kafrana, A. (2023). A low-cost table-top robot platform for measurement science education in robotics and artificial intelligence. *Acta Imeko*, *12*(2), 1-5.
Zardecki, C., Dutta, S., Goodsell, D. S., Lowe, R., Voigt, M., & Burley, S. K. (2022). PDB-101: Educational resources supporting molecular explorations through biology and medicine. *Protein Science*, *31*(1), 129-140.
Żyła, K., Kęsik, J., & Dakowicz, A. L. (2025). 3D Heritage Artefacts in Education—Enhancing Attractiveness of Computer Graphics Curriculum. *Applied Sciences*, *15*(14), 8069.
Wahidin, W. (2025). Pengembangan Media Pembelajaran Visual Untuk Meningkatkan Pemahaman Konsep Siswa. *Jurnal Ilmiah Edukatif*, *11*(1), 285-295.