Evaluating the Effectiveness of Blended Learning in Science Education: A Systematic Review

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Abstract- This study examines the effectiveness of blended learning approaches in science education from 2020 to 2024. Against the backdrop of educational transformation emphasizing technology integration, the research identifies challenges such as weak ICT literacy and differing attitudes between students and educators. The objective is to explore how blended learning enhances students' understanding of scientific concepts and skills. Using a systematic literature review (SLR) methodology, the study finds that blended learning provides significant opportunities to improve learning outcomes. Recommendations include emphasizing sufficient training and support for both students and educators to strengthen the implementation of blended learning in the context of science education.

Index Terms- Blended Learning, ICT Literacy, Science Education, Systematic Literature Review, Technology Integration

I. INTRODUCTION

Science education has undergone a significant transformation over the past decade, with increasing emphasis on blended learning approaches. The deep integration of technology into education—as highlighted in various research papers (Selvakumar & Sivakumar, 2023; Soelistya et al., 2023)—has shown promising results in transforming traditional teaching methods by providing interactive, engaging, and collaborative learning environments. In Malaysia, initiatives such as the Malaysia Education Blueprint have promoted the integration of technology in science education, aiming to develop a competent STEM workforce (Bahrum & Samsudin, 2021).

Blended learning, which combines traditional teaching with online activities, has gained significant popularity in science education due to its effectiveness in enhancing learning outcomes and aligning with modern educational needs (Obeidat & Yaqbeh, 2023; Baliya & Shikha, 2023). The study by Kumar and Moral (2023) found that students across various disciplines and genders preferred blended learning when supported by good infrastructure and effective electronic platforms, emphasizing the importance of both face-to-face and online interactions between students and teachers for successful educational implementation.

During the COVID-19 pandemic, the blended learning approach proved to be highly beneficial, enabling educational institutions to maintain teaching activities in a hybrid mode (Krishnan & Nagaratnam, 2023; Baliya & Shikha, 2023). Moreover, integrating online and traditional teaching methods in blended learning models has been found to create more engaging and flexible learning environments, although challenges such as instructional delivery quality and misuse of learning platforms during online assessments were observed (Sun et al., 2022).

Studies published in databases such as Web of Science, Springer, Scopus, and ERIC indicate that blended learning approaches can enhance students' academic achievement in science, including improvements in conceptual understanding and critical thinking skills. Research also shows that blended learning can help bridge achievement gaps among students from different backgrounds (Davidi et al., 2021).

A systematic literature review on the effectiveness of blended learning approaches in science education is essential to explore previous studies conducted in this domain. While there has been significant focus on technology, pedagogy, and content in blended learning practices, there is still a need for more studies on theoretical and methodological aspects of implementing blended learning in science education (Tonbuloğlu & Tonbuloğlu, 2022). Furthermore, the impact of blended learning on specific disciplines, such as biomedical engineering, remains an area that requires further exploration to understand its effectiveness compared to traditional methods (Topping et al., 2021). These research gaps highlight the necessity for more comprehensive studies to improve understanding and implementation of blended learning in science education.

Based on a comparison of previous studies, there remains a significant gap in comprehensive understanding regarding both the positive and negative impacts of the blended learning approach within the context of science education. Although many prior studies have extensively highlighted the benefits of blended learning, there is still a pressing need for further investigation into achieving an optimal balance between face-to-face and online components (Castro-Rodríguez et al., 2021).

Additionally, there is a need to identify the challenges faced by both students and teachers in implementing blended learning, as well as to develop appropriate strategies to overcome these challenges. While previous studies have acknowledged several obstacles, they have often lacked emphasis on solution-oriented strategies. Cheung et al. (2023) reported that issues such as self-regulation difficulties, poor time management, and low engagement were significant barriers to effective blended learning experiences, thus emphasizing the need for further research to address these issues and improve student outcomes. Similarly, Topping et al. (2021) questioned which strategies are most effective in integrating diverse learning styles within blended learning environments.

Therefore, in order to contribute to filling the gaps identified in past studies in this field, the following research questions are proposed to provide deeper insights into the effectiveness of blended learning in science education:

1. What are the common characteristics and trends in blended learning research?
2. How effective is the blended learning approach in science education?
3. What are the main challenges faced by students and teachers in implementing blended learning in science education, and what are the recommended strategies to overcome them?
4. What are the effective blended learning strategies in the context of science education?

II. METHODOLOGI

This study adopts a Systematic Literature Review (SLR) methodology guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to understand the impact of blended learning on students' motivation in science subjects. The SLR process is intended to address the research problem by identifying, critically evaluating, and synthesizing the findings of all relevant and high-quality prior studies to answer one or more research questions.

The SLR approach involves a rigorous and transparent process, emphasizing the importance of replicability and impact in research (Sauer & Seuring, 2023; Mere, 2023; dos Santos & Nakagawa, 2022). The steps undertaken include the formulation of a review protocol encompassing objectives, inclusion and exclusion criteria, search strategies, and quality assessment procedures using the PRISMA checklist.

1. Search Strategy

A comprehensive literature search was conducted using three major academic databases: Web of Science (WOS), SCOPUS, and ERIC to gather studies related to the topic of this research. The identified studies were then screened and evaluated according to the predetermined inclusion and exclusion criteria outlined in the review protocol (Higgins & Green, 2011). Figure 1 illustrates the selection process following the PRISMA flow diagram.

The keywords used for the search were "blended learning" and "science education" in English, and their equivalents in Malay, namely "pembelajaran teradun" and "pendidikan sains". Furthermore, the search was limited to articles published between 2020 and 2024 to ensure the inclusion of the most recent and relevant literature.

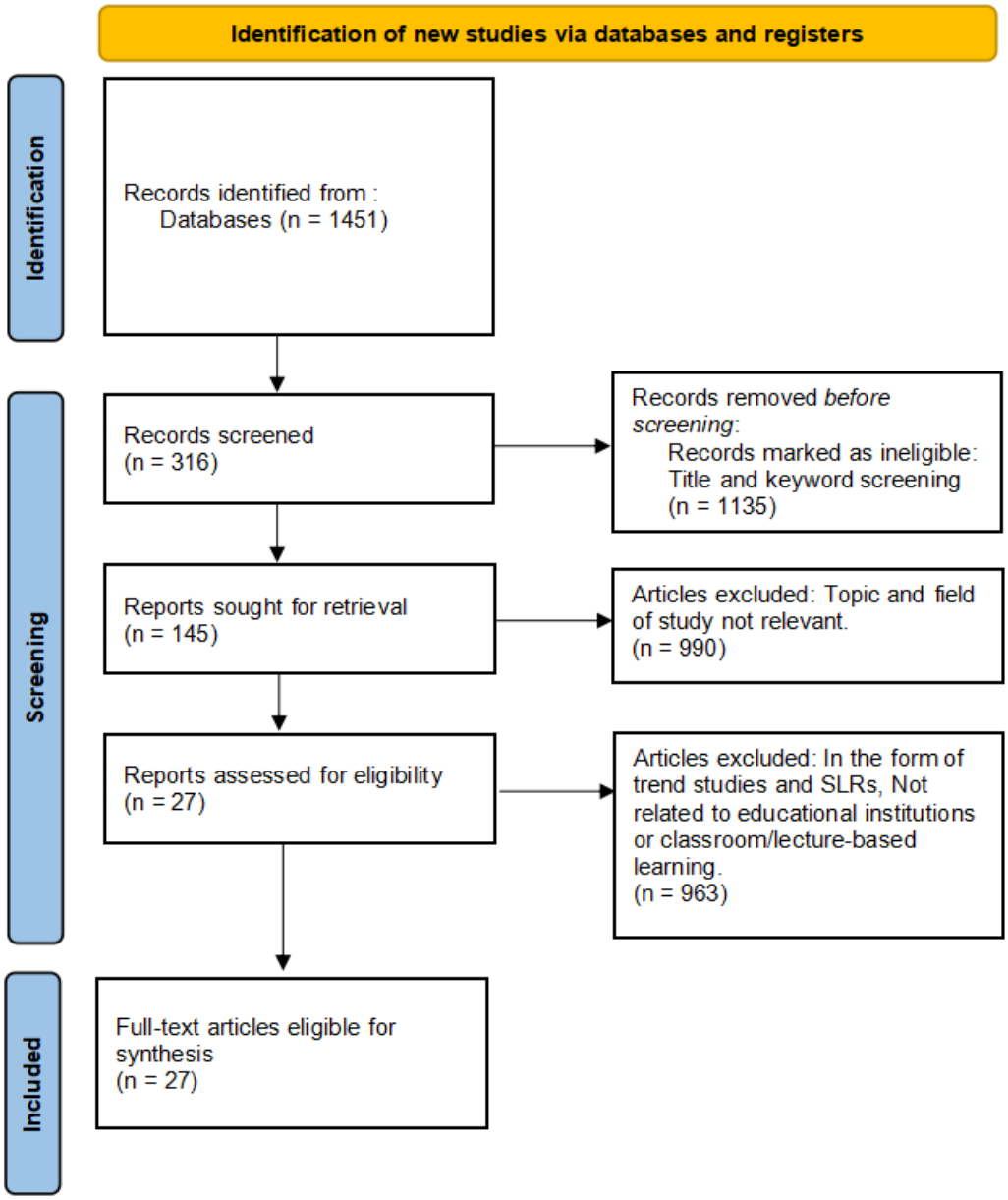


Figure 1: PRISMA 2020 Flow Diagram for Systematic Review

2. Selection Criteria

In conducting a Systematic Literature Review (SLR), the inclusion and exclusion table is a crucial tool to ensure consistency in the study selection process. Table 1 below presents the inclusion and exclusion criteria used to select relevant studies.

Inclusion Criteria	Exclusion Criteria
● Journals or conference proceedings not related to science subjects ● Studies that do not involve students as respondents ● Articles in foreign languages other than Malay, English, or Indonesian ● Articles published before the year 2020 ● Articles that do not contain all the specified keywords ● Articles deemed irrelevant after filtering by title,	● Articles containing relevant keywords (e.g., "blended learning," "science education") ● Studies conducted in the field of education ● Articles written in Malay, English, or Indonesian ● Articles with a clearly defined research methodology (e.g., experimental, quantitative/qualitative studies) ● Articles that provide clear study samples (e.g., number of respondents, demographics, etc.) ● Articles presenting key findings related to the effectiveness of blended

publication year, and abstract .	learning in science education ● Articles that offer conclusions related to either the positive or negative impacts on science learning

Table 1: Inclusion and Exclusion Criteria for the Studies.

III. RESULTS AND DISCUSSION

The selected articles used in this study are studies conducted by researchers within the last 5 years, from 2020 to 2024. After going through each article selection process, only 27 articles were chosen from a total of 1451 articles, consisting of 8 local articles and 19 international articles.

A. General characteristics of blended learning research trends.

The first thing to be discussed in this section is the findings on the general characteristics of blended learning research trends as shown in Table 2.

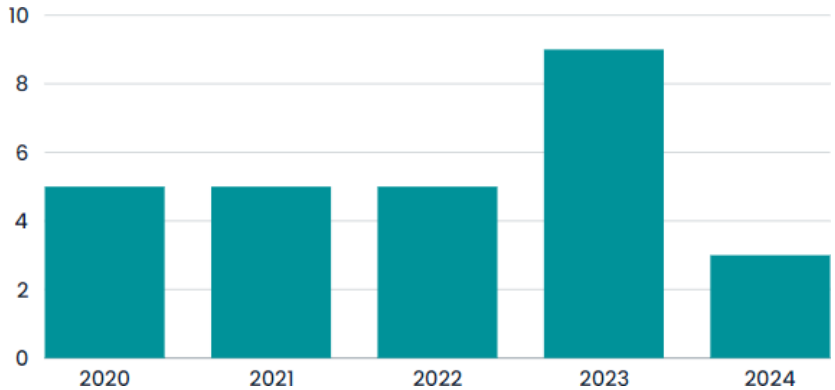
Year	Country	Research Design	Respondents Involved
2020	Indonesia, Canada, Thailand, Pakistan, United Kingdom	Quantitative and mixed methods	Students, teachers
2021	Malaysia, Indonesia, Mexico, Sweden	Quantitative and mixed methods	Undergraduate students, public university students, lecturers and university administrators, secondary school students, physics teachers, researchers
2022	Malaysia, Indonesia, Australia, Nigeria, United States	Quantitative and mixed methods	Students, teachers, master's students, undergraduate students
2023	Malaysia, Indonesia, Nigeria, Serbia, China	Quantitative and mixed methods	Secondary school students, Diploma and Bachelor's students, postgraduate students, academic staff, undergraduate programme staff, higher education educators, researchers, teachers, pre-service teachers
2024	Malaysia, Switzerland, Norway	Quantitative, qualitative, and mixed methods	Urban and rural secondary school teachers, 106 students from seven VET programmes, higher education students

Table 2: General characteristics of blended learning research trends.

Between the years 2020 and 2024, studies were conducted in several countries including Indonesia, Canada, Thailand, Pakistan, the United Kingdom, Malaysia, Mexico, Sweden, Australia, Nigeria, the United States, Serbia, China, Switzerland, and Norway. The most frequently employed research designs were quantitative and mixed methods, with a smaller number adopting a qualitative approach. These studies involved various groups of respondents such as students, teachers, lecturers, university administrators, and researchers from different levels of education. This reflects the diversity in both research subjects and methodologies during the period, as well as a broad focus on understanding various aspects of education across different countries.

B. Research Year Trend

Graph 1 shows the trend of studies on blended learning over the past five years.



Graph 1: Year of publication of past studies on blended learning in science education.

Based on Graph 1, the data shows a stable number of studies conducted from 2020 to 2022, with an average of five studies per year. This reflects a consistent level of interest in this field. In 2023, however, there was a significant increase in research activity, with the number of studies rising to nine. This increase can be interpreted as a positive development or a growing interest in research related to blended learning. Furthermore, in 2024 (with article searches conducted up to March 2024), a total of three studies were recorded, indicating that this area of research remains relevant in the field of education as it continues to grow steadily across various countries.

C. Effectiveness of the Blended Learning Approach

Theme	Category	Code	Author(s)
Effectiveness	Affective	Emotional awareness, intrinsic motivation, learning values, affective engagement, attitude change	Siddiqui S. et al.; Olatunde-Aiyedun, T. G. & Adams, S. O.; Radovan, M. & Radovan, D.M.; Anthony Jnr, B.; Cheung S.K.S. et al.; Anthony Jnr, B. et al.
	Cognitive	Academic performance, critical thinking, conceptual understanding, problem-solving.	Olatunde-Aiyedun, T. G. & Adams, S. O.; Anthony Jnr, B. et al.; Kantisa, P. & Sitthitikul, P.; M Alamsyah et al.; Gregorcic, B. & Haglund, J.

Table 3: Effectiveness of the Blended Learning Approach

Blended learning has been proven to have various affective impacts on students. Blended learning has been shown to positively influence students' intrinsic motivation (Siddiqui S. et al., 2020). Meanwhile, the study by Olatunde-Aiyedun, T. G. & Adams, S. O. (2022) highlighted the importance of understanding non-academic outcomes in a blended learning environment, such as students' self-regulated learning strategies, motivation, cognitive engagement, and resource management strategies. According to these researchers, the combination of online activities and resources, such as asynchronous online videos, can create an ideal blended learning environment that enhances student engagement and motivation.

In addition, collaborative learning in a blended learning environment was found to significantly increase student effort, emphasizing the importance of teamwork in boosting motivation levels (Radovan, M. & Radovan, D.M., 2024). Furthermore, the study by Anthony Jnr, B. (2024) also revealed that the integration of technology within blended learning settings enhances students' educational experience and satisfaction, ultimately increasing their motivation levels.

Moreover, the use of blended learning in higher education institutions has been associated with factors such as performance expectations, intrinsic motivation, satisfaction, and academic self-efficacy, all of which influence students' continued intention to engage in blended learning environments (Cheung S.K.S. et al., 2023). Therefore, blended learning not only improves academic achievement but also plays a crucial role in shaping students' emotional and motivational aspects, ultimately influencing their attitudes towards learning (Anthony Jnr, B. et al., 2021; Radovan, M. & Radovan, D.M., 2024).

From the aspect of cognitive ability, blended learning has been proven to have a positive impact on students, particularly in enhancing the effectiveness of learning and their academic performance (Olatunde-Aiyedun, T. G. & Adams, S. O., 2022; Anthony Jnr, B. et al., 2021). In addition, the study by Kantisa, P. & Sitthitikul, P. (2020) showed that metacognitive strategies, such as self-regulation and critical thinking, play a significant role in students' learning outcomes within blended and online learning contexts, highlighting the importance of cognitive and metacognitive processes in improving academic achievement.

Furthermore, blended learning has also enhanced students' understanding of concepts and problem-solving skills (Olatunde-Aiyedun, T. G. & Adams, S. O., 2022; M. Alamsyah et al., 2021). For instance, conceptual blending has gained attention in educational research, especially in physics education, as it helps students form physically meaningful combinations of ideas and comprehend abstract phenomena—such as wave behavior—through interconnected input spaces. This approach aids both problem-solving and conceptual understanding (Gregorcic, B. & Haglund, J., 2021).

D. Challenges in Implementing the Blended Learning Approach in Science Education

Theme	Category	Code	Author(s)
Challenges	Students	Weak ICT literacy, limited internet access, differing attitudes and learning styles, maintaining active learning	Oladejo, A.I. et al.; Wang, L. et al.; Olatunde-Aiyedun, T. G. & Adams, S. O.; Herliani et al.; Kantisa, P. & Sitthitikul, P.

	Educators	Difficulty in managing diverse learning styles, limited technological literacy, lack of training, time-consuming, increased workload	Herliani et al., Kantisa, P. & Sitthitikul, P., Ealangov, S. & Jamaludin, K.A., Wang, L. et al.; Radovan, M. & Radovan, D.M.
	Support	Technological barriers, budget and resource allocation	Razali, F. et al.; Kantisa, P. & Sitthitikul, P.

Table 4: Challenges in Implementing the Blended Learning Approach

The implementation of blended learning among students presents several challenges. One prominent issue is the need for students to improve their ICT literacy, which is often inadequate (Oladejo et al., 2023). In addition, factors such as weak internet connectivity and limited data plans hinder students' continuous access to learning materials, thus affecting their overall learning experience (Wang et al., 2024). Olatunde-Aiyedun and Adams (2022) also highlighted that limited internet access reduces students' motivation and disrupts their participation in online activities. Without sufficient motivation and active engagement, the intended benefits of blended learning may not be fully achieved (Herliani et al., 2023). The transition between online and traditional learning modes further requires students to be self-disciplined and proactive in their learning approach (Kantisa & Sitthitikul, 2020).

In addition, one of the key challenges in effectively implementing blended learning is the differing attitudes and learning styles between educators and students. These differences can significantly affect the overall effectiveness of the blended learning approach (Herliani et al., 2023). Therefore, educators need adequate training to manage the online components of blended learning. Teachers must be proficient in various technologies such as audio-video streaming, podcasting, and video conferencing, which can pose major challenges for those unfamiliar with these tools (Ealangov & Jamaludin, 2022). According to Kantisa and Sitthitikul (2020), insufficient training may lead to ineffective teaching practices and reduced learning outcomes.

The integration of blended learning also demands new forms of assessment and evaluation methods that can accurately measure student performance across both online and face-to-face components. Developing these methods can be complex and time-consuming (Kantisa & Sitthitikul, 2020). This contributes to an increased workload due to time-intensive course redesign and the need for efficient time management (Wang et al., 2024). The workload includes various aspects such as pre-class preparation, daily tasks, and after-school mentoring, which is particularly burdensome for teachers in rural areas (Radovan & Radovan, 2024).

In terms of support, the successful implementation of blended learning requires reliable access to both technology and the internet. Inadequate technological infrastructure can hinder the learning process, especially in areas with limited access to these resources (Razali et al., 2023). Furthermore, although blended learning can be cost-effective in the long term, the initial setup requires substantial investment in technology, training, and resources. Proper budget planning and resource allocation are essential to address these challenges (Kantisa & Sitthitikul, 2020).

E. Strategies to Enhance the Effectiveness of Blended Learning in Science Education

Theme	Category	Code	Author(s)
Strategy	Integration of Hands-On and Digital Learning	Digital learning tools, hands-on activities, practical skills, Science Learning Activity Model (SLAM), digital literacy, interactivity.	Ealangov, S. & Jamaludin, K.A.; Herliani et al.; Bhagat et al. (2021) Radovan, M. & Radovan, D.M.; Branda Le et al.
	Skill Development and Infrastructure Support	Workshops, online tutorials, practical sessions, internet access, stable connection, high-speed internet.	Ealangov, S. & Jamaludin, K.A.
	Time Management	Pre-class preparation, organizing workload, balancing teaching tasks, monitoring performance, restructuring the environment, managing time.	Ealangov, S. & Jamaludin, K.A.; Nur Eva et al. 2023; Wang, L. et al. 2024
	Teaching Quality	Interaction/engagement, course design, assessment and feedback mechanisms, technology integration, enhancing technological infrastructure, comprehensive training, professional development	Radovan, M. & Radovan, D.M. 2024, Cheung S.K.S. et al. 2023, Anthony Jnr, B. 2024, Oladejo, A.I. et al.

Table 5: Strategies to Enhance the Effectiveness of Blended Learning

i. Integration of Hands-On and Digital Learning

The combination of practical experiences and digital learning tools can enhance the effectiveness of blended learning. This approach ensures that students acquire practical skills while benefiting from the flexibility and accessibility of digital resources (Ealangov &

Jamaludin, 2022). Furthermore, the use of technology-based tools, such as the Science Learning Activity Model (SLAM), in science education has been shown to improve student motivation and collaboration, leading to better academic achievement (Herliani et al., 2023).

Studies by Bhagat et al. (2021) and Radovan & Radovan (2024) on the effectiveness of blended learning emphasize the importance of well-designed teaching strategies and pedagogical approaches for successful implementation. Additionally, the correlation between digital literacy, interactivity, and academic achievement highlights the significance of digital skills in enhancing student engagement with online resources in a blended learning environment (Branda Le et al., 2022).

ii. Development of Skills and Infrastructure Support

Providing comprehensive ICT literacy training programs for both students and educators to bridge the gap in digital skills is a crucial strategy to enhance the effectiveness of blended learning. This can include workshops, online tutorials, and practical sessions aimed at building confidence and proficiency in using digital tools (Ealangov & Jamaludin, 2022).

Furthermore, as stated by Ealangov and Jamaludin (2022), the strategy should also be reinforced by investing in upgrading internet infrastructure to ensure stable and high-speed connectivity. This may involve collaborations with internet service providers to offer affordable and reliable internet access to students, particularly in remote areas.

iii. Time Management in Implementing Blended Learning

Teachers often invest significant time in lesson preparation, online tasks, and post-class guidance, especially in rural areas. This increases the workload due to the lack of appropriate tools and confidence in students' independent learning capabilities (Ealangov & Jamaludin, 2022). Therefore, time management strategies for teachers in the blended learning approach are crucial and should include efficient pre-class preparation, effective workload organization, and balancing teaching tasks with online responsibilities (Nur Eva et al., 2023).

Additionally, intrinsic and extrinsic motivation play a pivotal role in teachers' implementation of blended learning, with factors such as technological interaction, academic workload, institutional support, and job satisfaction influencing their time management strategies (Wang et al., 2024). Implementing effective techniques, monitoring performance, restructuring the environment, and adapting future strategies, as suggested by Nur Eva et al. (2023), are key components of self-regulated learning strategies that can enhance teachers' time management skills in blended learning settings.

iv. Enhancing Teaching Quality

In the blended learning approach, the core components of teaching quality strategies by teachers encompass various elements such as interaction or engagement, learning design, assessment and feedback mechanisms, and technology integration (Radovan & Radovan, 2024). For instance, effective teacher-student interaction in online spaces supported by real-time dynamic AI systems can significantly enhance student engagement and improve academic outcomes (Cheung et al., 2023).

Moreover, the correlation between teaching approaches such as collaborative learning and assessment or feedback mechanisms with student satisfaction underscores the importance of these components in ensuring a successful blended learning experience (Anthony Jnr, 2024).

Additionally, the implementation of blended learning as a delivery mode emphasizes the importance of personalized learning experiences, technology integration, and the combination of traditional and digital resources to promote a comprehensive educational experience (Oladejo et al., 2023). Collectively, these components contribute to creating a dynamic and engaging learning environment that addresses diverse student needs in a blended learning context.

IV. CONLCUSION

The study on the effectiveness of blended learning in science education from 2020 to 2024 indicates that the blended approach offers substantial opportunities to enhance students' understanding of scientific concepts and skills. Despite challenges such as ICT literacy gaps, limited internet access, and differences in attitudes and learning styles between students and educators, this study provides comprehensive insights into the diversity of subjects and research methodologies conducted across various countries.

By emphasizing adequate training and support for both students and educators, along with a deeper understanding of the importance of digital skills in blended learning, this study makes a valuable contribution to strengthening the implementation of blended learning approaches in the context of science education.

V. RECOMMENDATIONS FOR FUTURE RESEARCH

For further research in the field of the effectiveness of blended learning in science education, several recommendations can be considered:

i. Investigation of the Impact of Specific Technologies: Conduct studies on the influence of specific technological tools in blended learning on students' academic achievement.

ii. Research on Effective Teaching Strategies: Examine the best instructional strategies to address ICT literacy challenges among students.

iii. Comparative Studies: Compare the effectiveness of blended learning in science education in online and traditional learning environments.

iv. Motivation and Affective Impact: Investigate the impact of intrinsic motivation and affective factors on blended learning in science education.

v. Longitudinal Studies: Conduct longitudinal studies to assess the long-term impact of blended learning on students' performance in science.

Further research in these areas will contribute to a more comprehensive understanding of the effectiveness of blended learning in science education and provide clearer guidelines for developing more effective learning approaches in the future.

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