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PAPER

Global Publication Trends in Augmented Reality and Virtual Reality for Learning: The Last Twenty-One Years

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ABSTRACT

Augmented reality (AR) and virtual reality (VR) provide new experiences in the digital and simulation worlds. While they are intended to stimulate users' perception and senses in general, the two differ significantly. This study aimed to seek and analyze international publications on the trends, similarities, differences, advantages, and disadvantages of AR and VR for learning over the period 2001–2021. In this study, bibliometric analysis using VOSViewer with the help of MS Excel was utilized to visualize metadata obtained from Scopus. Publish or Perish software supported the data collection of this study, which included retrieving and analyzing academic citations. The findings show that the AR/VR has trend continued to rise over the years. The results showed that Denmark and India (based on country bibliographic pairs), Journal of Physics Conference Series (based on journal bibliographic pairs), Y. Zhou publications (2018) (based on bibliographic pairs of publications), and Archana M. (India) with Lars K. (Denmark) (based on author bibliographic pairs) have become the most influential in the field of augmented reality and virtual reality for learning. AR and VR are two technologies changing how people use screens, thus creating new and exciting interactive experiences. In the future, it is expected that further research related to AR/VR and even Mixed Reality (MR) will continue to develop along with technological advancement. However, pedagogical competence remains an essential key to learning.

KEYWORDS

bibliometric analysis, augmented reality, virtual reality, sustainable development goals, education, learning

1 INTRODUCTION

Education is one of the foundations of a nation's development [1]. It plays an essential role in improving the quality of human resources [2]. The quality of education will reflect the quality of people in an area [3]. Quality education is also one of the world's development agendas aiming at improving human welfare globally, called the Sustainable Development Goals (SDGs) [4], [5]. To acquire quality

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education, the field of realm education should change, adapt, and develop over time. Likewise, technology continues to experience innovation and development. Technological innovation presents vast opportunities in education. It was critical in the industrial revolution 4.0 era as the principal capital in global competition. Technology and education have become inseparable. One of the roles of technology in education is to serve as a tool during teaching and learning. In the last two years, we have experienced a significant change in education with the emergence of the COVID-19 pandemic, which has become the catalyst for digital transformation in almost all sectors of life, including education [6].

The face-to-face (f2f) learning process was replaced by online or mixed learning. Learning media also evolved from paper-based media to digital-based media and cloud-based media [6]. The metaverse, NFT, blockchain, Web 3.0, AR, VR, artificial intelligence (AI), big data, automation, and the like had become technological trends by 2022 [7], [8]. Adopted by all United Nations member states in 2015, the 2030 Agenda for Sustainable Development presents a blueprint for peace and prosperity for people and the planet, now and in the future. At its core are the 17 Sustainable Development Goals (SDGs), representing an urgent call to action by all developed and developing countries in a global partnership. For countries to achieve Sustainable Development Goals (SDGs) in all contexts, they must use resources such as finance, knowledge, creativity, and technology. AR/VR has become the most crucial technological resource to stimulate unlimited creativity and facilitate knowledge through experience [9].

AR and VR technologies have been developed in various sectors of life, especially in fulfilling aspect No. 4 of the SDGs, namely, quality education. The use of AR/VR in education is intensively discussed in Indonesia, especially as a supporter of the teaching and learning process. Various researchers and institutions have conducted studies on AR/VR. Several studies discuss technology and its implementation in the field of education. This research was conducted to analyze, identify, and explore the topic of AR/VR and its development. The bibliometric analysis offers an excellent review quality by visualizing the most popular trends currently being developed [10]. An increased understanding of the distribution of research topics on AR and VR is undoubtedly helpful as it can be used as a reference for developing the technology in the future. This research utilized VOSViewer, and Ms-Excel to visualize the distribution of research results to create a more exciting and easier-to-understand information presentation [11].

This study also aimed to conduct a literature review on AR/VR in education in the last 21 years using bibliometric analysis. The following is a list of research questions that will become the focus of achieving this research problem:

1. What are the trends of publications in augmented reality (AR) and virtual reality (VR) for learning in the last 21 years?
2. What types of publications of the top 100 cited papers in AR and VR for learning from 2001–2021?
3. How is the distribution of the top 100 papers quoted from AR and VR for learning from 2001–2021?
4. How do AR and VR help achieve Sustainable Development Goals (SDGs)?
5. Who are the top 20 authors of the top 100 cited papers on AR and VR for learning from 2001 to 2021?
6. Which journal published the most papers on AR and VR for learning between 2001 and 2021?
7. What are the differences and similarities between AR and VR?
8. What are the advantages and disadvantages of AR, VR, and MR?

2 LITERATURE REVIEW

2.1 The Sustainable Development Goals (SDGs)

The Sustainable Development Goals (SDGs) are a global action plan agreed upon by world leaders, including Indonesia, to end missions, reduce tensions, and protect the environment. The SDGs include 17 Goals (see Figure 1) and 169 Targets that are expected to be met by 2030. The UN has stated that countries must use resources such as finance, knowledge, creativity, and technology to achieve the SDGs in all contexts. Furthermore, AR/VR and its immersive scenarios have emerged as an essential technological resource for stimulating unlimited creativity and facilitating knowledge through experience. AR/VR can help to achieve any SDGs by increasing awareness, empathy, sensitization, and training.

Fig. 1. Sustainable Development Goals (SDGs)

2.2 Bibliometric analysis

Bibliometrics is a statistical method for analyzing publications. It is the basis for determining the most popular and significant publications in a particular field. Bibliometrics is a research method that has complete information by combining science, mathematics, and statistics in analyzing knowledge quantitatively. Over the years, bibliometrics has evolved and become commonplace to analyze and map concepts and knowledge published in many fields.

3 METHODOLOGY

Quantitative research based on the Scopus database was selected for this study, while Publish or Perish (PoP) was utilized in data collection. Data analysis was conducted using bibliometric techniques with the help of VIOSViewer software to prove and determine novelty and trends in research [12], [13]. All data for this study were carried out on September 26, 2022, with the criteria in Table 1.

Table 1. Data identification

Description	Augmented Reality	Virtual Reality
Keywords	Title (Augmented Reality AND learning)	Title (Virtual Reality AND learning)
Publication type	Articles; Proceedings	Articles; Proceedings
Documents (all years)	4,284; 2,155 (6,439 total)	8,340; 3,188 (11,528 total)
Documents (2001–2021)	5,423 documents	9,736 documents

Subsequently, metadata were saved as CSV and RIS files. Additional analysis was then performed using MS Excel and VOSViewer to improve the data. According to Binar [31], the effectiveness of VOSViewer has been proven in a recent study carried out with the Scopus index. The research procedure consists of 4 stages, starting with 1) identification; 2) screening and filtering; 3) analysis and discussion, and 4) conclusion, as seen in Figure 2.

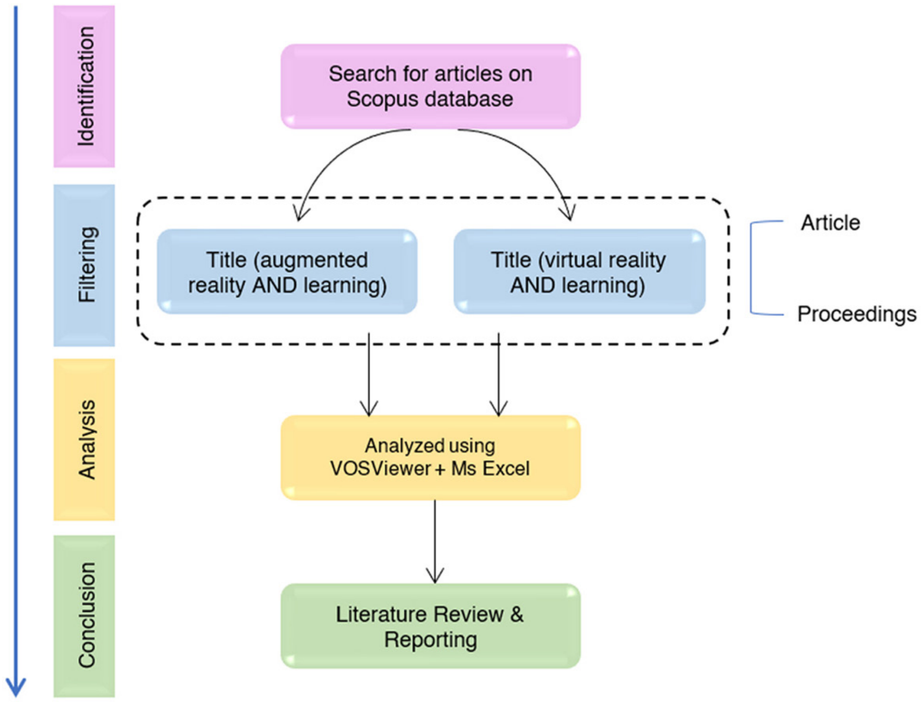
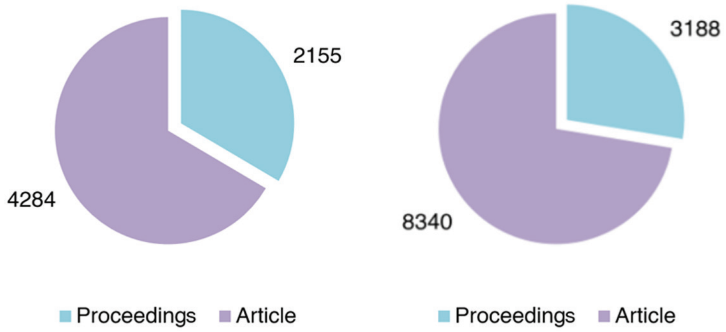


Fig. 2. Research procedure

4 RESULTS AND DISCUSSION

4.1 Global publication trends

Data were identified using keyword criteria described in Table 1 and data sources from the Scopus database. This study's type of publication was limited to articles and proceedings. Figures 3a and 3b show the screening results of 6,439 documents on AR technology in education for a year, comprising 4,284 articles and 2,155 proceedings. Publications discussing VR technology in learning were 11,528 (all years), comprising 8,340 articles and 3,188 proceedings.



(a) Publication type: AR and learning **(b) Publication type: VR and learning**

Fig. 3. Publication type: article and proceeding (all year)

Figures 4 and 5 depict the growth of Scopus article publications and proceedings on AR and VR for learning in the last 21 years, proving significant. This demonstrates that the trend toward AR/VR in learning is expanding. The data also demonstrate researchers' keen interest in the research topic. Figures 3 and 4 show five articles on AR technology and 64 articles on VR technology in learning published in 2001. In 2021, there were 1,369 Scopus articles on AR technology in learning and 2,179 on VR technology in learning. This is consistent with the fact that metaverse technology is a prevalent trend. AR/VR technology is inextricably linked with metaverse technology.

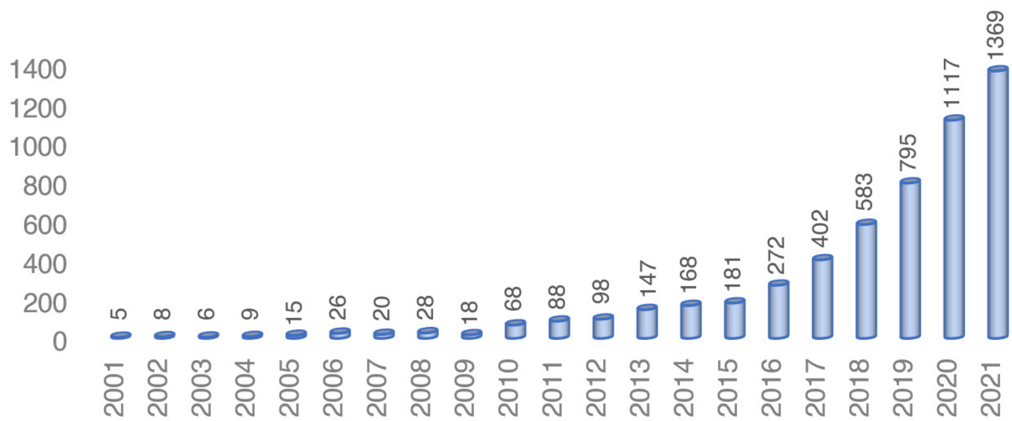


Fig. 4. Cumulative publication: augmented reality AND learning

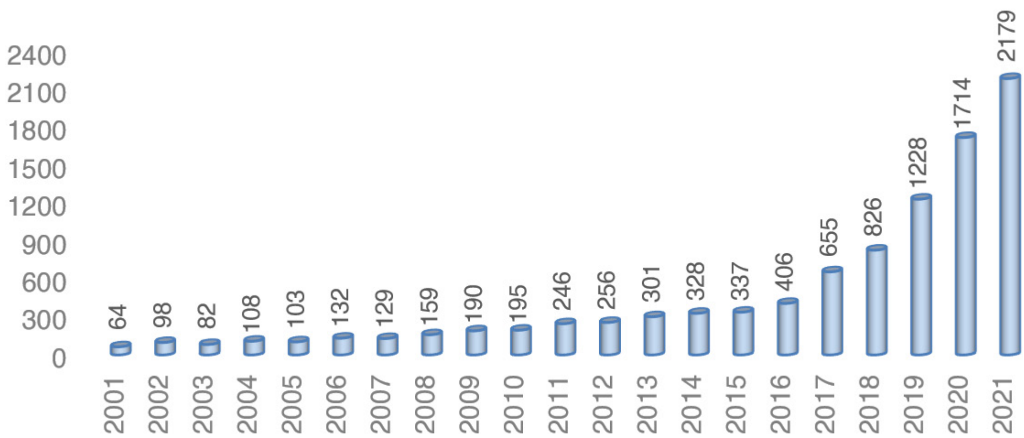


Fig. 5. Cumulative publication: virtual reality AND learning

4.2 Publication Type

This study examined 100 articles and proceedings that received the most citations in the last 21 years. Table 2 summarizes the top 100 publications with citations published on AR/VR technology in learning.

Table 2. Type of publication with the highest number of citations

Publication Type	Frequency		Total Citation		Average	
	AR	VR	AR	VR	AR	VR
Article	81	85	21,091*	37,202*	260.38*	437.67
Proceedings	19	15	4,876	8,742	256.63	582.80*
Total	**100**	**100**	**25,967**	**45,944**	**517.01**	**1,020.47**

Note: * = The highest number.

In Table 2, we can find 100 publications on AR technology in education: articles (81) and proceedings (19). Meanwhile, 100 publications on VR technology in education consist of articles (85) and proceedings (15). In addition, the highest number of review citations was for articles on VR in education (37,202), and the lowest number of review citations was for proceedings on AR in education (4,876). The highest average number of review citations was for proceedings regarding VR technology in education (582.80), and the lowest was for AR (256.63). The following section discuss the distribution of the 100 publications based on the highest number of citations.

4.3 Publication distribution

Table 3 below shows the distribution of 100 publications that discuss AR and VR for learning in education with the highest number of citations (top 100) over the last 20 years. The top 100 publications on AR had 25,967 total citations, with 5,292.4 ACPP, 673.09 ACPPY. The highest number of citation (3,802) was in 2014, and 2014 was considered the year with the highest number of publications from 15 documents. However, the highest ACPP (690) was in 2003. Meanwhile, the highest ACPPY (136.83) was in 2020. The top 100 publications on VR, 45,944 total citations, with 9,563.58 ACPP, 1,216.33 ACPPY. Similar to AR, the highest number of citation (4,405) was in 2014. However, the highest ACPP (715.75) was in 2015. Meanwhile, the highest ACPPY (205.67) was in 2020.

Table 3. Publication distribution

Augmented Reality					Virtual Reality				
Year	Pub.	Cit.	ACPP	ACPPY	Year	Pub.	Cit.	ACPP	ACPPY
2001	1	142	142	6.76	2001	2	1,315	657.5	31.31
2002	3	778	259.33	12.97	2002	3	1,305	435	21.75
2003	2	1,380	690*	36.32	2003	5	3,563	712.6	37.50
2004	2	520	260	14.14	2004	5	1,964	392.8	21.82
2005	1	168	168	9.88	2005	4	1,217	304.25	14.32
2006	4	1,344	336	21.00	2006	6	2,192	548	22.83

(Continued)

Table 3. Publication distribution *(Continued)*

Augmented Reality					Virtual Reality				
Year	Pub.	Cit.	ACPP	ACPPY	Year	Pub.	Cit.	ACPP	ACPPY
2007	3	735	245	16.33	2007	5	2,037	407.4	27.16
2008	1	348	348	24.68	2008	8*	2,804	350.5	25.04
2009	4	1,130	282.5	21.73	2009	8*	3,073	384.13	29.55
2010	3	558	186	15.50	2010	7	3,118	445.43	37.18
2011	2	421	210.5	19.14	2011	5	1,933	386.6	35.15
2012	5	913	182.6	21.73	2012	2	852	426	42.60
2013	11	3,510	319.09	35.46	2013	7	3,623	517.57	57.51
2014	15*	3,802*	253.47	31.69	2014	7	4,405*	629.29	67.54
2015	8	1,390	173.75	24.82	2015	4	2,863	715.75*	102.25
2016	7	1,437	205.28	34.21	2016	6	2,871	478.5	79.75
2017	9	2,575	286.11	57.22	2017	5	1,658	331.6	66.32
2018	10	2,921	292.1	73.02	2018	3	1,873	624.33	156.08
2019	6	1,074	179	59.66	2019	2	810	405	135
2020	3	821	273.67	136.83*	2020	6	2,468	411.33	205.67*
Total	**100**	**25,967**	**5,292.4**	**673.09**	**Total**	**100**	**45,944**	**9,563.58**	**1,216.33**

Notes: Pub. = Number of publications; Cit. = Number of citations; ACPP = Average Citations Per Paper; ACPPY = Average Citations Per Paper Per Year; * = The highest number.

In Figure 6, we can see that from 2001 to 2020 there were 15 publications about AR in 2014 that were included in the top 100 publications with top citations, and as many as 8 publications about VR in 2008–2009, were included in the top 100 publications category with top citations.

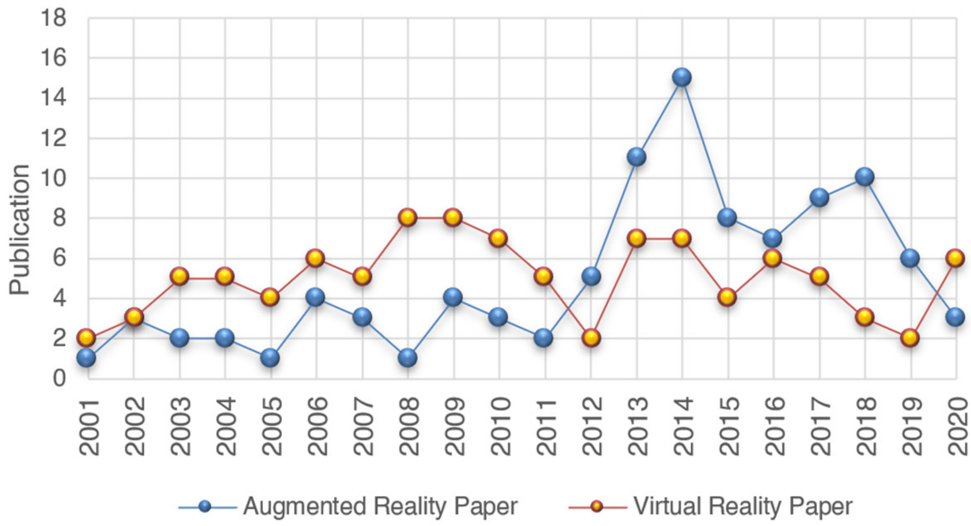


Fig. 6. Distribution of the top 100 cited publications

As seen in Figure 7, the average number of citation per paper per year (ACPPY) of the top 100 publications has increased significantly. The rapid increase occurred from 2014 to 2020.

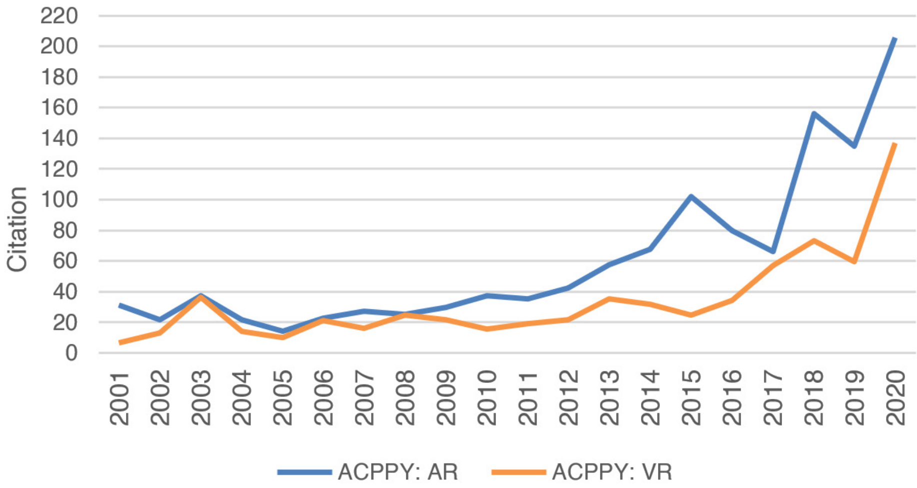


Fig. 7. Average citation per paper per year

Figure 8 shows that the ACPPY of AR/VR has tended to increase yearly. The highest number occurred in 2020 for AR (205.67) and VR (136.83). Meanwhile, the lowest ACPPY for AR was in 2005 (14.32), and the lowest ACPPY was for VR was in 2001 (6.76).

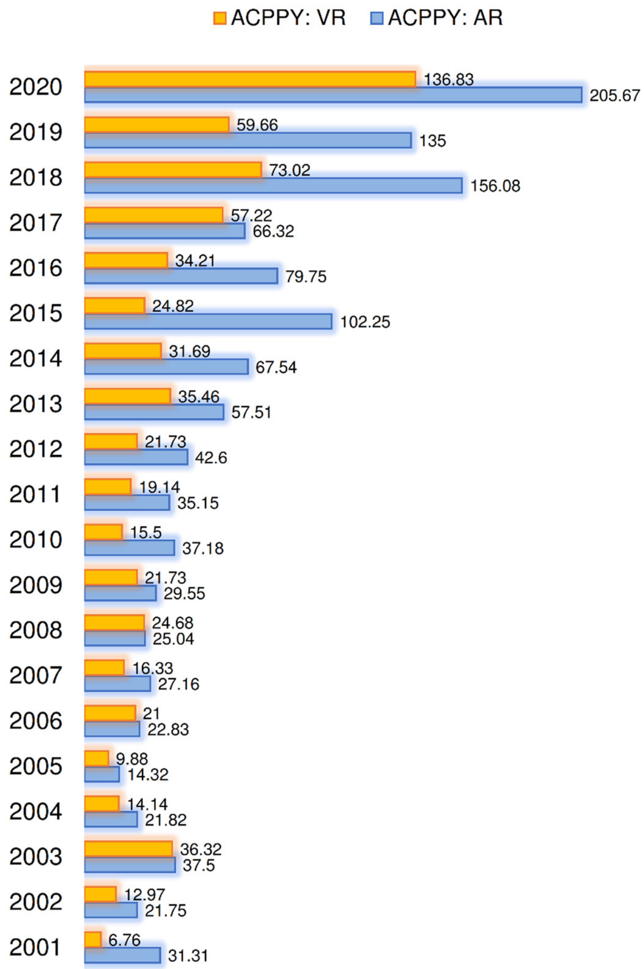


Fig. 8. ACPPY: AR & VR (2001–2020)

Notes: ACPP = Average Citations Per Paper; ACPPY = Average Citations Per Paper Per Year.

4.4 Publication categories

Figure 9 depicts a classification of publication distribution by research field. It was observed that informatics, computer science, and education dominate AR/VR technology publications, followed by psychology and health. There are 2,555 publications in the informatics and computer science category and 2,018 in the education category. This implies that researchers actively discussed AR/VR technology in literature studies and application development. AR/VR technology is widely used in education, medical therapy, psychology, health sciences, and engineering [14]–[19]. In education, it is widely used as a support for learning in the form of AR/VR-based media. In addition, VR has been applied in mental health therapy (psychology). AR/VR is also widely used in surgery and surgery simulations in the health sector.

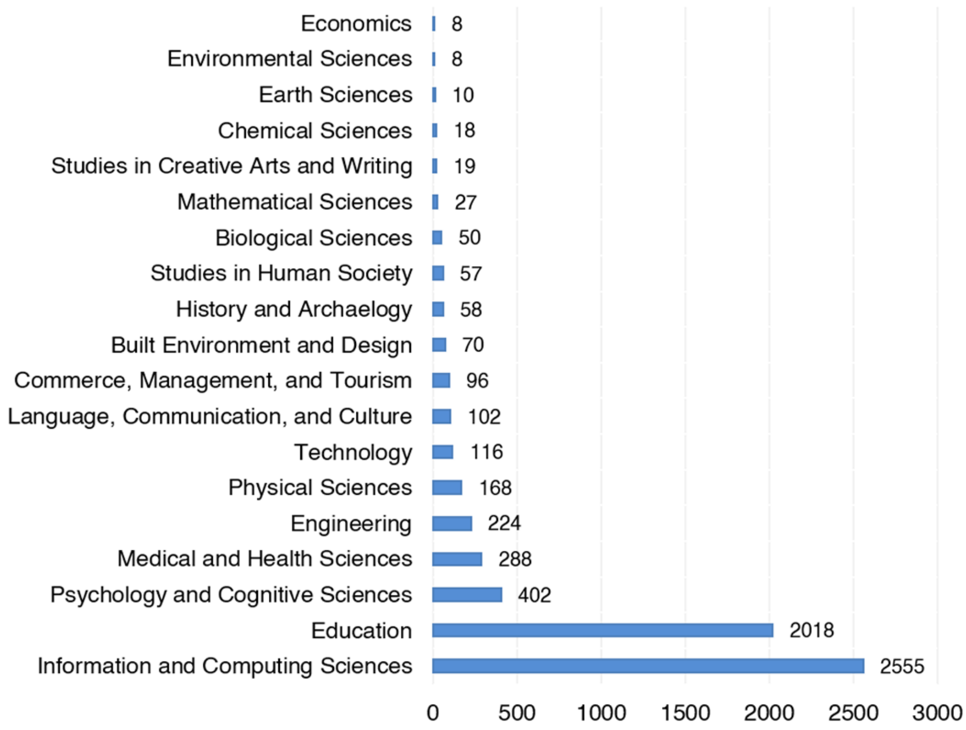


Fig. 9. AR classification by fields of publication research

The data results in Figure 10 further emphasize that AR/VR technology impacts aspects of the SDGs, namely "04—Quality Education". Thousands of publications discuss AR/VR technology as a tool to improve learning and education quality. Improving education will accelerate the achievement of other SDG goals and targets while significantly increasing the human development index. As a result, it is hoped that the role of education will boost competitiveness in support of the 2030 SDGs.

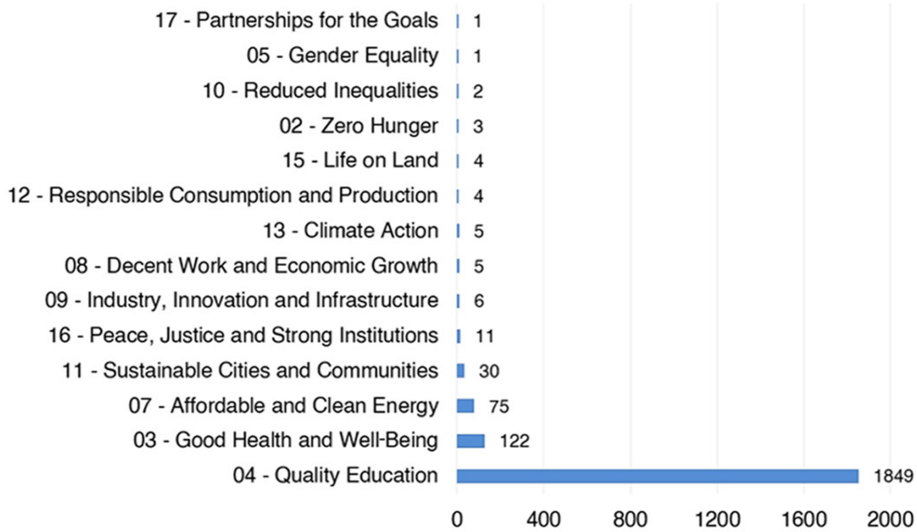


Fig. 10. AR classification by SDGs

4.5 Top 20 authors with more publications and citations

Table 4 and Figures 11–12 show the 20 authors with the highest number of documents from various countries in the last 21 years. M. Archana from Chitkara University (India) dominated the topic of augmented reality for learning with a total of 20 documents, followed by B. Fauzi from the State University of Jakarta (Indonesia) with 18 documents, N. B. Mark from the University of South Australia (Australia) with 16 documents, and C. Su from Beijing Normal University (China) with 13 documents. Meanwhile, K. Lars from Copenhagen Academy for Medical Education and Simulation (Denmark) dominated the topic of virtual reality for learning with 38 documents, followed by A. Rajesh from Thomas Jefferson University (USA) with 37 documents, W. D. Ara from Imperial College London (England) with 37 documents, and G. Makransky from the University of Copenhagen (Denmark) with 20 documents.

Table 4. Top 20 authors with most publications in AR/VR for learning

Augmented Reality for Learning			Virtual Reality for Learning		
Author	No. of Docs.	Country	Author	No. of Docs.	Country
Archana M.	20	Chitkara University (India)	Lars K.	38	Copenhagen Academy for Medical Education and Simulation (Denmark)
Fauzi B.	18	University of Jakarta (Indonesia)	Rajesh A.	37	Thomas Jefferson University (USA)
Mark N. B.	16	University of South Australia (Australia)	Ara W. D.	37	Imperial College London (England)
Su C.	13	Beijing Normal University (China)	Makransky G.	20	University of Copenhagen (Denmark)
Nassir A. N.	13	Technical University of Munich (Germany)	Shih-Ching Y.	17	National Central University (Taiwan)
Jorge M. G.	12	University of La Laguna (Spain)	Thomas D. P.	16	University of North Texas (USA)

(Continued)

Table 4. Top 20 authors with most publications in AR/VR for learning *(Continued)*

Augmented Reality for Learning			Virtual Reality for Learning		
Author	**No. of Docs.**	**Country**	**Author**	**No. of Docs.**	**Country**
Maria B. I.	10	Carlos III University of Madrid (Spain)	Wern H. T.	16	National Tsing Hua University (China)
M-Carmen J.	12	Universitat Politècnica de València (Spain)	Suvranu D.	15	Rensselaer Polytechnic Institute (USA)
Silvia M. B.	12	Universidad Internacional De La Rioja (Spain)	Albert	14	University of Southern California (USA)
Eleni E M.	11	University College Dublin (Ireland)	Giuseppe R.	14	Catholic University of the Sacred Heart (Italy)

Note: No. of Docs.= Number of documents.

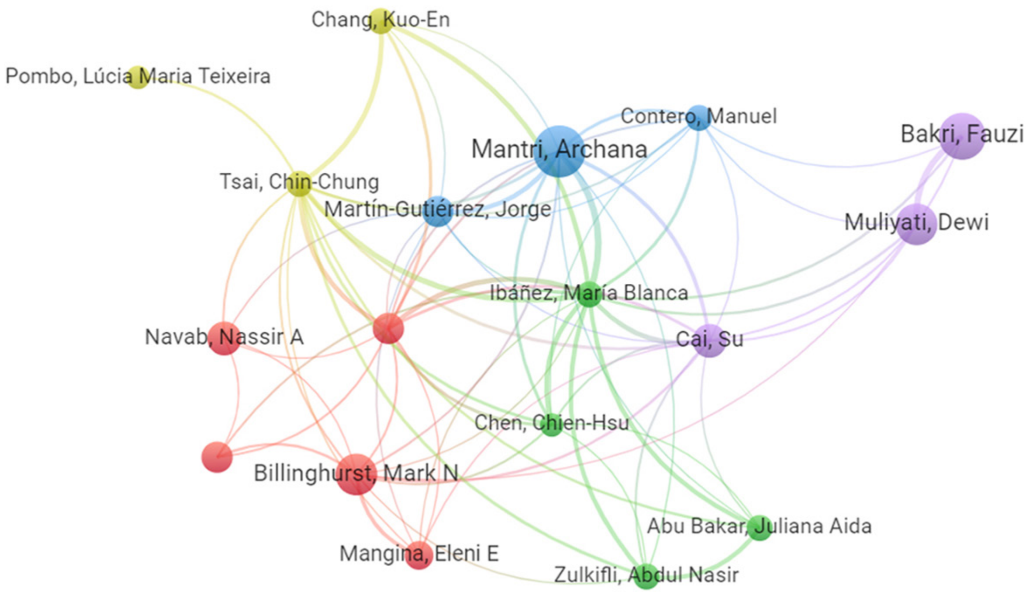


Fig. 11. Top authors with most publications: AR for learning (VOSViewer)

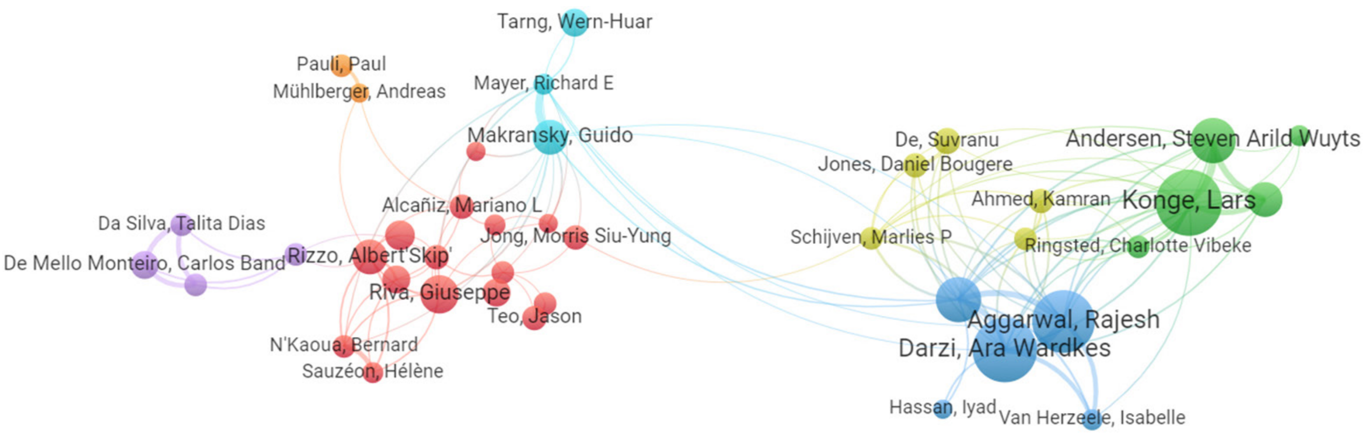


Fig. 12. Top authors with most publications: VR for learning (VOSViewer)

Table 5 shows the 20 authors with the highest number of citations in the last 21 years. It was dominated by Y. Zhou (2018) with 1,202 citations, followed by H. Wu (2013) with 1,103 citations, followed by F. A. Gers (2003) with 1,047 citations.

Table 5. Top 20 authors with most citations in AR/VR for learning

Author	Year	Journal/Conference	No. of. Cits.
Y. Zhou	2018	Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition	1,202
H. Wu	2013	Computers and Education	1,103
FA Gers	2003	Journal of Machine Learning Research	1,047
M. Akçayır	2017	Educational Research Review	764
M. Dunleavy	2009	Journal of Science Education and Technology	697
J. Bacca	2014	Educational Technology and Society	593
A. Di Serio	2013	Computers and Education	548
J. Radianti	2020	Computers and Education	485
A.S. Merians	2002	Physical Therapy	400
V. Potkonjak	2016	Computers and Education	399
I. Radu	2014	Personal and Ubiquitous Computing	397
Z. Pan	2006	Computers and Graphics (Pergamon)	361
N. Gavish	2015	Interactive Learning Environments	351
H. Ishii	2008	2nd International Conference on Tangible and Embedded Interaction	348
J. Martinez	2017	30th IEEE Conference on Computer Vision and Pattern Recognition	341
H. Kaufmann	2003	Computers and Graphics (Pergamon)	333
KD. Squire	2007	Journal of Science Education and Technology	326
M.B. Ibáñez	2018	Computers and Education	325
C. Moro	2017	Anatomical Sciences Education	323

4.6 Top 20 journals with most publications on AR/VR for learning

Table 6 shows the top 20 journals and proceedings with the most documents discussing AR/VR for learning. The Journal of Physics Conference Series led with a total of (140) documents, followed by Procedia Computer Science with 62, then IOP Conference Series Material Science and Engineering with 52, Applied Sciences with 47, IEEE Access with 46, AIP Conference Proceedings with 39, Interactive Learning Environments with 39 documents, Advances in Social Science, Education, and Humanities Research with 38, and International Journal of Interactive Mobile Technologies (iJIM) with 37.

Table 6. Top 20 journals and proceedings with most publications on AR/VR for learning

No	Journal	No. of Pubs.
1	Journal of Physics Conference Series	140
2	Procedia Computer Science	62
3	IOP Conference Series Materials Science and Engineering	52
4	Applied Sciences	47
5	IEEE Access	46
6	AIP Conference Proceedings	39
7	Interactive Learning Environments	39
8	Advances in Social Science, Education and Humanities Research	38
9	International Journal of Interactive Mobile Technologies (iJIM)	37
10	Computers & Education	36
11	Sensors	35
12	Multimedia Tools and Applications	32
13	International Journal of Emerging Technologies in Learning (iJET)	29
14	Virtual Reality	27
15	Education Sciences	27
16	Education and Information Technologies	23
17	Sustainability	22
18	International Conference on Education & New Learning Technologies	21
19	Procedia—Social and Behavioural Sciences	19
20	Journal of Educational Computing Research	18

4.7 Differences and similarities between AR and VR

After reviewing all the literature and other scientific sources, we conclude that there are similarities and differences between AR and VR. To reduce misconceptions about AR and VR, we briefly summarize the similarities and differences in Tables 7 and 8.

Table 7. Similarities and differences between AR and VR

Description	Augmented Reality	Virtual Reality
Definition	Augmented reality is a technology where the real world is equipped with additional information such as text, images, animations, videos, or 3D objects that can move. This technology adds digital elements and illuminates that these elements are part of the real world. [20]	Virtual reality is a technology that allows users to interact with a virtual world simulated by a computer. Users using virtual reality equipment such as gloves can feel that they are in a virtual world [21].
Purpose	Technology adds to reality and augments the real-world environment.	The technology replaces reality and completely simulates the virtual environment.
Function	Provide an immersive experience of 25% virtual and 75% real experience.	Provide an immersive experience of 75% virtual and 25% real experience.
Concept	Users stay connected to the real world while interacting with surrounding virtual objects.	Users are isolated from the real world and feel fully immersed entirely in the virtual world.

(Continued)

Table 7. Similarities and differences between AR and VR *(Continued)*

Description	Augmented Reality	Virtual Reality
Technology	The technology can be accessed through a phone's camera, and the virtual content display can be viewed through the device screen.	To experience this technology, users need a device such as a headset.
Utilization	Augmented reality technology is widely used in various industrial fields such as games, entertainment, education, and science.	Virtual reality technology is widely used in various industrial fields and for games, entertainment, education, and science.
Device	Smartphone, computers	Gloves, VR headsets
Example	Pokemon Go, IKEA Place	Beat Saber, Virtual Experience

VR is a technology that uses computer technology to create a simulated environment [22]; VR immerses users in it to create a lifelike experience. Its application necessitates using a VR headset linked to a computer or smartphone that already supports VR technology [16], [23]. AR is a technology that adds layers of digital information to our physical world, such as objects that do not exist in the real world [19]—making it appear as if it is part of a realistic environment, similar to the game Pokemon.

AR does not require a headset like VR but a smartphone with AR capabilities. MR (Mixed Reality) is the simultaneous use of AR and VR technologies, as shown in Figure 13, to create new environments and visualizations in which physical and digital objects coexist and interact in real-time [25]. In its implementation, MR employs both a headset and a console.

Table 8. Comparison of AR, VR, and MR

Technology	Virtual Content	Real Content	Interactivity
Augmented Reality (AR)	Low	High	Mid
Virtual Reality (VR)	High	Low	Mid
Mixed Reality (MR)	Mid	High	High

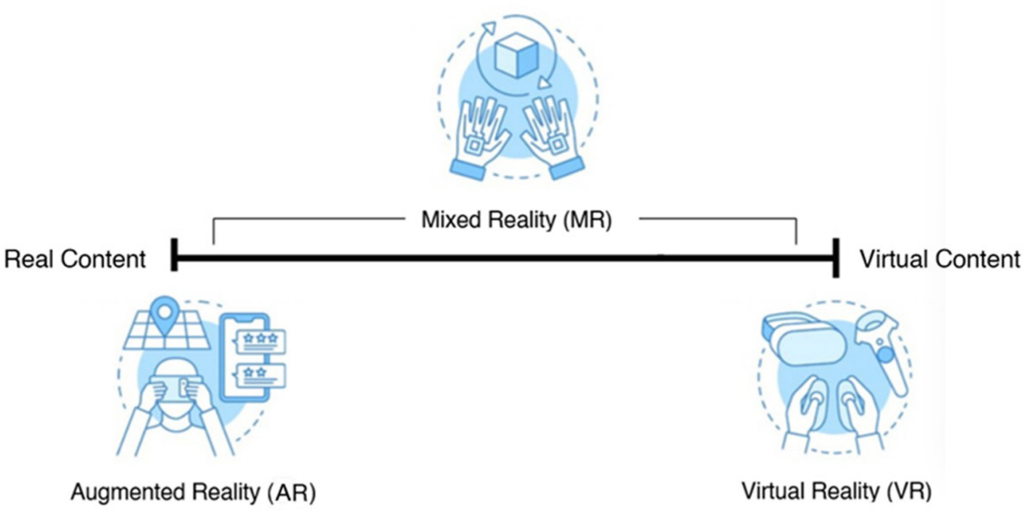


Fig. 13. Comparison of AR, VR, and MR

4.8 Advantages and disadvantages of AR, VR, and MR

AR/VR/MR allows students in higher education to engage in an immersive learning experience. AR is a simpler technology to develop than VR and MR, which are more complex, require more hardware, and are more expensive. A VR headset is required to experience the thrill of VR. Meanwhile, mixed reality (MR) is a hybrid between AR and VR. MR superimposes a virtual experience in the real world, allowing users to escape the fully immersive VR environment and interact with real and virtual objects. MR is typically viewed with head-mounted displays and smart goggles produced by Microsoft, Magic Leap, and Third Eye, among others.

The benefits of AR, VR, and MR in learning are that they increase student engagement and foster better understanding. However, only AR and VR are currently widely used in education. Using AR and VR to enable more immersive and interactive earning, teachers may explain complicated topics in a controlled environment. Some areas in which AR and VR are used include:

- **Medicine and Science.** AR/VR can be useful for medical students in human and animal anatomy, molecular biology, chemistry, and atomic physics courses. Astronauts and pilot training also make extensive use of augmented reality technology.
- **Literature.** Virtual tours of historical buildings and archaeological sites in remote areas enrich the learning experience of history, archaeology, and political science students. In addition, art students can directly experience the world's top museums and works of art collections through VR [24].
- **Engineering.** AR/VR can be implemented in engineering practice to better display or simulate learning tools by creating full-scale 3D models and address limitations of physics and mechanics by creating the most imaginative and innovative designs.

The ability of AR to superimpose virtual enhancements on real-world objects and the ability of VR/MR to simplify complex concepts or theories without using intricate machinery in-house can be instrumental in the education sector. There are many benefits that the use of these technologies offer. The most significant advantage of AR/VR in tertiary institutions is improving student learning outcomes. AR/VR enables a more immersive and experiential learning experience. AR/VR makes learning more immersive and experiential while helping students mainly increase their memory retention; it is also beneficial for students with learning disabilities by simulating and simplifying complex topics and concepts to help students gain a better understanding while simultaneously making distance learning exciting and fun. However, despite the seemingly overwhelming advantages, AR/VR/MR has shortcomings that must be addressed. One of the disadvantages of AR is that the results occasionally appear less lifelike. AR objects in the real world do not look precisely like the original object. Sometimes the developed form of AR also has a quality that does not match the original object.

VR and MR also have weaknesses and some limitations that have emerged. VR/MR requires substantial utilization of cables. VR/MR also uses an enclosed environment, suggesting that mobility can be significantly restricted and problematic. Users can easily collide with walls or trip over objects they cannot see in the virtual world. Many users are also susceptible to dizziness and nausea after prolonged VR/MR use. Therefore, VR/MR is best suited for brief intervals per session rather than lengthy instructional demonstrations.

4.9 Research implications

This bibliometric research is anticipated to benefit scientists, researchers, and the academic community directly. Scientists conducting research can find out topics to be studied, unresearched topics, trending topics to be researched, or topics that have been researched. The results of bibliometric research can serve as a reference and starting point for other scientists in future studies. This research can serve for further research examining current technological trends, especially AR and VR technology in learning. The results of this study are also expected to be a new source related to AR/VR technology in learning, as well as a source of information for practitioners, consultants, and stakeholders in formulating policies so that they can make better decisions with consideration based on valid information obtained in this research article.

5 CONCLUSIONS

This study found that the trend of publications about AR and VR for learning helped improve education quality. Based on the publication category, there were 1849 publications discussing AR and VR technology used to improve the learning process and quality of education. From our classification of publication distribution by research field, it was observed that informatics, computer science, and education dominate AR/VR technology publications, followed by psychology and health. However, AR/VR technology is not used in earth science, chemistry, or mathematics. These are area in which AR/VR researchers in this field need to conduct further research. Most of the large number of publications are dominated by discussions regarding the development and implementation of AR/VR-based applications, without relating to other variables such as pedagogy, the relationship between learning media and pedagogy, or how they can be integrated with current pedagogical techniques, including the critical field of digital pedagogy.

The COVID-19 pandemic has forced learning to go online for the past couple of years. There have been many obstacles and challenges in the field. At present, overcoming economic deficiencies and limited facilities is only part of what is needed. The main problem is boredom with online learning. This has challenged educators, who need to understand pedagogy and dare to be creative in online learning by utilizing the technological sophistication that is developing rapidly today.

For this reason, a new model and orientation for 21st-century education are needed, which emphasize creative education as a starting point to encourage significant changes in the role of the teacher, public relations, technology, and teacher professionalization. The 21st-century teacher must know how to provide student-learning opportunities supported by technological advances and understand how technology supports learning. Critical digital pedagogy involves students paying attention to learning styles, and assuming that each individual has at least two or three learning styles.

Besides that, recent technological advances, such as AR, VR, and MR, can provide students in various disciplines with more opportunities to expand and grow their creativity and innovation in education in new and different ways. From the results obtained in this study, we can conclude that VR, AR, and MR technologies that can change the world and enhance human collaboration have quietly arrived. As can be seen in the last 20, AR/VR technology has continued to improve, and its use in learning also continues to grow year by year. Today, the technology is available and has considerable market potential [26]. Applying immersion technology such as AR/VR encourages students to be curious about new material. Students can also experience things that may be barely possible in the real world. AR and VR, combined with the concept of pedagogy, will make these technologies a medium and a stimulant for a more enjoyable experience. AR and VR technology can enhance student engagement and interest, the learning environment, content comprehension, collaboration, memory, sensory development, and cost-effectiveness. AR and VR play an essential role in learning, such as digitizing education and eliminating the time-distance gap. The fact that one does not need to be physically present to learn anything is reinforced by the more straightforward means of comprehensive understanding and a promising approach to the student's point of view, as AR/VR brings lessons to life through simulations. In addition, another vital key is whether teachers or lecturers can understand digital pedagogy, which is interpreted as involvement and reflective practice in teaching and learning activities through digital technology and its distinctive characteristics namely, uniting theory and practice, making and thinking; fostering creativity, play, and problem-solving; encouraging participation, collaboration, and public engagement which aims to increase critical understanding of the digital environment.

Based on publications on the contribution of AR/VR technology in supporting the achievement of SDGs, quality education is one of the promising development areas for AR and VR technology. These technologies can motivate students and teachers to think outside the box and into a new, interdisciplinary mode. Incorporating new technologies into the classroom rather than resisting them is essential and can contribute significantly in the long run. With the power of AR/VR, future classrooms may not look like the traditional classrooms of the past. In the coming 5–10 years, with the maturity of various new technologies such as block-chain technology, AI technology, VR/AR and sensing technology, mobile communication technology, and ubiquitous computing technology, further development of the metaverse of education is likely to happen. Besides that, entering the digital era and the era of society 5.0, the existence and presence of educators remain significant in learning. It is just that the learning paradigm used by teachers and lecturers needs adjustment and even a change from the old paradigm to the new paradigm. In other words, the applied pedagogy must be changed and shifted by applying critical digital pedagogy.

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