Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Virtual Laboratory and Artificial Intelligence in Science Education: Bibliometric Analysis Based on Scopus Source

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ABSTRACT

This study examines the development of research related to virtual laboratories and artificial intelligence in education. With the assistance of VOSviewer, this study aims to conduct computational mapping on bibliometric data of articles on the keywords: artificial intelligence, virtual laboratories, and education. The method used in this research is bibliometric analysis using VOSviewer. Article data obtained from Scopus-based data, article titles, and abstracts are used to guide the search process by referring to the keywords "laboratorium virtual" and "artificial intelligence in education". It found 359 allegedly relevant articles. The study period used as study material in this study was for the last 5.5 years, namely from 2018 to June 2023. The results of laboratorium virtual and artificial intelligence research in education can be separated into 3 terms, namely artificial intelligence, laboratorium virtual, and education. The term artificial intelligence has 304 links with a total link strength of 12065, the term Laboratorium virtual has 416 links with a total link strength of 5451 links with an accuracy of 212 terms, and the term education has 399 links with a total link strength of 3142 accuracies of 113. The analysis results indicate a significant increase in research related to virtual laboratories and artificial intelligence in education over the past four years. However, the relationship between virtual laboratories and artificial intelligence in education is still relatively rare. In fact, there is no existing relationship between virtual laboratories and artificial intelligence. Based on this information, the opportunity for developing research on virtual laboratories based on artificial intelligence in the field of education is substantial.

Keywords:
Artificial intelligence; Science education; virtual laboratory; VOSviewer

1. Introduction

Virtual laboratories are exact duplicates of genuine laboratories that can enhance the learning process in the same way [1-3]. Virtual laboratories have evolved alongside the advancement of science and technology [4]. They have become one of the favoured choices for performing virtual experiments [5]. Especially in specific domains like medicine, pharmacy, and chemistry, virtual

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https://doi.org/10.37934/araset.60.2.103123

laboratories are frequently used as a first step before doing real laboratory experiments. This serves as an initial introduction to prepare for practical laboratory work, aiming to reduce the likelihood of mistakes during actual laboratory procedures. Virtual laboratories are occasionally employed as alternatives to actual laboratories [6,7]. In the modern era, the limitations of laboratory equipment continue to be a classic argument for some educational institutions to refrain from conducting practical experiments. These limitations stem from various reasons, ranging from budget constraints to the unavailability of equipment for specific practical topics. These constraints will continue to pose challenges for educational institutions in achieving their desired competency targets. Many educational institutions find themselves in similar situations, especially those located in remote areas far from government centres [8].

Nevertheless, this does not mean that there are no solutions to these issues. Researchers and educational practitioners are continuously innovating to address every challenge that arises. The advent of digitization offers a new hope to address some of the existing challenges, one of which is the limitation of laboratory access [9-11]. Digital technology can serve as a source of innovation in the creation of virtual laboratories, and it can even surpass the capabilities of physical laboratories. Equipment that is not physically available can be replicated through digital sophistication. Consequently, virtual laboratories can complement the limitations of physical laboratory equipment [12]. Therefore, the existence of virtual laboratories can minimize the concerns of educators in facilitating hands-on learning for students.

Lately, the online world has been abuzz with the emergence of various applications that harness artificial intelligence [13-15]. Some of these artificial intelligences include Copy.AI, Lalai.AI, ChatGPT, DALL-E2, Luminar AI, Oracel AI, and the like [16,17]. These various artificial intelligence applications can be integrated into other applications to streamline human affairs [18]. Artificial intelligence mimics the decision-making processes of humans, enabling machines to handle certain human tasks through the application of artificial intelligence. In the realm of education, particularly in the learning process, artificial intelligence can be leveraged to facilitate the smooth flow of teaching and learning [19].

On the other hand, the development of educational media in the form of virtual laboratories continues to undergo refinements [20]. Both fields, artificial intelligence, and virtual laboratories, are highly relevant to the current educational needs. Education must undergo acceleration in the learning process so that learners are better prepared to face various challenges. One way to expedite the learning process is by incorporating technology into the heart of the learning process. Therefore, it is not impossible that the integration of artificial intelligence into the development of virtual laboratories will be the focus of researchers and educational practitioners in the future.

Research in the fields of virtual laboratories, artificial intelligence, and social humanities is currently progressing independently. However, there may be constructive intersections among these fields. Therefore, a technique of analysis is required to both blend and identify the interconnections among these intersections. One analysis technique that can help connect the intersections of various research outcomes is bibliometric analysis. Bibliometrics is a statistical analysis tool for specific sources such as articles, books, or other publications [21]. Bibliometric analysis identifies objects by analysing data on the number of authors and their publications [22]. This tool can identify specific keywords entered as input, resulting in outputs like research teams, institutions, references, and publication types [23].

Many studies employ bibliometric analysis techniques, such as bibliometric analysis in the field of health [24], agriculture [25], economics [26,27], business [28], social humanities [29], science [30], technology [31], politics [32], special needs education, secondary education, higher education, instructional media, virtual laboratories [30,33]. However, bibliometric research mapping the relationships between virtual laboratories, artificial intelligence, and science education has not been conducted, especially bibliometric analysis spanning the period from 2018 to 2023 using the VOSviewer application. Detailed information for the bibliometric is shown in Table 1.

Table 1
Previous studies on bibliometric

No	Title	Ref.
1	Involving Particle Technology in Computational Fluid Dynamics Research: A Bibliometric Analysis	[34]
2	Bibliometric Computational Mapping Analysis of Trend Metaverse in Education using VOSviewer	[35]
3	The Use of Information Technology and Lifestyle: An Evaluation of Digital Technology Intervention for Improving Physical Activity and Eating Behaviour	[36]
4	How language and technology can improve student learning quality in engineering? definition, factors for enhancing students' comprehension, and computational bibliometric analysis	[37]
5	Mapping of nanotechnology research in animal science: Scientometric analysis	[38]
6	Scientific research trends of flooding stress in plant science and agriculture subject areas (1962-2021)	[39]
7	Introducing ASEAN Journal of Science and Engineering: A bibliometric analysis study	[40]
8	A bibliometric analysis of chemical engineering research using VOSviewer and its correlation with Covid-19 pandemic condition	[41]
9	A bibliometric analysis of materials research in Indonesian journal using VOSviewer	[42]
10	Bibliometric analysis of engineering research using VOSviewer indexed by google scholar	[43]
11	Bibliometric computational mapping analysis of publications on mechanical engineering education using VOSviewer	[44]
12	Research trend on the use of mercury in gold mining: Literature review and bibliometric analysis	[45]
13	Domestic waste (eggshells and banana peels particles) as sustainable and renewable resources for improving resin-based brakepad performance: Bibliometric literature review, techno-economic analysis, dual-sized reinforcing experiments, to comparison with commercial product	[46]
14	Bibliometric analysis of educational research in 2017 to 2021 using VOSviewer: Google scholar indexed research	[47]
15	Corncob-derived sulfonated magnetic solid catalyst synthesis as heterogeneous catalyst in the esterification of waste cooking oil and bibliometric analysis	[48]
16	The compleat lextutor application tool for academic and technological lexical learning: Review and bibliometric approach	[49]
17	Use of blockchain technology for the exchange and secure transmission of medical images in the cloud: Systematic review with bibliometric analysis.	[50]
18	Computational bibliometric analysis of research on science and Islam with VOSviewer: Scopus database in 2012 to 2022.	[51]
19	Digital transformation in special needs education: Computational bibliometrics.	[52]
20	Antiangiogenesis activity of Indonesian local black garlic (Allium Sativum 'Solo): Experiments and bibliometric analysis.	[53]
21	Characteristics of tamarind seed biochar at different pyrolysis temperatures as waste management strategy: experiments and bibliometric analysis.	[54]
22	The compleat lextutor application tool for academic and technological lexical learning: Review and bibliometric approach.	[55]
23	Corncob-derived sulfonated magnetic solid catalyst synthesis as heterogeneous catalyst in the esterification of waste cooking oil and bibliometric analysis.	[56]

Therefore, this research is focused on mapping the connections between virtual laboratories, artificial intelligence, and education through the aid of VOSviewer. All data sources under study in this research are indexed by Scopus and obtained from the website https://www.scopus.com/. The articles with the highest citations from these data sources can be found in Table 2.

Table 2
The top citations from the collected data

No.	Authors	Document title	Years	Cited	Ref
1	Chen *et al.,*	Artificial Intelligence in Education: A Review	2020	206	[57]
2	Mirchi *et al.,*	The virtual operative assistant: An explainable artificial intelligence tool for simulation-based training in surgery and medicine	2021	78	[58]
3	Yang *et al.,*	Human-centred artificial intelligence in education: Seeing the invisible through the visible	2021	74	[59]
4	Ouyang and Jiao	Artificial intelligence in education: The three paradigms	2021	55	[60]
5	Husnaini and Chen	Effects of guided inquiry virtual and physical laboratories on conceptual understanding, inquiry performance, scientific inquiry self-efficacy, and enjoyment	2019	50	[61]
6	Salmerón-Manzano and Manzano-Agugliaro	The higher education sustainability through virtual laboratories: The Spanish University as case of study	2018	47	[33]
7	Cheong and Koh	Integrated laboratorium virtual in engineering mathematics education: Fourier theory	2019	36	[62]
8	Khosravi *et al.,*	Explainable Artificial Intelligence in education	2022	36	[17]
9	El Kharki *et al.,*	Design and implementation of a laboratorium virtual for physics subjects in Moroccan universities	2021	25	[63]
10	Kolil *et al.,*	Virtual experimental platforms in chemistry laboratory education and its impact on experimental self-efficacy	2020	25	[64]
11	Tobarra *et al.,*	Students' acceptance and tracking of a new container-based laboratorium virtual	2020	25	[65]
12	Altalbe, A.A.	Performance Impact of Simulation-Based Laboratorium virtual on Engineering Students: A Case Study of Australia Virtual System	2019	19	[66]
13	Yu and Wiedmann	Implementing hybrid LCA routines in an input–output laboratorium virtual	2018	19	[67]
14	Asraf *et al.,*	Computer assisted e-laboratory using LabVIEW and internet-of-things platform as teaching aids in the industrial instrumentation course	2018	19	[6]
15	Munawar *et al.,*	Move to smart learning environment: Exploratory research of challenges in computer laboratory and design intelligent laboratorium virtual for eLearning technology	2018	19	[68]
16	Paek and Kim	Analysis of worldwide research trends on the impact of artificial intelligence in education	2021	18	[69]
17	Yusuf and Widyaningsih	Implementing e-learning-based laboratorium virtual media to students' metacognitive skills	2020	17	[70]
18	Khairudin *et al.,*	Mobile virtual reality to develop a virtual laboratorium for the subject of digital engineering	2019	16	[71]
19	Yee Chung *et al.,*	Artificial Intelligence in education: Using heart rate variability (HRV) as a biomarker to assess emotions objectively	2021	15	[72]
20	Lameras and Arnab	Power to the Teachers: An Exploratory Review on Artificial Intelligence in Education	2022	14	[73]

The research presented in Table 2 is all related to the keywords: artificial intelligence, virtual laboratories, and education. Among these three keywords, the most frequently co-occurring keywords in a single research topic are artificial intelligence with education and virtual laboratories with education. However, there are no instances of the keyword’s artificial intelligence and virtual laboratories co-occurring. Based on the description above and to further strengthen the relationship between these three keywords, this research aims to conduct a computational mapping of bibliometric data on the keyword’s artificial intelligence, virtual laboratories, and education with the assistance of VOSviewer. The method used in this research is bibliometric analysis using the

VOSviewer application. The research stages include data harvesting, data visualization, and data analysis. The novelty of this research lies in mapping the relationship between the keyword's artificial intelligence and virtual laboratories in education from 2018 to 2023. It is hoped that the results of this research can serve as a reference for future research to align with current trends, especially in higher education.

2. Methodology

This research employed bibliometric analysis methods, with the primary data source derived from the Scopus database. The selection of this source was based on its open access availability. Additionally, the articles obtained from this source were of unquestionably high credibility. Article credibility was, in part, determined by stringent article selection mechanisms and indexing systems. Scopus, as one of the world's reputable indexing institutions, is beyond doubt. The various stages conducted in this research can be observed in Figure 1. Detailed information regarding bibliometric is shown elsewhere [74,75].

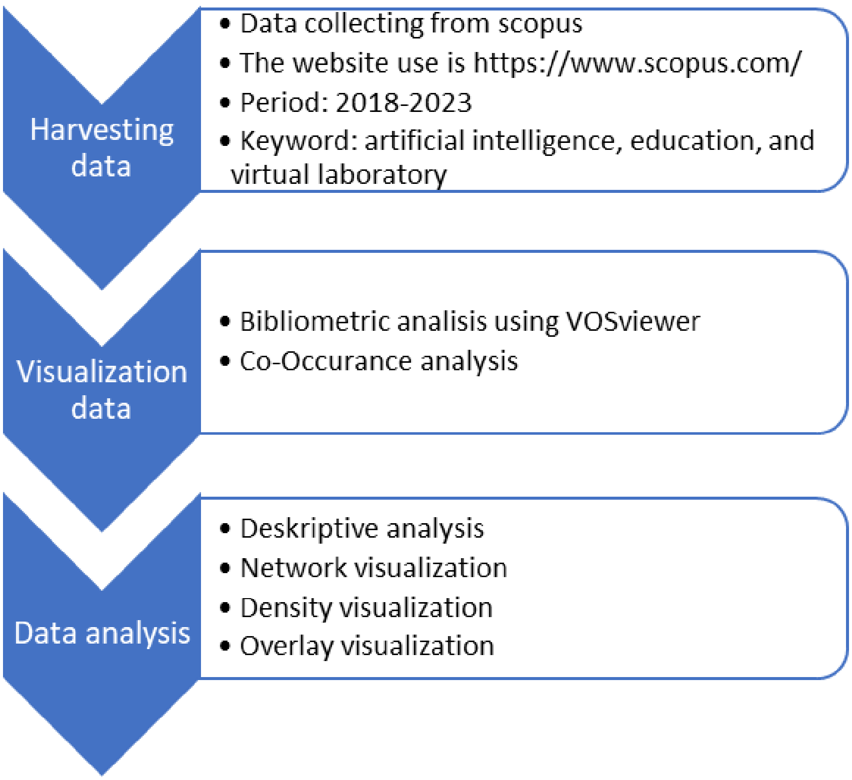

Fig. 1. Research procedure

2.1 Harvesting Data

At this stage, data collection was conducted, and the data collected was entirely sourced from Scopus, accessed through the website https://www.scopus.com/ using the keywords artificial intelligence, virtual laboratory, and education. The data retrieved consisted of published articles from 2018 to 2023. A total of 359 relevant articles, as per the keywords, were exported in two file formats: the research information system (*.ris) and comma-separated value format (*.csv).

2.2 Visualization Data

The data stored in the (*.ris) format was then imported into the VOSviewer application for analysis. The analysis results included three variations of publication mapping visualization: network visualization, overlay visualization, and keyword density visualization.

2.3 Analysis Data

The visualizations obtained in the previous stage was analysed in this phase. The analysis was related to network visualization, overlay visualization, and keyword density visualization.

3. Results and Discussion

3.1. Research Development in the Laboratorium Virtual and Artificial Intelligence in Education

Based on data retrieved from the https://www.scopus.com website, 359 relevant articles meeting the research criteria were obtained. The collected data consists of article metadata, including the author's name, article title, publication year, journal name, publisher name, citation count, article links, and URLs. Figure 2 illustrates the fluctuation in the development of research related to virtual laboratories and artificial intelligence in education published in Scopus-indexed journals. These articles were published between 2018 and 2023. In 2018, a total of 38 relevant articles were found, 45 in 2019, 56 in 2020, 82 in 2021, 97 in 2022, and up to mid-2023, 39 relevant articles have been published.

Based on the analysis of the collected article data, it is evident that research on virtual laboratories and artificial intelligence in education is still relatively rare [76]. Furthermore, there is no networking relationship between artificial intelligence and virtual laboratories within this dataset. Research on virtual laboratories and artificial intelligence in education has seen a significant increase, especially in the years 2020, 2021, and 2022. We predict that research in this topic will continue to grow until the end of 2023. The fluctuations in the development of research on virtual laboratories and artificial intelligence in education can be observed in the visualization in Figure 2.

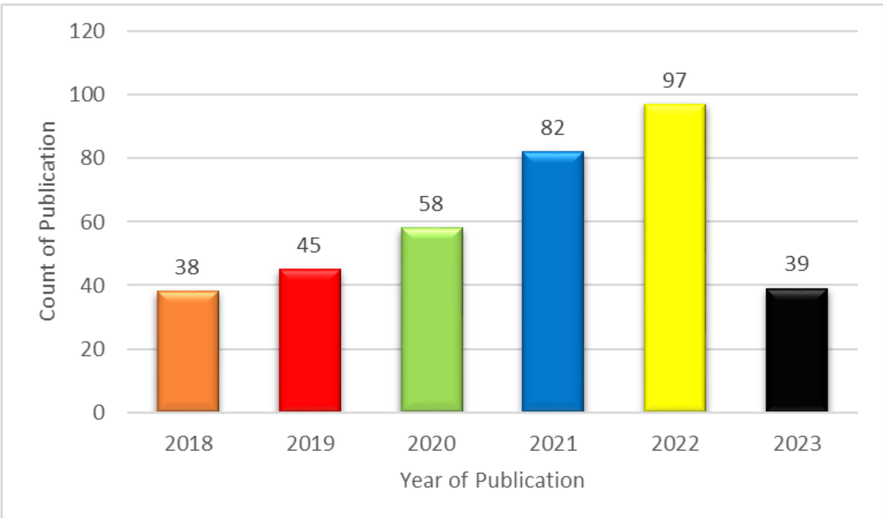

Fig. 2. The trends in research on virtual laboratories and artificial intelligence in education 2018-2023

Based on Figure 2, from 2018 to 2023, the research trends related to the three keywords, artificial intelligence, virtual laboratories, and education, have been on the rise. This increase is closely tied to the events of the COVID-19 pandemic that has affected the world [77,78]. Education is one of the fields significantly impacted by COVID-19, necessitating a shift to remote learning. Spontaneously, education transitioned from offline to online systems. Under such circumstances, educators were compelled to utilize available online media to support the learning process, with virtual laboratories being one of these tools.

On the other hand, research related to artificial intelligence has gained increasing popularity among researchers across various fields in recent times [79]. The field of education, closely intertwined with science and technology, has not been left behind and is actively using and developing these applications. Artificial intelligence has piqued the interest of many, as the development of this technology is believed to have a positive impact on enhancing learners' thinking skills. The broader utilization of artificial intelligence in the learning process is expected to encourage learners to develop their thinking skills further rather than making them complacent. These challenges are developed based on expert systems and can be tailored to meet users' needs.

3.2 Visualization Artificial Intelligence Topic Area using VOSviewer

Computational mapping was performed on all the article data that had been obtained. The VOSviewer application was used as a tool for this computational mapping. The computational mapping results revealed 275 items, each of which is related to virtual laboratories, artificial intelligence, and education. The mapping data is divided into 6 clusters, which are:

i. Cluster 1 consists of 56 items, marked in red, which include Accessibility, achievement, active learning, activity, chemistry, computer simulation, concept, conceptual understanding, content, creativity, demonstration, difference, difficulty, dimension, effectiveness, exercise, experience, experimental design, experimental group, experimentation, expert, explanation, improvement, innovation, inquiry, instruction, instrument, intervention, knowledge, laboratory activity, laboratory experiment, learning, learning environment, lot, perception, performance, physical laboratory, physics, practical skill, principle, quality, quantitative data, science education, self-efficacy, significant difference, skill, student engagement, suggestion, teaching method, undergraduate student, video, virtual laboratory activity, virtual laboratory, application, virtual laboratory environment, virtual laboratory experience, and virtual laboratory simulation.
ii. Cluster 2 consists of 48 items, marked in green, which include Accuracy, advance, analysis, analytic, application, artificial intelligence, assessment, attention, Australian industrial ecology virtual laboratory, case study, characteristic, development, direction, Dissemination, distribution, education, educational data mining, educational technology, foundation, Framework, function, future, high level, hypothesis, impact, implication, importance, increase, industry, insight, interpretation, investigation, language, literature, monitoring, potential, practice, prediction, progress, publication, recent years, recommendation, reference, regard, relation, relationship, research, and systematic review.
iii. Cluster 3 consists of 72 items, marked in blue, which include Algorithm, behaviour, cloud, cognitive load, combination, computer, confidence, control, control system, controller, detection, device, educational tool, efficiency, engineering education, environment,

equipment, error, evaluation, experiment, experimental procedure, experimental result, feasibility, frequency, functionality, implementation, interaction, interest, laboratory, lack, limitation, location, machine, maintenance, mathematical model, modelling, monitoring, observation, operation, optimization, parameter, phenomenon, practical work, procedure, process, production, real laboratory, real time, reality, reduction, requirement, safety, sector, simulation, simulation result, situation, software, solution, source, step, strategy, system, technique, temperature, tool, usability, virtual, virtual environment, virtual experiment, virtual laboratory, virtual reality, and visualization.

iv. Cluster 4 consists of 54 items, marked in yellow, which include academic performance, adoption, animation, approach, awareness, challenge, collaboration, communication technology, comparison, connection, consideration, curriculum, decision, e-learning, educational institution, educational process, educational purpose, engagement, engineering student, exploration, face, feedback, higher education, home, ICT, information, infrastructure, institution, involvement, lab, laboratory course, learning outcome, learning process, mode, online, online learning, opportunity, pandemic, pedagogy, remote laboratory, response, student motivation, support, task, teaching, theory, training, transformation, transition, undergraduate, university, usage, virtual lab, and virtual laboratories.

v. Cluster 5 consists of 44 items, marked in purple, which include Architecture, area, attitude, capability, choice, communication, component, consequence, context, contribution, creation, critical thinking, education process, employment, engineering, feature, flexibility, game, goal, guideline, inclusion, indicator, influence, integration, intention, internet, IoT, issue, kind, methodology, new technology, platform, programming, project, resource, science, service, society, student learning, survey, technology, topic, usefulness, and web.

vi. Cluster 6 consists of 2 items, marked in sky blue, which are augmented reality and overview.

The network relationships between terms are indicated within each cluster. The coloured circles serve as labels provided by the computational system to distinguish each cluster. The size of each term's circle varies depending on the frequency of its occurrence [80]. The size of the label circles serves as an indicator of the positive relationship with the appearance of terms in titles and abstracts [81]. The more frequently a term is detected, the larger its circle size [82]. The computer mapping visualization analysed in this study consists of three parts: Network Visualization (Figure 3), Density Visualization (Figure 4), and Overlay Visualization (Figure 5).

Figure 3 illustrates the network visualization of frequently occurring keywords in the source articles. While there are many keywords that appear, upon closer examination, only a few standouts among the many. Keywords like virtual laboratory, study, and artificial intelligence are prominent. The largest circle in Figure 3 is the term 'virtual laboratory,' indicating that this term appears most frequently in the collected article documents. The network relationship of the term “virtual laboratory” with others is quite extensive, including terms like environment, development, laboratory, experiment, problem, users, paper, source, modelling, algorithm, and others.

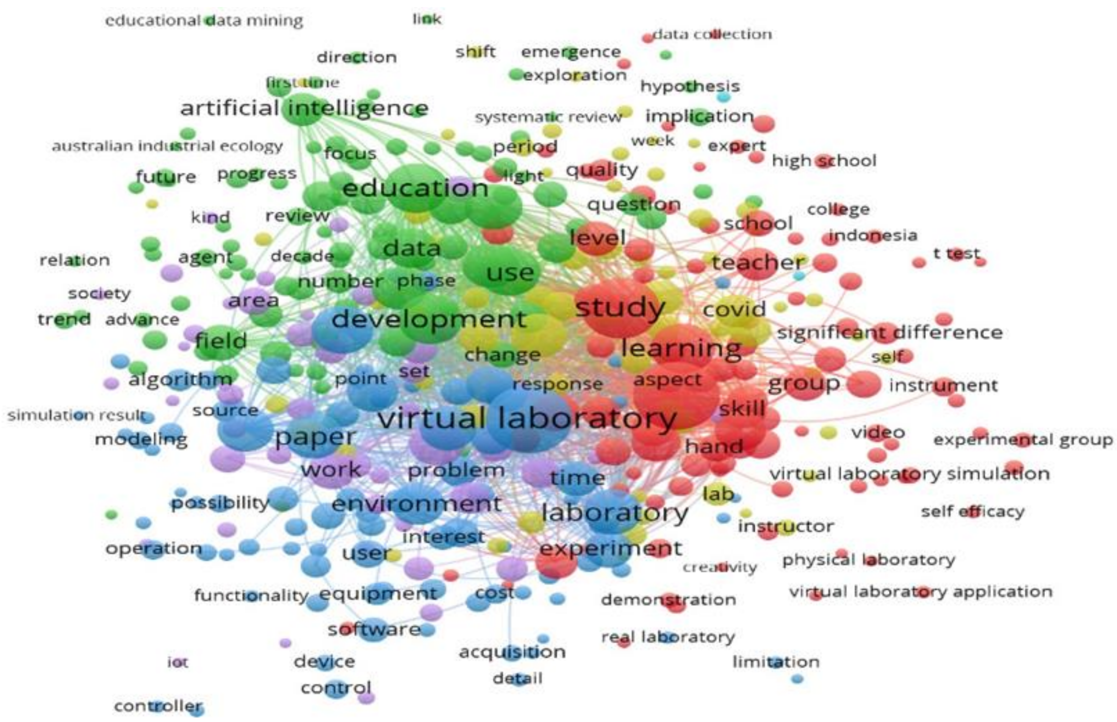

Fig. 3. Network visualization

The term "study" is related to words such as learning, skills, teacher, level, aspects, group, school, quality, and so on. Meanwhile, the term "artificial intelligence" is associated with terms such as education, data, benefits, field, focus, development, review, and inquiries, among others. The network of these keywords with others indicates that these words are frequently used in a specific research topic. This implies that the use of these words continues to be of interest among researchers. As of 2023, the research trend with the mentioned keywords remains a hot topic. It is undeniable that technological advancements have had a significant impact on human interactions and interactions with others [83].

The word “covid” in Figure 2 is highlighted in yellow. This network of words is substantial, and among the words connected to “covid” are virtual laboratory, instructor, approach, task, school, and others. This signifies that the term “covid” has been a significant focus for researchers from 2018 to 2023. This is primarily due to the COVID-19 pandemic that occurred from late 2019 to 2021. The repercussions of this event included the disruption of direct human interactions in various fields, including education [84]. Consequently, the use of the term “covid” in various research areas was inevitable. Apart from reflecting the significant event of that time, the word “covid” also represents the novelty of research.

The network visualization serves as a marker to draw simple conclusions from the current research trends. Based on this network, it can be said that some keywords have strong relationships with each other, while others have moderate connections or none. For instance, the keywords “virtual laboratory” and “artificial intelligence” have no network connection at all. Despite both keywords being research trends, there is no data indicating research on both within a specific research topic. Therefore, the opportunity for in-depth studies on these two keywords remains wide open.

Figure 3 illustrates the density-level visualization of several keywords. Bright yellow indicates that those keywords appear most frequently in research topics [85]. Conversely, if the colour fades to a bluish hue, it suggests that the keywords are less common in research topics. This means that fewer researchers are associating their work with these keywords, presenting an opportunity for other researchers to conduct more comprehensive studies on these terms. Some keywords in bright yellow include virtual laboratory simulation, study, education, learning, skills, and utilization. Meanwhile, some keywords with a bluish-yellow tint include artificial intelligence, experiments, environment, facilities, and so forth.

The term “virtual laboratory simulation” appears most prominently in bright yellow, followed by study, and development in this context, these keywords are quite compelling as potential research topics. However, this does not mean that these keywords will no longer be hot topics in the future. In fact, they will remain intriguing when juxtaposed with other keywords like “artificial intelligence”. Artificial intelligence has gained significant popularity in recent years, as various technologies leverage its features to enhance production in areas such as smartphones, drones, high-speed trains, electric cars, the Internet of Things, and robotics [86].

Artificial intelligence has become the most advanced option to assist humanity in its activities. It can provide insights, simplify tasks, and even replace human work [86]. Its presence continues to be developed under the pretext of transformation and innovation. The sophistication of artificial intelligence features can have a profoundly positive impact on the progress of human civilization. However, if not controlled, it could potentially become a source of catastrophe in this modern age. In the context of education, artificial intelligence should be positioned with great wisdom, serving as a catalyst for transforming learning rather than the sole source or even a replacement for educators. After all, artificial intelligence is just a tool created by humans. Therefore, at some point, it may not be able to handle cases beyond the capabilities that have been programmed into it. This means that the presence of human expertise must persist, ensuring that the use of such tools is controlled and maximized.

The presence of artificial intelligence in education should be used exclusively to aid the learning process, such as integrating it into virtual laboratories or utilizing it as a search engine and data analysis tool. This is highly recommended to accelerate and internalize knowledge among learners [87]. The use of artificial intelligence in education should also be accompanied by ethical guidelines to ensure it does not violate educational norms. Implementing these ethical guidelines can be achieved once users understand the boundaries of appropriateness for the tools in resolving the challenges they face. However, so far, the implementation of artificial intelligence in educational infrastructure and facilities is highly necessary. This is aimed at enhancing the effectiveness and productivity of available resources.

Figure 4 displays an overlay visualization, where two prominent colours are evident: deep blue and yellow. The intensity of the deep blue circles indicates their frequent appearance in research topics [88]. Conversely, circles that are lighter, even turning bright yellow, suggest that they have been rarely or never studied at all. In Figure 4, it is noticeable that the yellow colour began to be studied around mid-2021. Prominent keywords in yellow include artificial intelligence, COVID, and video. In fact, the keywords artificial intelligence and COVID have an extensive network compared to others. This was primarily due to the global COVID-19 pandemic that compelled people to shift from offline to online work during that time.

Future research on artificial intelligence will continue to be captivating and could potentially become the focal point for researchers. This appeal is even more significant if it can be aligned with previously popular keywords. For example, juxtaposing artificial intelligence with virtual laboratory simulation in the context of education. Because in Figure 4, there is no evident network relationship between artificial intelligence and computer simulation from a learning perspective. The use of virtual laboratory simulations in education has been widespread [89,90]. However, it is now time for these virtual laboratory simulations to be innovated so they can operate based on artificial intelligence.

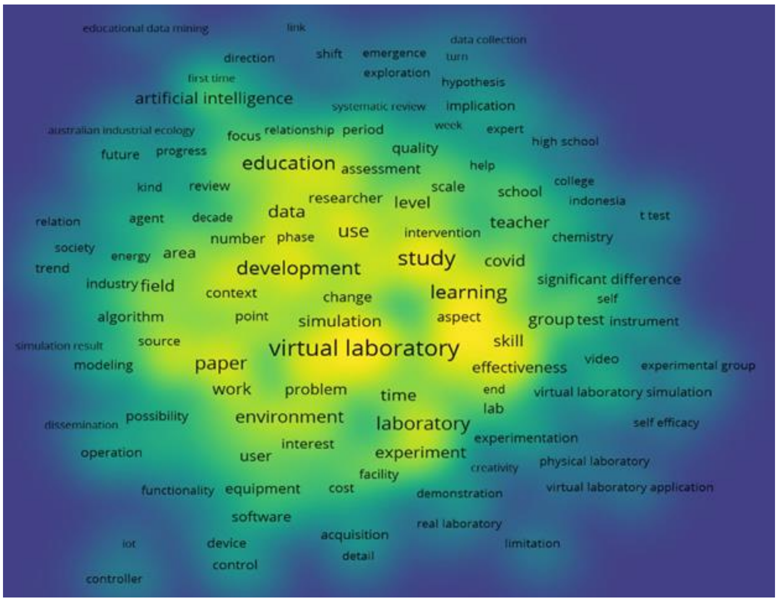

Fig. 4. Density visualization

Upon closer inspection, artificial intelligence does not have many connections. This is evident in Figure 6. Figure 6 illustrates how limited the connections of the term "artificial intelligence" are with other popular terms in the field of education, especially concerning the development and innovation of online-based learning media. The connections observed in Figure 5 include relationships between artificial intelligence and terms such as students, learning, education, development, application, data, research, benefits, technology, system, and field. Among these connections, the strongest one is between the term "artificial intelligence" and "students". This connection is, of course, interpreted in a broad sense, encompassing all aspects of a student's learning activities. However, there is no guarantee that this connection is related to learning media, especially with virtual laboratory simulations. The second-strongest connection is with the term "study", and this too should be interpreted broadly. In this context, "study" has many connotations, such as research, learning, investigation, reports, and others.

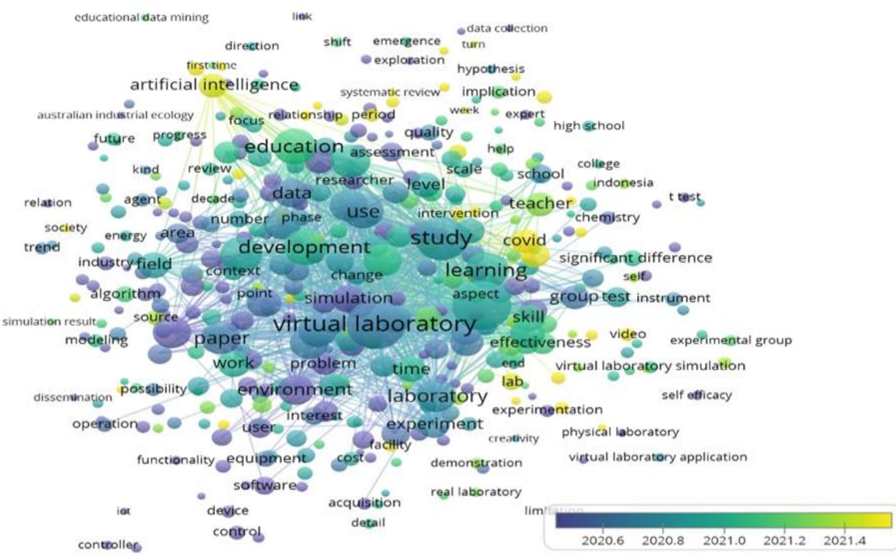

Fig. 5. Overlay visualization

The network relationships of the term “artificial intelligence”, as seen in Figure 6, are still quite limited in the context of education. Further research needs to be developed in efforts toward digital transformation. For instance, the incorporation of artificial intelligence in the development of learning media, the creation of electronic learning materials, the design of evaluation tests, the development of monitoring systems, and others. The visualization in Figure 5 illustrates the relational connections of artificial intelligence with other terms, such as education, research, AIED (Artificial Intelligence in Education), applications, teachers, users, data, development, approaches, learning, students, systems, fields, and technology. Based on this data, it can be observed that artificial intelligence still has relatively few connections with other terms. According to the mapping results, artificial intelligence has 304 links and is connected to 15 terms. On the other hand, the terms “virtual laboratory” and “education” tend to have a higher degree of relevance to the existing terms. Therefore, it can be stated that research in the field of artificial intelligence still holds great potential when connected to virtual laboratories and education. Hence, this can be claimed as a novel aspect of future research.

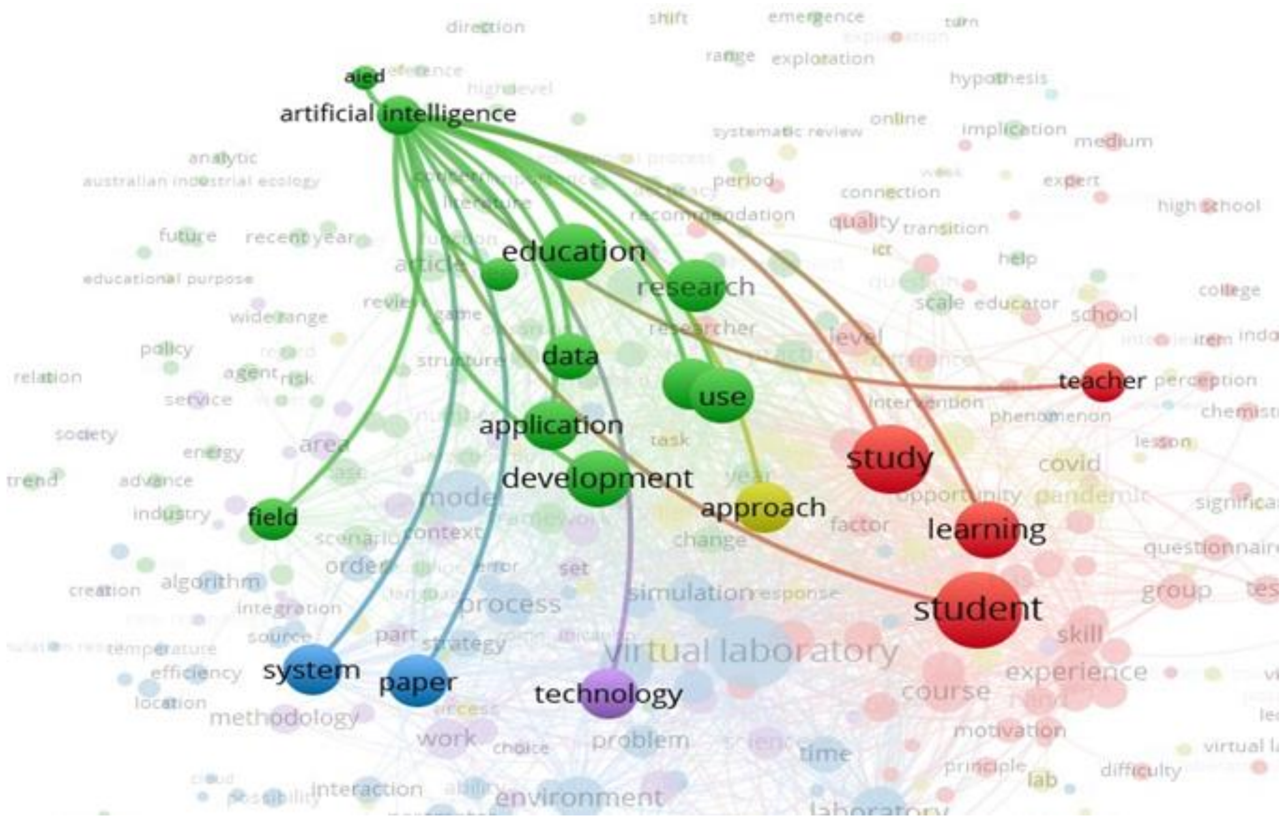

Fig. 6. Network visualization of artificial intelligence term

Based on the computational mapping results of the collected article data, it can be said that the keyword “artificial intelligence” is still rarely used in research. Most of the research terms are associated with or related to virtual laboratories and education. However, no relationship between artificial intelligence and virtual laboratories was found at all. Therefore, exploring the research relationship between artificial intelligence and virtual laboratories in the field of education would be highly intriguing. This study gives information for further development as reported elsewhere regarding several subjects:

i. Mathematics [91-118]
ii. Biology [119-128]
iii. Physics [129-133]
iv. Chemistry [134-140]
v. Engineering [141-146]

4. Conclusions

The analysis results indicate a significant increase in research related to virtual laboratories and artificial intelligence in education over the past four years. However, the relationship between virtual laboratories and artificial intelligence in education is still relatively rare. In fact, there is no existing relationship between virtual laboratories and artificial intelligence. Based on this information, the opportunity for developing research on virtual laboratories based on artificial intelligence in the field of education is substantial.

Acknowledgement
Thanks very much to Lembaga Pengelola Dana Pendidikan (LPDP), Indonesian Ministry of Finance for providing me with financial support during my study at Universitas Pendidikan Indonesia, Bandung.

References

[1] Bugarso, John Marc S., Ramel E. Cabantugan, D. Tapiculin Que-ann, and Amera C. Malaco. "Students' learning experiences and preference in performing science experiments using hands-on and virtual laboratory." *Indonesian Journal of Teaching in Science* 1, no. 2 (2021): 147-152. https://doi.org/10.17509/ijotis.v1i2.41122
[2] Azizah, Elza Varih, Asep Bayu Dani Nandiyanto, Tedi Kurniawan, and Muhammad Roil Bilad. "The effectiveness of using a virtual laboratory in distance learning on the measurement materials of the natural sciences of physics for junior high school students." *ASEAN Journal of Science and Engineering Education* 2, no. 3 (2022): 207-214.
[3] Sison, Arnolfo Jade Ryan N., Jason M. Bautista, Janine L. Javier, Renee Juselle B. Delmonte, and Rizalyn B. Cudera. "Development and acceptability of virtual laboratory in learning systematics." *ASEAN Journal of Educational Research and Technology* 3, no. 1 (2024): 9-26.
[4] Ma, Hongyue, Yangqi Li, Haiming Zhang, Qian Li, Fei Chen, and Zhenshan Cui. "A virtual laboratory based on full-field crystal plasticity simulation to characterize the multiscale mechanical properties of AHSS." *Scientific reports* 12, no. 1 (2022): 5054. https://doi.org/10.1038/s41598-022-09045-8
[5] Hao, Chuanyan, Anqi Zheng, Yuqi Wang, and Bo Jiang. "Experiment information system based on an online virtual laboratory." *future internet* 13, no. 2 (2021): 27. https://doi.org/10.3390/fi13020027
[6] Muhammad Asraf, H., K. A. Nur Dalila, M. Y. Zakiah, Z. A. Amar Faiz, and M. T. Nooritawati. "Computer assisted e-laboratory using LabVIEW and internet-of-things platform as teaching aids in the industrial instrumentation course." *International Journal of Online and Biomedical Engineering (iJOE)* 14, no. 12 (2018): 26-42. https://doi.org/10.3991/ijoe.v14i12.8992
[7] Phang, Fatin Aliah, Victor Kayode Ojomoh, and Nina Diana Nawi. "The Effect of the Virtual Laboratory Method on the Conceptual Understanding of Thermal Physics among Undergraduates." *International Journal of Advanced Research in Future Ready Learning and Education* 34, no. 1 (2024): 124-130. https://doi.org/10.37934/frle.34.1.124130
[8] Vazquez Gonzalez, Jose Luis, Juan Barrios Aviles, Alfredo Rosado Muñoz, and Ruben Alejos Palomares. "An industrial automation course: Common infrastructure for physical, virtual and remote laboratories for PLC programming." *International Journal of Online Engineering, 2018, vol. 14, num. 08, p. 4-19* (2018). https://doi.org/10.3991/ijoe.v14i08.8758
[9] Qayyum, Faisal, Sergey Guk, Rudolf Kawalla, and Ulrich Prahl. "On attempting to create a virtual laboratory for application-oriented microstructural optimization of multi-phase materials." *Applied Sciences* 11, no. 4 (2021): 1506. https://doi.org/10.3390/app11041506
[10] Zaid, Norasykin Mohd, and Zaidatun Tasir. "Developing Synchronous Online Teaching Practices through Emotion Contagion Theory using ADDIE." *Semarak International Journal of Innovation in Learning and Education* 1, no. 1 (2024): 12-23. https://doi.org/10.37934/sijile.1.1.1223

[11] Ismail, Safinah, Aemy Elyani Mat Zain, Haslina Ibrahim, Nazneen Ismail, Nur Aisyah Abu Hassan, and Fatin Farzana Dass Meral. "Kepentingan Aplikasi Digital dalam Pembelajaran Anak Muda Era Industri 4.0: The Importance of Digital Applications in Young Children's Learning Industry Era 4.0." *Semarak International Journal of STEM Education* 1, no. 1 (2024): 28-38. https://doi.org/10.37934/sijste.1.1.2838

[12] Mulya, Rudi, Nizwardi Jalinus, and Hansi Effendi. "Practical Work of Digital System Course Based on Virtual Laboratory." *International Journal of Online & Biomedical Engineering* 17, no. 8 (2021). https://doi.org/10.3991/ijoe.v17i08.23359

[13] Al-Khassawneh, Yazan Alaya. "A review of artificial intelligence in security and privacy: Research advances, applications, opportunities, and challenges." *Indonesian Journal of Science and Technology* 8, no. 1 (2023): 79-96. https://doi.org/10.17509/ijost.v8i1.52709

[14] Alimi, Adebayo Emmanuel, Oluwaseun Funmilola Buraimoh, Gboyega Ayodeji Aladesusi, and Ebenezer Omolafe Babalola. "University students' awareness of, access to, and use of artificial intelligence for learning in Kwara State." *Indonesian Journal of Teaching in Science* 1, no. 2 (2021): 91-104. https://doi.org/10.17509/ijotis.v1i2.38014

[15] Agarry, Rachael Ojima, Eyiyemi Veronica Omolafe, Victoria O. Animashaun, and Ebenezer Omolafe Babalola. "Primary education undergraduates' competency in the use of artificial intelligence for learning in Kwara State." *ASEAN Journal of Educational Research and Technology* 1, no. 2 (2022): 111-118.

[16] Stojanov, Ana. "Learning with ChatGPT 3.5 as a more knowledgeable other: An autoethnographic study." *International Journal of Educational Technology in Higher Education* 20, no. 1 (2023): 35. https://doi.org/10.1186/s41239-023-00404-7

[17] Khosravi, Hassan, Simon Buckingham Shum, Guanliang Chen, Cristina Conati, Yi-Shan Tsai, Judy Kay, Simon Knight, Roberto Martinez-Maldonado, Shazia Sadiq, and Dragan Gašević. "Explainable artificial intelligence in education." *Computers and Education: Artificial Intelligence* 3 (2022): 100074. https://doi.org/10.1016/j.caeai.2022.100074

[18] Lai, Tinghong, Chuyin Xie, Minhua Ruan, Zheng Wang, Hong Lu, and Shimin Fu. "Influence of artificial intelligence in education on adolescents' social adaptability: The mediatory role of social support." *Plos one* 18, no. 3 (2023): e0283170. https://doi.org/10.1371/journal.pone.0283170

[19] Roslan, Nur Widad, Normaliza Abd Rahim, Nur Maisarah Roslan, and Siti Nur Aliaa Roslan. "Students' presupposition towards incooperating AI (Artifical Intelligence) technology in virtual and face-to-face classes." *International Journal of Advanced Research in Future Ready Learning and Education* 27, no. 1 (2022): 16-19.

[20] Lei, Zhongcheng, Hong Zhou, Wenshan Hu, and Guo-Ping Liu. "Toward an international platform: A web-based multi-language system for remote and virtual laboratories using react framework." *Heliyon* 8, no. 10 (2022). https://doi.org/10.1016/j.heliyon.2022.e10780

[21] Liao, Huchang, Ming Tang, Li Luo, Chunyang Li, Francisco Chiclana, and Xiao-Jun Zeng. "A bibliometric analysis and visualization of medical big data research." *Sustainability* 10, no. 1 (2018): 166. https://doi.org/10.3390/su10010166

[22] Prahani, Binar, Iqbal Rizki, Budi Jatmiko, Nadi Suprapto, and Amelia Tan. "Artificial intelligence in education research during the last ten years: A review and bibliometric study." *International Journal of Emerging Technologies in Learning (iJET)* 17, no. 8 (2022): 169-188. https://doi.org/10.3991/ijet.v17i08.29833

[23] Guo, Yi-Ming, Zhen-Ling Huang, Ji Guo, Hua Li, Xing-Rong Guo, and Mpeoane Judith Nkeli. "Bibliometric analysis on smart cities research." *Sustainability* 11, no. 13 (2019): 3606. https://doi.org/10.3390/su11133606

[24] Tran, Bach Xuan, Giang Thu Vu, Giang Hai Ha, Quan-Hoang Vuong, Manh-Tung Ho, Thu-Trang Vuong, Viet-Phuong La *et al.,* "Global evolution of research in artificial intelligence in health and medicine: a bibliometric study." *Journal of clinical medicine* 8, no. 3 (2019): 360.

[25] Si, Hongyun, Jian-gang Shi, Daizhong Tang, Shiping Wen, Wei Miao, and Kaifeng Duan. "Application of the theory of planned behavior in environmental science: a comprehensive bibliometric analysis." *International journal of environmental research and public health* 16, no. 15 (2019): 2788. https://doi.org/10.3390/ijerph16152788

[26] Aparicio, Gloria, Txomin Iturralde, and Amaia Maseda. "Conceptual structure and perspectives on entrepreneurship education research: A bibliometric review." *European research on management and business economics* 25, no. 3 (2019): 105-113. https://doi.org/10.1016/j.iedeen.2019.04.003

[27] Wang, Xinxin, Zeshui Xu, and Marinko Škare. "A bibliometric analysis of Economic Research-Ekonomska Istra zivanja (2007–2019)." *Economic research-Ekonomska istraživanja* 33, no. 1 (2020): 865-886. https://doi.org/10.1080/1331677X.2020.1737558

[28] Chandra, Ashish, and Ruchi Shukla. "A bibliometric analysis of COVID-19 across economics and business research landscape." *Transnational Marketing Journal* 9, no. 3 (2021): 667-680. https://doi.org/10.33182/tmj.v9i3.1316

[29] Garrigos-Simon, Fernando J., M. Dolores Botella-Carrubi, and Tomas F. Gonzalez-Cruz. "Social capital, human capital, and sustainability: A bibliometric and visualization analysis." *Sustainability* 10, no. 12 (2018): 4751. https://doi.org/10.3390/su10124751

[30] Santos, Marc Lancer, and Maricar Prudente. "Effectiveness of virtual laboratories in science education: A meta-analysis." *International Journal of Information and Education Technology* 12, no. 2 (2022): 150-156. https://doi.org/10.18178/ijiet.2022.12.2.1598

[31] Ekundayo, Temitope Cyrus, and Anthony I. Okoh. "A global bibliometric analysis of Plesiomonas-related research (1990–2017)." *PloS one* 13, no. 11 (2018): e0207655. https://doi.org/10.1371/journal.pone.0207655

[32] Li, Wenjuan, and Fengkai Liu. "[Retracted] Exploration on College Ideological and Political Education Integrating Artificial Intelligence-Intellectualized Information Technology." *Computational Intelligence and Neuroscience* 2022, no. 1 (2022): 4844565. https://doi.org/10.1155/2022/4844565

[33] Salmerón-Manzano, Esther, and Francisco Manzano-Agugliaro. "The higher education sustainability through virtual laboratories: The Spanish University as case of study." *Sustainability* 10, no. 11 (2018): 4040. https://doi.org/10.3390/su10114040

[34] Nandiyanto, Asep Bayu Dani, Risti Ragadhita, and Muhammad Aziz. "Involving particle technology in computational fluid dynamics research: A bibliometric analysis." *CFD Letters* 15, no. 11 (2023): 92-109. https://doi.org/10.37934/cfdl.15.11.92109

[35] Muktiarni, M., Nur Indri Rahayu, Affero Ismail, and Amalia Kusuma Wardani. "Bibliometric computational mapping analysis of trend metaverse in education using vosviewer." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 32, no. 2 (2023): 95-106. https://doi.org/10.37934/araset.32.2.95106

[36] Rahayu, Nur Indri, Adang Suherman, and M. Muktiarni. "The use of information technology and lifestyle: An evaluation of digital technology intervention for improving physical activity and eating behavior." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 32, no. 1 (2023): 303-314. https://doi.org/10.37934/araset.32.1.303314

[37] Al Husaeni, D. F., D. N. Al Husaeni, R. Ragadhita, M. R. Bilad, A. S. M. Al-Obaidi, A. Abduh, and A. B. D. Nandiyanto. "How language and technology can improve student learning quality in engineering? Definition, factors for enhancing students comprehension, and computational bibliometric analysis." *International Journal of Language Education* 6, no. 4 (2022): 445-476. https://doi.org/10.26858/ijole.v6i4.53587

[38] Kumar, Kutty. "Mapping of nanotechnology research in animal science: Scientometric anlaysis." *Kumar (22021) Mapping of Nanotechnology Research in Animal Science: Scientometric Analysis. ASEAN Journal of Science and Engineering* 1, no. 2 (2021): 111-126. https://doi.org/10.17509/ajse.v1i2.35092

[39] Nurrahma, Arinal Haq Izzawati, Hana Haruna Putri, and Ray March Syahadat. "Scientific research trends of flooding stress in plant science and agriculture subject areas (1962-2021)." *ASEAN Journal of Science and Engineering* 3, no. 2 (2023): 163-178. https://doi.org/10.17509/ajse.v3i2.46148

[40] Nandiyanto, Asep Bayu Dani, Dwi Novia Al Husaeni, and Dwi Fitria Al Husaeni. "Introducing ASEAN journal of science and engineering: A bibliometric analysis study." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 31, no. 3 (2023): 173-190.

[41] Nandiyanto, Asep Bayu Dani, D. N. Al Husaeni, and D. F. Al Husaeni. "A bibliometric analysis of chemical engineering research using vosviewer and its correlation with covid-19 pandemic condition." *Journal of Engineering Science and Technology* 16, no. 6 (2021): 4414-4422.

[42] Nandiyanto, Asep Bayu Dani, and Dwi Fitria Al Husaeni. "A bibliometric analysis of materials research in Indonesian journal using VOSviewer." *Journal of Engineering Research* (2021).

[43] Nandiyanto, Asep Bayu Dani, and Dwi Fitria Al Husaeni. "Bibliometric analysis of engineering research using vosviewer indexed by google scholar." *Journal of Engineering Science and Technology* 17, no. 2 (2022): 883-894.

[44] Al Husaeni, Dwi Fitria, and Asep Bayu Dani Nandiyanto. "Bibliometric using Vosviewer with Publish or Perish (using google scholar data): From step-by-step processing for users to the practical examples in the analysis of digital learning articles in pre and post Covid-19 pandemic." *ASEAN Journal of Science and Engineering* 2, no. 1 (2022): 19-46. https://doi.org/10.17509/ajse.v2i1.37368

[45] Nandiyanto, A. B. D., R. Ragadhita, D. N. Al Husaeni, and W. C. Nugraha. "Research trend on the use of mercury in gold mining: Literature review and bibliometric analysis." *Moroccan Journal of Chemistry* 11, no. 1 (2023): 11-1.

[46] Nandiyanto, Asep Bayu Dani, Risti Ragadhita, Meli Fiandini, Dwi Fitria Al Husaeni, Dwi Novia Al Husaeni, and Farid Fadhillah. "Domestic waste (eggshells and banana peels particles) as sustainable and renewable resources for improving resin-based brakepad performance: Bibliometric literature review, techno-economic analysis, dual-sized reinforcing experiments, to comparison..." *Communications in Science and Technology* 7, no. 1 (2022): 50-61. https://doi.org/10.21924/cst.7.1.2022.757

[47] Al Husaeni, Dwi Novia, Asep Bayu Dani Nandiyanto, and Rina Maryanti. "Bibliometric analysis of special needs education keyword using VOSviewer indexed by google scholar." *Indonesian Journal of Community and Special Needs Education* 3, no. 1 (2023): 1-10. https://doi.org/10.17509/ijcsne.v3i1.43181

[48] Mardina, Primata, Hesti Wijayanti, Rinna Juwita, Meilana Dharma Putra, Iryanti Fatyasari Nata, Rowina Lestari, Muhammad Faqih Al-Amin, Regi Abizar Suciagi, Oktefani Kusuma Rawei, and Liza Lestari. "Corncob-derived sulfonated magnetic solid catalyst synthesis as heterogeneous catalyst in the esterification of waste cooking oil and bibliometric analysis." *Indonesian Journal of Science and Technology* 9, no. 1 (2024): 109-124. https://doi.org/10.17509/ijost.v9i1.64219

[49] Abduh, Amirullah, Ade Mulianah, Besse Darmawati, Fairul Zabadi, Umar Sidik, Wuri Handoko, Karta Jayadi, and Rosmaladewi Rosmaladewi. "The compleat lextutor application tool for academic and technological lexical learning: Review and bibliometric approach." *Indonesian Journal of Science and Technology* 8, no. 3 (2023): 539-560. https://doi.org/10.17509/ijost.v8i3.63539

[50] Lizama, Maria Guzman, Jair Huesa, and Brian Meneses Claudio. "Use of blockchain technology for the exchange and secure transmission of medical images in the cloud: Systematic review with bibliometric analysis." *ASEAN Journal of Science and Engineering* 4, no. 1 (2024): 71-92. https://doi.org/10.17509/ajse.v4i1.65039

[51] Al Husaeni, Dwi Novia, Dwi Fitria Al Husaeni, Asep Bayu Dani Nandiyanto, and Abdulkareem Sh Mahdi Al-Obaidi. "Introducing ASEAN Journal of Science and Engineering Education: A bibliometric analysis study for understanding internationalization." *Data and Metadata* 1 (2022): 43-43. https://doi.org/10.56294/dm202282

[52] Al Husaeni, Dwi Fitria, and W. Wahyudin. "Digital transformation in special needs education: Computational bibliometrics." *ASEAN Journal of Community and Special Needs Education* 2, no. 2 (2023): 97-110.

[53] Arianingrum, Retno, Nurfina Aznam, Sri Atun, S. Senam, Alya Rizkita Irwan, Nida Qurbaniah Juhara, Nadiya Fitri Anisa, and Latifah Kurnia Devani. "Antiangiogenesis activity of Indonesian local black garlic (Allium Sativum 'Solo): Experiments and bibliometric analysis." *Indonesian Journal of Science and Technology* 8, no. 3 (2023): 487-498. https://doi.org/10.17509/ijost.v8i3.63334

[54] Rahmat, Ali, Sutiharni Sutiharni, Yetti Elfina, Yusnaini Yusnaini, Hadidjah Latuponu, Faidliyah Nilna Minah, Yeny Sulistyowati, and Abdul Mutolib. "Characteristics of tamarind seed biochar at different pyrolysis temperatures as waste management strategy: experiments and bibliometric analysis." *Indonesian Journal of Science and Technology* 8, no. 3 (2023): 517-538. https://doi.org/10.17509/ijost.v8i3.63500

[55] Abduh, Amirullah, Ade Mulianah, Besse Darmawati, Fairul Zabadi, Umar Sidik, Wuri Handoko, Karta Jayadi, and Rosmaladewi Rosmaladewi. "The compleat lextutor application tool for academic and technological lexical learning: Review and bibliometric approach." *Indonesian Journal of Science and Technology* 8, no. 3 (2023): 539-560. https://doi.org/10.17509/ijost.v8i3.63539

[56] Mardina, Primata, Hesti Wijayanti, Rinna Juwita, Meilana Dharma Putra, Iryanti Fatyasari Nata, Rowina Lestari, Muhammad Faqih Al-Amin, Regi Abizar Suciagi, Oktefani Kusuma Rawei, and Liza Lestari. "Corncob-derived sulfonated magnetic solid catalyst synthesis as heterogeneous catalyst in the esterification of waste cooking oil and bibliometric analysis." *Indonesian Journal of Science and Technology* 9, no. 1 (2024): 109-124. https://doi.org/10.17509/ijost.v9i1.64219

[57] Chen, Lijia, Pingping Chen, and Zhijian Lin. "Artificial intelligence in education: A review." *Ieee Access* 8 (2020): 75264-75278. https://doi.org/10.1109/ACCESS.2020.2988510

[58] Mirchi, Nykan, Vincent Bissonnette, Recai Yilmaz, Nicole Ledwos, Alexander Winkler-Schwartz, and Rolando F. Del Maestro. "The Virtual Operative Assistant: An explainable artificial intelligence tool for simulation-based training in surgery and medicine." *PloS one* 15, no. 2 (2020): e0229596. https://doi.org/10.1371/journal.pone.0229596

[59] Yang, Stephen JH, Hiroaki Ogata, Tatsunori Matsui, and Nian-Shing Chen. "Human-centered artificial intelligence in education: Seeing the invisible through the visible." *Computers and Education: Artificial Intelligence* 2 (2021): 100008. https://doi.org/10.1016/j.caeai.2021.100008

[60] Ouyang, Fan, and Pengcheng Jiao. "Artificial intelligence in education: The three paradigms." *Computers and Education: Artificial Intelligence* 2 (2021): 100020. https://doi.org/10.1016/j.caeai.2021.100020

[61] Hung, Jeng-Fung, and Chun-Yen Tsai. "The Effects of a Virtual Laboratory and Metacognitive Scaffolding on Students' Data Modeling Competences." *Journal of Baltic Science Education* 19, no. 6 (2020): 923-939. https://doi.org/10.33225/jbse/20.19.923

[62] Cheong, Kang Hao, and Jin Ming Koh. "Integrated virtual laboratory in engineering mathematics education: Fourier theory." *IEEE Access* 6 (2018): 58231-58243. https://doi.org/10.1109/ACCESS.2018.2873815

[63] El Kharki, Khadija, Khalid Berrada, and Daniel Burgos. "Design and implementation of a virtual laboratory for physics subjects in Moroccan universities." *Sustainability* 13, no. 7 (2021): 3711. https://doi.org/10.3390/su13073711

[64] Kolil, Vysakh Kani, Sharanya Muthupalani, and Krishnashree Achuthan. "Virtual experimental platforms in chemistry laboratory education and its impact on experimental self-efficacy." *International Journal of Educational Technology in Higher Education* 17, no. 1 (2020): 30. https://doi.org/10.1186/s41239-020-00204-3

[65] Tobarra, Llanos, Antonio Robles-Gomez, Rafael Pastor, Roberto Hernandez, Andres Duque, and Jesus Cano. "Students' acceptance and tracking of a new container-based virtual laboratory." *Applied Sciences* 10, no. 3 (2020): 1091. https://doi.org/10.3390/app10031091
[66] Altalbe, Ali A. "Performance impact of simulation-based virtual laboratory on engineering students: A case study of Australia virtual system." *Ieee Access* 7 (2019): 177387-177396. https://doi.org/10.1109/ACCESS.2019.2957726
[67] Yu, Man, and Thomas Wiedmann. "Implementing hybrid LCA routines in an input–output virtual laboratory." *Journal of Economic Structures* 7, no. 1 (2018): 33. https://doi.org/10.1186/s40008-018-0131-1
[68] Munawar, Saima, Saba Khalil Toor, Muhammad Aslam, and Muhammad Hamid. "Move to smart learning environment: Exploratory research of challenges in computer laboratory and design intelligent virtual laboratory for eLearning technology." *EURASIA Journal of Mathematics, Science and Technology Education* 14, no. 5 (2018): 1645-1662. https://doi.org/10.29333/ejmste/85036
[69] Paek, Seungsu, and Namhyoung Kim. "Analysis of worldwide research trends on the impact of artificial intelligence in education." *Sustainability* 13, no. 14 (2021): 7941. https://doi.org/10.3390/su13147941
[70] Yusuf, Irfan, and Sri Wahyu Widyaningsih. "Implementing e-learning-based virtual laboratory media to students' metacognitive skills." (2020). https://doi.org/10.3991/ijet.v15i05.12029
[71] Khairudin, M., A. K. Triatmaja, W. J. Istanto, and M. N. A. Azman. "Mobile virtual reality to develop a virtual laboratorium for the subject of digital engineering." (2019): 80-95.
[72] Chung, Joanne Wai Yee, Henry Chi Fuk So, Marcy Ming Tak Choi, Vincent Chun Man Yan, and Thomas Kwok Shing Wong. "Artificial Intelligence in education: Using heart rate variability (HRV) as a biomarker to assess emotions objectively." *Computers and Education: Artificial Intelligence* 2 (2021): 100011. https://doi.org/10.1016/j.caeai.2021.100011
[73] Lameras, Petros, and Sylvester Arnab. "Power to the teachers: an exploratory review on artificial intelligence in education." *Information* 13, no. 1 (2021): 14. https://doi.org/10.3390/info13010014
[74] Azizah, Nissa Nur, Rina Maryanti, and Asep Bayu Dani Nandiyanto. "How to search and manage references with a specific referencing style using google scholar: From step-by-step processing for users to the practical examples in the referencing education." *Indonesian Journal of Multidiciplinary Research* 1, no. 2 (2021): 267-294. https://doi.org/10.17509/ijomr.v1i2.37694
[75] Al Husaeni, Dwi Fitria, and Asep Bayu Dani Nandiyanto. "Bibliometric using Vosviewer with Publish or Perish (using google scholar data): From step-by-step processing for users to the practical examples in the analysis of digital learning articles in pre and post Covid-19 pandemic." *ASEAN Journal of Science and Engineering* 2, no. 1 (2022): 19-46. https://doi.org/10.17509/ajse.v2i1.37368
[76] Munawar, Saima, Saba Khalil Toor, Muhammad Aslam, and Esma Aimeur. "Paca-its: A multi-agent system for intelligent virtual laboratory courses." *Applied Sciences* 9, no. 23 (2019): 5084. https://doi.org/10.3390/app9235084
[77] Hassan, Jahan, Anamika Devi, and Biplob Ray. "Virtual laboratories in tertiary education: Case study analysis by learning theories." *Education Sciences* 12, no. 8 (2022): 554. https://doi.org/10.3390/educsci12080554
[78] Bima, Marshal, Herman Saputro, and Agus Efendy. "Virtual laboratory to support a practical learning of micro power generation in Indonesian vocational high schools." *Open engineering* 11, no. 1 (2021): 508-518. https://doi.org/10.1515/eng-2021-0048
[79] Lin, Hualiang. "Influences of artificial intelligence in education on teaching effectiveness: The mediating effect of teachers' perceptions of educational technology." *International Journal of Emerging Technologies in Learning (Online)* 17, no. 24 (2022): 144. https://doi.org/10.3991/ijet.v17i24.36037
[80] Nandiyanto, Asep Bayu Dani, D. N. Al Husaeni, and D. F. Al Husaeni. "A bibliometric analysis of chemical engineering research using vosviewer and its correlation with covid-19 pandemic condition." *Journal of Engineering Science and Technology* 16, no. 6 (2021): 4414-4422.
[81] Nandiyanto, Asep Bayu Dani, and Dwi Fitria Al Husaeni. "A bibliometric analysis of materials research in Indonesian journal using VOSviewer." *Journal of Engineering Research* (2021).
[82] Nandiyanto, Asep Bayu Dani, Dwi Fitria Al Husaeni, and Dwi Novia Al Husaeni. "Social impact and internationalization of "Indonesian journal of science and technology" the best journal in Indonesia: A bibliometric analysis." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 32, no. 2 (2023): 42-59. https://doi.org/10.37934/araset.32.2.4259
[83] Tapalova, Olga, and Nadezhda Zhiyenbayeva. "Artificial intelligence in education: AIEd for personalised learning pathways." *Electronic Journal of e-Learning* 20, no. 5 (2022): 639-653. https://doi.org/10.34190/ejel.20.5.2597
[84] Raman, Raghu, Ricardo Vinuesa, and Prema Nedungadi. "Acquisition and user behavior in online science laboratories before and during the COVID-19 pandemic." *Multimodal Technologies and Interaction* 5, no. 8 (2021): 46. https://doi.org/10.3390/mti5080046

[85] Zhang, Xinmin, Ronald C. Estoque, Hualin Xie, Yuji Murayama, and Manjula Ranagalage. "Bibliometric analysis of highly cited articles on ecosystem services." *PloS one* 14, no. 2 (2019): e0210707. https://doi.org/10.1371/journal.pone.0210707
[86] Banerjee, Maya, Daphne Chiew, Keval T. Patel, Ieuan Johns, Digby Chappell, Nick Linton, Graham D. Cole *et al.,* "The impact of artificial intelligence on clinical education: perceptions of postgraduate trainee doctors in London (UK) and recommendations for trainers." *BMC medical education* 21 (2021): 1-10. https://doi.org/10.1186/s12909-021-02870-x
[87] Douali, Latifa, Sabah Selmaoui, and Widad Bouab. "Artificial intelligence in education: Fears and faiths." *International Journal of Information and Education Technology* 12, no. 7 (2022): 650-657. https://doi.org/10.18178/ijiet.2022.12.7.1666
[88] Hao, Tianyong, Xieling Chen, Guozheng Li, and Jun Yan. "A bibliometric analysis of text mining in medical research." *Soft Computing* 22, no. 23 (2018): 7875-7892. https://doi.org/10.1007/s00500-018-3511-4
[89] Prieto-Blázquez, Josep, Jordi Herrera-Joancomartí, and Ana-Elena Guerrero-RoldÃ. "A virtual laboratory structure for developing programming labs." *International Journal of Emerging Technologies in Learning (iJET)* 4, no. 2009 (2009). https://doi.org/10.3991/ijet.v4s1.789
[90] Cheng, Ka Wai Eric, and Chung Lun Chan. "Remote hardware controlled experiment virtual laboratory for undergraduate teaching in power electronics." *Education Sciences* 9, no. 3 (2019): 222. https://doi.org/10.3390/educsci9030222
[91] Dallyono, Ruswan, Didi Sukyadi, and Lukman Hakim. "A mathematical model of the cognitive semantics of the English preposition on." *Indonesian Journal of Science and Technology* 5, no. 1 (2020): 133-153. https://doi.org/10.17509/ijost.v5i1.22774
[92] Hashim, Suhaizal, Alias Masek, Bismi Nurnazatul Shima Mohd Mahthir, Ana Haziqah A. Rashid, and Danakorn Nincarean. "Association of interest, attitude and learning habit in mathematics learning towards enhancing students' achievement." *Indonesian Journal of Science and Technology* 6, no. 1 (2021): 113-122. https://doi.org/10.17509/ijost.v6i1.31526
[93] Akinoso, Sabainah Oyebola. "Motivation and ICT in secondary school mathematics using unified theory of acceptance and use of technology model." *Indonesian Journal of Educational Research and Technology* 3, no. 1 (2023): 79-90. https://doi.org/10.17509/ijert.v3i1.47183
[94] Radiamoda, Arsad A. "Difficulties encountered by the students in learning mathematics." *Indonesian Journal of Educational Research and Technology* 4, no. 1 (2024): 63-70.
[95] Husnah, Annisa Ul, Muhammad Alif Hidayat, and Miftahul Jannah. "The journey of a math: As a mathematics learning innovation." *Indonesian Journal of Multidiciplinary Research* 1, no. 1 (2021): 129-136. https://doi.org/10.17509/ijomr.v1i1.33814
[96] Marasabessy, Rosida. "Study of mathematical reasoning ability for mathematics learning in schools: A literature review." *Indonesian Journal of Teaching in Science* 1, no. 2 (2021): 79-90. https://doi.org/10.17509/ijotis.v1i2.37950
[97] Maryati, Wahyuni Eka, Endah Retnowati, and Ng Khar Thoe. "Learning mathematics formulas by listening and reading worked examples." *Indonesian Journal of Teaching in Science* 2, no. 1 (2022): 61-74. https://doi.org/10.17509/ijotis.v2i1.45801
[98] Ogunjimi, Mayowa Olurotimi, and Taofeek Akolade Gbadeyanka. "Effect of guided inquiry and explicit-instructional strategies on lower basic students' academic performance in mathematics." *Indonesian Journal of Teaching in Science* 3, no. 1 (2023): 23-32. https://doi.org/10.17509/ijotis.v3i1.54191
[99] Obafemi, K. E., U. T. Saadu, A. Adesokan, O. Yahaya, J. T. Sulaimon, T. O. Obafemi, and F. M. Yakubu. "Self-efficacy as a correlate of pupils' academic achievement in mathematics." *Indonesian Journal of Teaching in Science* 3, no. 2 (2023): 113-120. https://doi.org/10.17509/ijotis.v3i2.59775
[100] Mitrayana, M., and Elah Nurlaelah. "Computational thinking in mathematics learning: Systematic literature review." *Indonesian Journal of Teaching in Science* 3, no. 2 (2023): 133-142. https://doi.org/10.17509/ijotis.v3i2.60179
[101] Camenda, Datu Yuri, Cybelle Angela Gaba, Nazirev Lacord, Dania Natango, Alecshane Pabl, and Hassanal Abusam. "How difficult is 1+ 1? A phenomenological study of high school students struggling in mathematics." *ASEAN Journal of Science and Engineering Education* 1, no. 2 (2021): 111-116. https://doi.org/10.17509/ajsee.v1i2.33403
[102] Omolafe, Eyiyemi Veronica. "Primary educators experts' validation of the developed mathematics mobile application to enhance the teaching of mathematics in Nigeria primary schools." *ASEAN Journal of Science and Engineering Education* 1, no. 3 (2021): 157-166. https://doi.org/10.17509/ajsee.v1i3.38505
[103] Serra, Elmer JR P., Nikko Jay R. Senope, and Charls M. Lariosa. "Potholes in the implementation of printed module in mathematics and feedbacks of learners in Lambayong national high school during covid-19 pandemic." *ASEAN Journal of Science and Engineering Education* 1, no. 3 (2021): 177-182. https://doi.org/10.17509/ajsee.v1i3.40897

[104] Wijaya, Hanna, Rina Maryanti, Verra Wulandary, and Asep Rudi Irawan. "Numerical minimum competence assessment for increasing students' interest in mathematics." *ASEAN Journal of Science and Engineering Education* 2, no. 3 (2022): 183-192.
[105] Awofala, Adeneye Olarewaju A. "Examining sources of mathematics self-efficacy beliefs of senior secondary school students." *ASEAN Journal of Science and Engineering Education* 3, no. 3 (2023): 229-244.
[106] Awofala, Adeneye Olarewaju A., Oladiran S. Olabiyi, Omolabake T. Ojo, Adenike J. Oladipo, Alfred O. Fatade, and Uchenna N. Udeani. "Personal and contextual factors as correlates of entrepreneurial intentions among pre-service science, technology, and mathematics teachers." *ASEAN Journal of Science and Engineering Education* 3, no. 3 (2023): 265-278.
[107] Obafemi, Kayode Ezecheal, Ayodele Fajonyomi, and Eniola Keji Ola-Alani. "Effect of reversed jigsaw instructional strategy on pupils academic achievement in mathematics." *ASEAN Journal of Science and Engineering Education* 3, no. 3 (2023): 297-304.
[108] Awofala, Adeneye Olarewaju A., Sabainah O. Akinoso, Comfort O. Adeniyi, Sufiyanu H. Jega, Alfred O. Fatade, and Abayomi A. Arigbabu. "Primary teachers' mathematics anxiety and mathematics teaching anxiety as predictors of students' performance in mathematics." *ASEAN Journal of Science and Engineering Education* 4, no. 1 (2024): 9-24.
[109] Obafemi, K. E. "Enhancing pupils' academic performance in mathematics using brainstorming instructional strategy." *ASEAN Journal of Science and Engineering Education* 4, no. 2 (2024): 99-106.
[110] Maryanti, Rina. "Assessment of mathematical abilities of students with intellectual disabilities during the COVID-19 pandemic." *Indonesian Journal of Community and Special Needs Education* 1, no. 2 (2021): 47-52. https://doi.org/10.17509/ijcsne.v1i2.33402
[111] San Jose, Maria Tricia N. "Factors that affect the performance of selected high school students from the third district of Albay in International Mathematics Competitions." *ASEAN Journal for Science Education* 1, no. 1 (2022): 9-16.
[112] Dermawan, Rian, M. Muktiarni, and Jonah Mupita. "Efforts to increase the interest of junior high school students in mathematics lessons using the tik tok learning tool." *ASEAN Journal for Science Education* 1, no. 2 (2022): 81-88.
[113] Lagcao, Yvrin Gabriel D., Jean Paul Andrei D. Dechavez, Daven John G. Goleng, Alyssa Khate E. Lamzon, Khalid Yasper M. Tangkli, and Welard Jay C. Vicera. "Math readiness and its Effect on the online academic performance of science, technology, engineering, and mathematics students." *ASEAN Journal for Science Education* 2, no. 1 (2023): 33-38.
[114] Awofala, Adeneye Olarewaju A., and Afolabi Oladayo Olaniyi. "Assessing teachers' formative evaluation strategy as related to senior secondary school students' achievement in mathematics." *ASEAN Journal for Science Education* 2, no. 2 (2023): 77-86.
[115] Obafemi, K. E., U. T. Saadu, O. Yahaya, T. O. Obafemi, and F. M. Yakubu. "Exploration of the effect of scaffolding instructional strategy on pupils' academic performance in mathematics." *ASEAN Journal for Science Education* 2, no. 2 (2023): 121-128.
[116] Awofala, Adeneye Olarewaju A., and Felicia OO Agbolade. "Effect of peer-tutoring strategy on senior secondary school students' achievement in mathematics." *ASEAN Journal for Science Education* 3, no. 1 (2023): 1-12.
[117] Padmore, Edward Abanie, and Clement Ayarebilla Ali. "Exploring effective differentiated instruction in the teaching and learning of mathematics." *ASEAN Journal for Science Education* 3, no. 1 (2024): 41-54.
[118] Lasisi, Adekola Kamil, Abdulhafis Adeyinka Hassan, and Habibat Bolanle Abdulkareem. "Impact of single parenting on academic performance of junior secondary school students in mathematics." *ASEAN Journal for Science Education* 3, no. 2 (2024): 129-138.
[119] Glorifica, Ivonne. "Media analysis of biology teaching book grade xii: A study based on science literation category." *Indonesian Journal of Educational Research and Technology* 1, no. 1 (2021): 17-22. https://doi.org/10.17509/ijert.v1i1.32659
[120] Olumorin, Charles Olabode, Ebenezer Omolafe Babalola, Gboyega Ayodeji Aladesusi, Ahmed Idris Issa, and Eyiyemi Veronica Omolafe. "Experts' validation of the developed 3-dimensional automated model of the human heart to teach a biology concept in Ilorin, Nigeria." *Indonesian Journal of Multidiciplinary Research* 1, no. 2 (2021): 299-308. https://doi.org/10.17509/ijomr.v1i2.37840
[121] Babalola, Ebenezer Omolafe. "Design and development of 3-dimensional model of human circulatory system to teach a concept of biology in senior secondary schools." *Indonesian Journal of Teaching in Science* 2, no. 1 (2022): 17-28. https://doi.org/10.17509/ijotis.v2i1.39006
[122] Olumorin, Charles Olabode, Ebenezer Omolafe Babalola, and Desire Adunola Ayoola. "Design and development of human excretory system model to teach a biology concept in Ilorin, Nigeria." *Indonesian Journal of Teaching in Science* 2, no. 2 (2022): 107-116. https://doi.org/10.17509/ijotis.v2i2.45782
[123] Hofifah, Siti Nur, and S. Sumiati. "The effectiveness of the practicum video guide on distance learning in improving biology learning outcomes in enzyme content." *Indonesian Journal of Teaching in Science* 3, no. 2 (2023): 201-212. https://doi.org/10.17509/ijotis.v3i2.62905

[124] Alhassan, Najmuddeen, Amina Alhassan, and Akazi Frances Chioma. "Examining the role of biology teachers' beliefs, motivations, and self-reported practices in constructing curves for biology class." *Indonesian Journal of Teaching in Science* 4, no. 1 (2024): 11-26.
[125] Tipmontiane, Krittin, and P. John Williams. "The integration of the engineering design process in biology-related STEM activity: A review of Thai secondary education." *ASEAN Journal of Science and Engineering Education* 2, no. 1 (2022): 1-10. https://doi.org/10.17509/ajsee.v2i1.35097
[126] Abdussemiu, Ahmad. "Problems of teaching practical biology in senior secondary schools." *ASEAN Journal of Science and Engineering Education* 2, no. 3 (2022): 199-206.
[127] Babalola, Ebenezer Omolafe, Desire Adunola Ayoola, and Eyiyemi Veronica Omolafe. "Analysis of experts' opinion on the human excretory system model for teaching biology in Nigeria." *ASEAN Journal of Science and Engineering Education* 3, no. 1 (2023): 19-26.
[128] Ala, N. A., A. O. Onojah, A. M. Ishyaku, and S. B. Adamu. "Development of an animation package in biology for teaching vertebrate, anatomy, and physiology." *ASEAN Journal for Science Education* 1, no. 2 (2022): 117-130.
[129] Susilowati, Nisfullail Indah, Winny Liliawati, and Dadi Rusdiana. "Science process skills test instruments in the new indonesian curriculum (merdeka): Physics subject in renewable energy topic." *Indonesian Journal of Teaching in Science* 3, no. 2 (2023): 121-132. https://doi.org/10.17509/ijotis.v3i2.60112
[130] Lestari, Dwi Ayu, I. R. Suwarma, and Endi Suhendi. "Feasibility analysis of the development of STEM-based physics e-book with self-regulated learning on global warming topics." *Indonesian Journal of Teaching in Science* 4, no. 1 (2024): 1-10.
[131] Abosede, Peter Joy, Samuel A. Onasanya, and Okonkwo Clementina Ngozi. "Students self-assessment of demonstration-based flipped classroom on senior secondary school students' performance in physics." *Indonesian Journal of Teaching in Science* 4, no. 1 (2024): 27-40.
[132] Azizah, Elza Varih, Asep Bayu Dani Nandiyanto, Tedi Kurniawan, and Muhammad Roil Bilad. "The effectiveness of using a virtual laboratory in distance learning on the measurement materials of the natural sciences of physics for junior high school students." *ASEAN Journal of Science and Engineering Education* 2, no. 3 (2022): 207-214.
[133] Ibrahim, Abdulwaheed Opeyemi. "Impact of blended learning method on secondary school physics students' achievement and retention in Lokoja, Nigeria." *ASEAN Journal for Science Education* 2, no. 2 (2023): 57-66.
[134] Francis, Torpev Terver, and Salaudeen Jaleel Baba. "Effect of concept mapping teaching approach on students' academic performance in chemistry in senior secondary schools." *Indonesian Journal of Educational Research and Technology* 3, no. 1 (2023): 69-78. https://doi.org/10.17509/ijert.v3i1.46145
[135] Putri, Silmi Ridwan, Siti Nur Hofifah, Gabriela Chelvina Santiuly Girsang, and Asep Bayu Dani Nandiyanto. "How to identify misconception using certainty of response index (CRI): A study case of mathematical chemistry subject by experimental demonstration of adsorption." *Indonesian Journal of Multidiciplinary Research* 2, no. 1 (2022): 143-158. https://doi.org/10.17509/ijomr.v2i1.38738
[136] Wirzal, Mohd Dzul Hakim, and Nur Syakinah Abd Halim. "Short play approach for analytical chemistry class." *ASEAN Journal of Science and Engineering Education* 2, no. 2 (2022): 163-168. https://doi.org/10.17509/ajsee.v2i2.42762
[137] Barke, Hans-Dieter, and Joline Büchter. "Laboratory jargon and misconceptions in Chemistry–an empirical study." *ASEAN Journal of Science and Engineering Education* 3, no. 1 (2023): 65-70.
[138] Sombria, Khezel Jean F., Diane L. Celestial, Clea Grace M. Jalagat, and Anamarie G. Valdez. "Online learning through google classroom: Effects on students critical thinking skills in chemistry." *ASEAN Journal of Science and Engineering Education* 3, no. 2 (2023): 193-210.
[139] Swafiyah, Bawa, Binta Asabe Muhammad, and Abdullahi Zaharaddeen Yamusa. "Effect of conceptual change instructional strategy on chemistry students' performance in acids and bases concepts." *ASEAN Journal for Science Education* 2, no. 1 (2023): 47-54.
[140] Bilad, Muhammad Roil. "Bibliometric analysis for understanding the correlation between chemistry and special needs education using vosviewer indexed by google." *ASEAN Journal of Community and Special Needs Education* 1, no. 2 (2022): 61-68.
[141] Sambudi, Nonni Soraya, and Raihan Mahirah Ramli. "Integrated project as innovative assessment to enhance learning experience in thermodynamics class." *ASEAN Journal of Science and Engineering Education* 1, no. 3 (2021): 167-176. https://doi.org/10.17509/ajsee.v1i3.40896
[142] Haritha, K. "Exploring historical seismic events through secondary data analysis: Implications for understanding submarine earthquakes in marine geophysics for educational purposes." *Indonesian Journal of Multidiciplinary Research* 3, no. 2 (2023): 349-370.
[143] Bilad, Muhammad Roil, and Saiful Prayogi. "Portfolio workbook as an effective method for student-centered learning of chemical engineering principles." *ASEAN Journal of Science and Engineering Education* 1, no. 1 (2021): 31-36. https://doi.org/10.17509/ajsee.v1i1.32404

[144] Andika, Riezqa, and Zulfan Adi Putra. "Teaching programming to chemical engineering students." *ASEAN Journal of Science and Engineering Education* 2, no. 1 (2022): 51-60. https://doi.org/10.17509/ajsee.v2i1.36935
[145] Samsuri, Shafirah. "Teaching chemical engineering thermodynamics using substituted blended learning techniques." *ASEAN Journal of Science and Engineering Education* 4, no. 2 (2024): 143-162.
[146] Wirzal, Mohd Dzul Hakim, and Zulfan Adi Putra. "What is the correlation between chemical engineering and special needs education from the perspective of bibliometric analysis using vosviewer indexed by google scholar." *Indonesian Journal of Community and Special Needs Education* 2, no. 2 (2022): 103-110. https://doi.org/10.17509/ijcsne.v2i2.44581