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Ni Nyoman Sri Putu Verawati, Joni Rokhmat, Ahmad Harjono, Muh Makhrus, Aa Sukarso Sukarso

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Integrating Ethnoscience-PBL and Virtual Technology to Improve Critical Thinking Skills: A Literature Review and Model Design

Ni Nyoman Sri Putu Verawati [1], Joni Rokhmat, Ahmad Harjono [1], Muh Makhrus [1] , Aa Sukarso Sukarso [1]

[1] *University of Mataram, Jl Majapahit No 62, Mataram, Indonesia*

Abstract **– This paper reviews literature and proposes an innovative learning model integrating ethnoscience, Problem-based Learning (PBL), and virtual technology to enhance students' critical thinking (CT) skills. Ethnoscience provides a culturally relevant context, making scientific concepts more relatable, while PBL engages students in active problem-solving. Virtual technology further amplifies these methods by offering interactive environments that enable students to visualize abstract concepts and improve analytical reasoning. Using the PRISMA methodology based on SCOPUS database, 56 studies were reviewed to examine the potential of these three approaches. The findings suggest that individually, ethnoscience, PBL, and virtual technology contribute to CT development, but their integration offers a more comprehensive framework. The proposed Ethnoscience-PBL model with virtual simulations embedded throughout. This model not only supports the development of CT but also prepares students to solve real-world problems through a combination of cultural context and advanced technological tools.**

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Corresponding author: Ni Nyoman Sri Putu Verawati, *University of Mataram, Jl Majapahit No 62, Mataram, Indonesia.*
Email: veyra@unram.ac.id

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1. Introduction

Training critical thinking (CT) skills in university students is essential as one of the educational goals in Indonesia. In modern higher education systems, CT is recognized as a competency that supports students' professional abilities in the future [1]. CT is part of higher-order thinking, which is a primary focus of 21st-century education. This skill also serves as a strong indicator of higher-order thinking processes. In education, it has been studied that CT skills improve academic performance [2] and equip learners to handle complex situations and solve problems effectively [3], [4]. Stimulating CT skills during the learning process can encourage learners to build new knowledge [5]. CT is one of the desired skills as a result of the learning process in science education [6].

CT skills have long been a parameter of the success of education systems in various countries and are a core competency for graduates in the curriculum of developed countries. Currently, Indonesia also places CT as an integrated part of curriculum achievement at all levels of education, including higher education, with one of its focuses on science learning and education [7]. For this reason, every learning effort must be oriented toward improving students' CT performance. However, this is not easy, as training in CT remains a challenge [8], mainly due to the lack of intervention through the appropriate learning models [9]. Consequently, students' CT performance has not met expectations.

Several previous studies have examined students' CT performance. For example, an essay study on 38 students in Sweden showed poor analytical skills [10]. Learning experiences that do not emphasize CT with effective pedagogy resulted in low CT performance among students in China [11]. The study results in Indonesia are equally concerning, as the CT of pre-service science teachers has not developed during learning [12]. A recent study [13] shows the tendency of students' CT is mostly below the critical threshold.

Moreover, in science education, students are often confronted with highly abstract material, increasing learning difficulties and hindering the development of their thinking skills [14].

A serious and well-planned effort is recommended to address the issue of low CT skills among pre-service science teachers, especially in Indonesia [12].

The development of an appropriate learning model to support CT skills is a necessity, where the learning model must be designed not only as a teaching instrument but also as a framework that effectively guides the learning process. The learning model is expected to optimally stimulate the development of learners' potential, especially in terms of CT skills. CT potential can emerge through a holistic and integrative learning process, in which every aspect of the learning model must align with the development and characteristics of individual learners [15]. In the context of science, holistic learning that supports CT encourages the formation of a comprehensive mindset by internalizing local wisdom, which can be achieved through ethnoscience learning [16]. Ethnoscience learning is also aligned with the principles of authentic learning, where learners are engaged in real-world contexts relevant to everyday life problems, particularly those related to the culture in which they grow and develop [17]. However, the challenge of teaching ethnoscience to cultivate CT lies in the difficulty of harmoniously integrating traditional knowledge with modern scientific concepts [18]. A learning process must be able to bridge these two contexts without sacrificing scientific accuracy or neglecting the value of local culture. Additionally, students are often unfamiliar with the relevance of ethnoscience knowledge in a scientific context, so a contextual and interactive learning model must be created as one that utilizes technology to enable students to develop CT skills [19].

Education in the modern era increasingly demands active learner involvement, prompting the development of a science learning model that enables learners to collaborate effectively in the exploration process, as reflected in Problem-based Learning (PBL) [20]. PBL is also seen as the basis for an exploratory learning process that can support learners' potential to think critically [21]. Although PBL is widely accepted as an effective way to cultivate thinking skills, challenges remain in fostering CT among learners. Previous study [22] identified several issues in implementing PBL, including learners' difficulties in problem formulation, high costs of learning environments, and challenges in monitoring the assessment process.

The findings of a recent study [23] indicate that PBL is less effective in training CT when applied as a standalone model.

Previous study [24] also identified evidence of low CT skills among students during PBL implementation, for example, in the inference indicator. Additionally, the CT improvement parameters were found not categorized as high post-PBL intervention in the classroom [24]. Research needs to be intensified to adapt PBL to be more oriented towards learner CT, which can yield positive results and enhance learners' CT [25]. A literature review on PBL interventions concerning various factors that influence students' effectiveness has been conducted [26]. In conclusion, although PBL can generally encourage the acquisition of CT (both skills and dispositions) in students, further research is needed to explore the effectiveness of PBL in various learning strategies, environments, and authentic problem-based tasks [26].

Innovative learning plays a crucial role in creating a dynamic and adaptive learning environment that supports exploration, especially for modern learners who grow up in a digital era familiar with technology. Therefore, dynamic, flexible, and adaptive learning processes must utilize technology to enhance engaging learning experiences [27]. Interactive learning environments can be presented through digital systems that motivate students in their learning [28]. This aligns with advances in digital technology, interest in the internet, and the trend of virtual learning, which has brought changes to technology-based learning environments. It is predicted that by 2025, online systems will be used extensively in all modes of education and learning worldwide [29]. This poses a challenge to ensure that pedagogical models are built with digital systems [30], while also providing a great opportunity to continue supporting the achievement of students' CT skills [18].

Several previous study have highlighted the use of virtual technology in science teaching, which impacts better concept mastery, preference for science theories, and improved thinking skills [14]. Virtual technology can visualize abstract science concepts, thus broadening students' thinking, which positively impacts their critical analytical abilities [31]. Students have also shown a high level of acceptance of technology application, which has proven to positively impact knowledge acquisition, skills, and attitudes [32]. The clear advantage of virtual technology is its ability to address learning challenges, especially related to accessibility [33]. Another advantage is that virtual technology can be developed in spaces and designs where students can manipulate science experiment parameters as needed [34]. While virtual technology offers many benefits in the learning process, there is still a lack of empirical evidence on how simulation technology can train students' CT skills, according to the current literature.

An innovative science learning model must also adapt to the dynamics of curriculum changes and global education goals and align with the needs and developments of the times, especially in facing the challenges of modern education, which emphasize 21st-century skills such as CT [35]. Therefore, the development of learning models must be innovative and futuristic, forward-looking to support learners' mastery of CT. The development of CT in science education requires stimulation through a well-designed learning process [36]. A structured learning process stimulus greatly determines learning success [37]. A study [36] highlights that a lack of comprehensive learning process design hinders the teaching of CT. Several scholars contend that critical-thinking instruction ought to begin in university-level teacher-education programs [36], [38], so that prospective teachers are well prepared to cultivate these skills in their future students [39].

Highlighting the challenges in science learning processes that accommodate holistic, authentic, and modern contexts, which result in low CT skills among students, it is essential to conduct in-depth analysis and review of the existing literature on how learning can train students' CT. Learning based on the context of ethnoscience, PBL, and the use of virtual technology has been studied separately for various learning outcomes. The strengths of these three approaches offer opportunities for creating an integrative learning model that can train students' CT skills.

Therefore, the current study also proposes a learning model design that can train CT by integrating ethnoscience concepts, PBL, and virtual simulation technology. Specifically, the objectives of this study are as follows:

a. Reviewing the literature on the potential of ethnoscience, PBL, and virtual technology-based learning in enhancing students' CT skills.
b. Designing an innovative learning model framework that integrates ethnoscience concepts, PBL, and virtual technology to support the development of students' CT skills.

2. Methodology

This literature review follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology, which provides a transparent and replicable process for identifying, selecting, and evaluating relevant research studies [40]. The review focuses on the potential of integrating ethnoscience, Problem-based Learning (PBL), and virtual simulation technology to enhance students' CT skills. The process is divided into four main stages: identification, screening, eligibility, and inclusion. The data source used for the review is the SCOPUS database (https://www.scopus.com), applying specific Boolean search strings. The PRISMA framework and the results of the identification, screening, eligibility, and inclusion are illustrated in Figure 1.

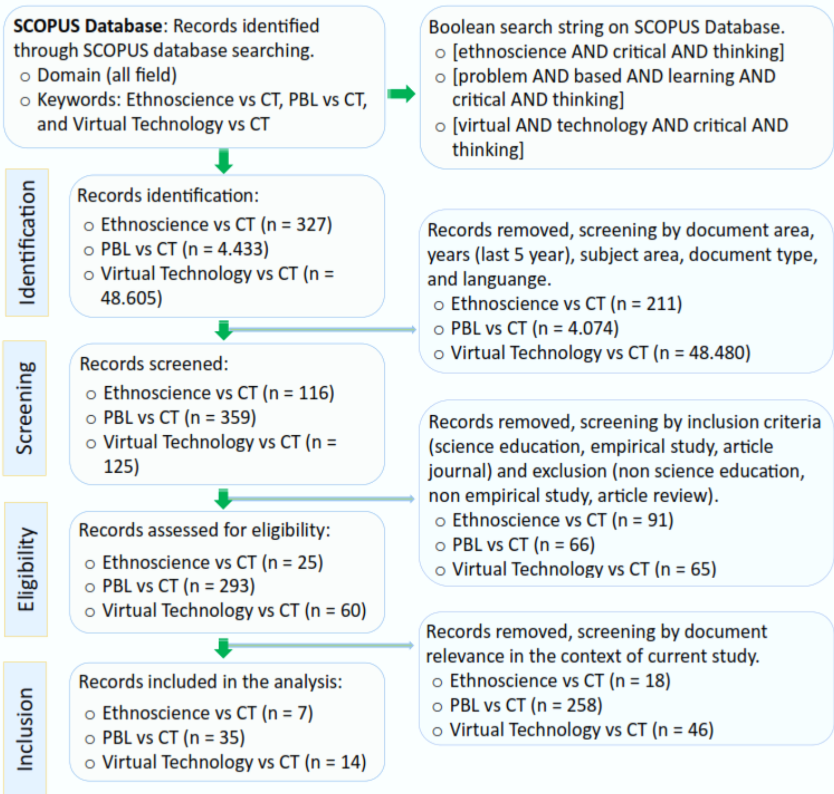

Figure 1. The framework and the results of PRISMA

2.1. Identification

The identification phase focused on gathering relevant studies using SCOPUS, a comprehensive database covering a wide range of disciplines. The search strategy employed three core keywords: ("ethnoscience AND critical AND thinking"), ("problem AND based AND learning AND critical AND thinking"), and ("virtual AND technology AND critical AND thinking"). These keywords were chosen to capture studies that examine the intersection of critical thinking (CT) skills with three key pedagogical approaches—ethnoscience, Problem-based Learning (PBL), and virtual technology. The search was conducted on 30 September 2024, without restrictions on publication year, subject area, document type, or language. The initial search resulted in a total of 53,365 documents: 327 records related to "Ethnoscience vs CT," 4,433 records on "PBL vs CT," and 48,605 records on "Virtual Technology vs CT."

2.2. Screening

The screening process applied several filters to refine the document pool. First, studies were screened for relevance based on search terms in the title, abstract, or keywords. The selection was limited to works published between 2019–2024, focusing on social science, specifically education and science education. Only peer-reviewed journal articles and conference papers in English were included to ensure quality and accessibility. This process reduced the search results to 600 records, of which 116 were on ethnoscience, 359 on Problem-based Learning, and 125 on virtual technology.

2.3. Eligibility

The eligibility phase refined the study pool using inclusion and exclusion criteria. Full texts were examined to ensure relevance to the review's focus on ethnoscience, Problem-based Learning (PBL), and virtual technology in science education and their impact on critical thinking (CT) skills. Inclusion criteria targeted empirical studies involving secondary or tertiary learners or science teachers and those presenting original research. Exclusion criteria removed studies unrelated to CT development or outside science education, as well as review or non-empirical papers. This process reduced the pool to 378 articles: 25 on ethnoscience, 293 on PBL, and 60 on virtual technology.

2.4. Inclusion

The final inclusion phase focused on a qualitative analysis of the selected studies. This phase involved a detailed examination of each article to determine its contribution to understanding the role of ethnoscience, Problem-based Learning (PBL), and virtual technology in fostering critical thinking (CT) skills. The final selection included 7 studies on ethnoscience, 35 on PBL, and 14 on virtual technology, making a total of 56 studies that met the inclusion criteria for this review. Each included article was assessed based on its specific focus on CT, the methodological rigor of the study, and the relevance of its findings to the broader objective of this review.

2.5. Data Analysis and Model design

The data extracted from the included studies were subjected to qualitative content analysis. This involved coding the studies based on their focus, methodology, and findings regarding the development of critical thinking (CT) skills. Based on this analysis, the framework for the innovative learning model was developed. The model integrates ethnoscience, PBL, and virtual technology, drawing on the strengths of each approach. This integrative model aims to provide a comprehensive approach to developing students' CT skills in science education.

The initial design of the model, referred to as the preliminary form of product [41], was conceptualized as a flexible framework adaptable to various learning environments. This model is expected to stimulate CT through a combination of ethnoscience, Problem-based Learning, and virtual technology, addressing the challenges identified in previous studies. The proposed model offers a holistic and flexible framework that can be adapted to different educational contexts, particularly in science education, where the cultivation of CT is essential.

3. Results and Discussion

In today's educational landscape, critical thinking (CT) is increasingly recognized as essential, particularly in higher education, where students must navigate complex problems and generate innovative solutions. As educational models evolve, there is a growing interest in integrating diverse approaches to enhance CT. Ethnoscience, Problem-based Learning (PBL), and virtual technology have emerged as effective strategies. Ethnoscience connects scientific knowledge with local culture, providing a contextualized learning experience.

PBL promotes active problem-solving and engagement, while virtual technology offers immersive platforms that allow students to visualize and experiment with abstract scientific concepts.

Figure 2 illustrates the distribution of study documents on ethnoscience, PBL, and virtual technology from 2019 to 2024.

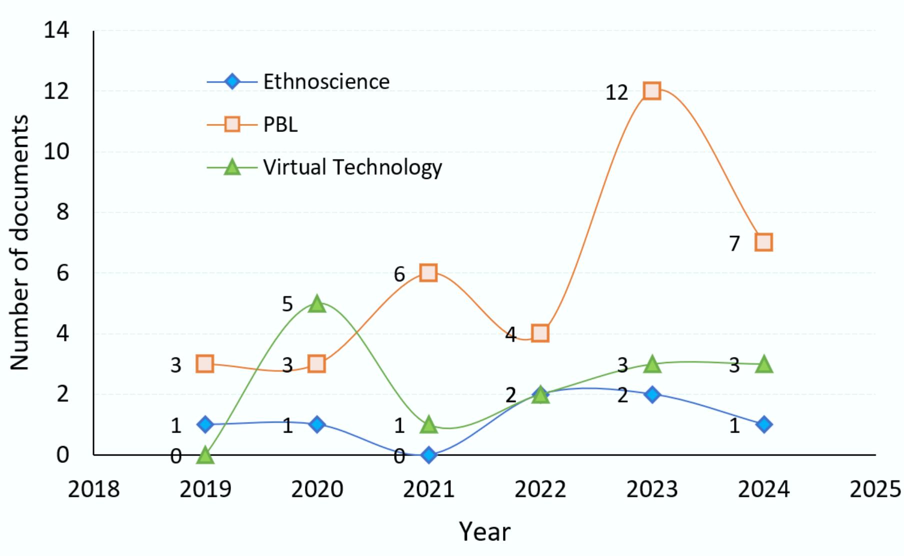

Figure 2. Distribution of study documents meeting the inclusion criteria

PBL shows a notable rise, peaking at 12 documents in 2023, indicating growing interest in this method. Virtual technology also gained traction, with increasing publications, especially in 2021 and 2023. Ethnoscience, however, remained less explored but consistent, with modest growth observed in 2023 and 2024. This pattern reflects the varied adoption and research interest in these approaches, highlighting the need for further exploration of their combined potential to enhance CT.

Despite their individual benefits, there is a need to investigate how integrating these methods can holistically support CT development. This review synthesizes the current literature to evaluate the impact of ethnoscience, PBL, and virtual technology on students' CT skills. By examining empirical studies, the aim is to propose an innovative learning model that integrates these approaches, offering a comprehensive framework for modern science education.

3.1. The Ethnoscience Learning to Improve Students' CT Skills

The literature review identified a total of 7 studies that specifically addressed the relationship between ethnoscience learning and the development of students' critical thinking (CT) skills. These studies highlight how integrating local cultural knowledge into science education can enhance students' cognitive abilities by providing a contextual framework for critical analysis and problem-solving. The selected studies demonstrate various strategies for incorporating ethnoscience into the curriculum, showing its potential to make scientific concepts more relatable and to stimulate higher-order thinking. Table 1 presents the details of these studies, summarizing the key findings to the theme of ethnoscience learning and its impact on CT skills.

Table 1. Studies related to the theme of ethnoscience learning to improve students' CT skills

Study	Findings
[42]	Ethnoscience instruction significantly enhanced CT skills in biology students, without gender differences.
[18]	The approach led to significant improvements in students' CT, particularly in analysis, inference, and evaluation.
[19]	The blend of inquiry and ethnoscience on an e-learning platform significantly enhanced CT in future science educators.
[43]	Inquiry-creative learning with ethnoscience significantly improved CT in prospective science teachers compared to traditional methods.
[44]	The ethno-inquiry model significantly improved CT skills in the experimental group compared to the control group.
[45]	Ethnoscience-STEM projectbased learning significantly improved CT skills, with most students achieving medium to high levels of CT.
[16]	The PBL based worksheets significantly improved students' CT, with moderate gains in logical inference and scale awareness.

Ethnoscience integrates culturally relevant content into the curriculum, promoting deeper engagement with scientific concepts. Studies [18], [42] demonstrate that students engage more deeply when the content resonates with their cultural experiences, improving critical thinking (CT) through real-world application of scientific reasoning.

Project-based and inquiry-based models, as explored [19], [43], further enhance CT by fostering higher-order thinking. These models push students to not only recall knowledge but to apply it, improving their analytical and problem-solving abilities. Ethnoscience's integration into these models supports knowledge that is both scientifically accurate and culturally meaningful.

Additionally, digital platforms for delivering ethnoscience content, as examined [44], provide flexibility and accessibility, addressing diverse learner needs and potentially expanding CT development. Ethnoscience's alignment with STEM, noted [45], further supports CT by blending scientific concepts with real-world applications, making learning more comprehensive and impactful. Incorporating ethnoscience remains a powerful strategy for fostering CT in diverse educational settings.

3.2. Application of Problem-based Learning in Enhancing Students' CT Skills

The final selection for this review included 35 studies examining the use of Problem-based Learning (PBL) as a method to enhance students' critical thinking (CT) skills.

These studies emphasize PBL's effectiveness in promoting CT by engaging students in collaborative, inquiry-driven problem solving, which encourages them to analyze complex issues. PBL fosters an active learning environment where students critically engage with real-world problems, thus improving their reasoning and reflective thinking abilities. Table 2 presents the studies related to the application of PBL in enhancing students' CT skills.

PBL has demonstrated significant potential in cultivating CT skills, a key cognitive ability for success in both academic and professional fields. Through PBL, students engage in structured problem-solving activities, allowing them to apply theoretical knowledge to practical, real-world scenarios. This model promotes higher-order thinking, such as analysis, evaluation, and solution creation, which are essential components of CT [23], [46]. The inquiry-based framework of PBL encourages active learning, enhancing cognitive engagement and reflective thinking [47].

Table 2. Studies related to the theme of PBL to improve students' CT skills

Study	Findings
[48]	The findings reveal a statistically significant improvement in students' CT skills. The enhanced engagement and understanding through PBL-iSpring were also positively received by students.
[49]	The findings revealed that PBL enhances teamwork, presentation skills, and notably CT in physics, while traditional learning favors individual theoretical knowledge suitable for exams with closed-ended questions.
[50]	Significant improvements were observed in the development of CT components among participants, with increases in information analysis, logic, and argumentation skills.
[51]	The PBGL model significantly enhanced CT in programming, with the experimental group showing marked improvements in Python, Java, and Web programming compared to the control group.
[52]	Students typically displayed low-level CT in physics, with the highest scores in "Evaluating" and the lowest in "Synthesis," indicating a need for educational interventions like POPBL.
[53]	The CS-PBL model significantly improved students' CT and problem-solving skills, demonstrating effectiveness in a controlled experimental setting.
[54]	The E-module, validated by experts, showed significant improvement in students' CT, with a high N-Gain score and better outcomes compared to conventional methods.
[55]	The intervention revealed significant improvements in students' CT abilities and motivation towards learning physics, with notable differences between government and private school students.
[56]	Results show significant improvement in experimental design among doctoral students, demonstrating the efficacy of the PBL curriculum in fostering CT and applied scientific skills
[57]	Implementing the PBL model significantly bolstered students' problem-solving abilities and CT in the probability theory course, as evidenced by qualitative observations and quantitative improvements from pretest to posttest
[58]	Findings indicate that ill-structured problems using an integrative PBL approach effectively unlock CT potentialities in adult learners, supporting both self-learning and collaborative learning contexts.
[59]	The findings indicate no significant difference in chemistry learning outcomes between the PBL and PjBL methods, with both effectively engaging students in critical and creative tasks.
[60]	Integrating TPS and PBL significantly improved the CT abilities of lower-ability students in biology by approximately 24.63%.
[61]	The findings indicate that students developed enhanced cognitive skills, enabling them to analyze and infer correct solutions in physics problems through PBL.
[62]	The PBL intervention significantly improved problem-solving; however, enhancements in CT, logical reasoning, and decision-making were less pronounced, indicating a nuanced effect of PBL on different cognitive skills.
[63]	PBL with environmental content significantly improved students' CT, demonstrating moderate gains in the experimental group compared to the control.
[64]	While academic achievements were similar between groups, the PBL approach significantly enhanced students' CT skills regarding magnetism topics compared to traditional methods.
[65]	The study revealed a significant improvement in students' self-regulation skills using the CPBL method compared to the PBCL method, highlighting the efficacy of CPBL in fostering critical cognitive abilities in a controlled educational setting.
[23]	PBL combined with PhET assistive virtual simulations effectively improved students' CT, as demonstrated by significant gains in pretest-posttest comparisons and n-gain scores.
[66]	The findings indicate that the PBL model enhances CT and concept mastery, contributing to a 65.3% improvement in problem-solving skills among students.
[67]	The integration of PBL and inquiry significantly enhanced CT in youth by encouraging solution-oriented investigations, hypothesis testing, and data collection through collaborative efforts.
[68]	Students exposed to metacognitive prompts in PBL settings showed significantly enhanced argumentation and CT skills compared to those in high and low-intensity PBL.
[69]	The PBL model with argumentation scaffolding significantly improved CT levels from "less critical" to "critically sufficient" among teacher candidates, with moderate n-gain scores across different personality types and genders.
[70]	Both PBL and Digital Mind Maps-Integrated PBL significantly improved students' CT, although no significant difference was found between the two methods in their effectiveness.
[71]	The study found that the PBL approach supported by Web 2.0 tools significantly enhanced the CT skills and academic achievement of teacher candidates compared to those using traditional methods.
[72]	The experimental group, using PBL with an analytical rubric, showed increased, albeit not statistically significant, scores from pre-test to post-test, suggesting a potential improvement in CT skills.
[73]	The study indicated a significant improvement in CT tendencies among prospective science teachers, particularly in areas like inquisitiveness, self-confidence, and systematicity, following a PBL approach.
[74]	The experimental group, utilizing the PBL model, demonstrated significant improvements in CT, outperforming the control group, which suggests that PBL effectively enhances these skills in education.
[75]	PBL with character emphasis significantly improved students' CT skills, irrespective of their naturalist intelligence levels.
[76]	The study found that PBL significantly enhanced both the self-efficacy and CT abilities of pre-service elementary teachers compared to traditional teaching methods.
[47]	The study found a significant correlation between CT and knowledge acquisition with a correlation coefficient of 0.861, indicating that enhancements in one could foster improvements in the other.
[46]	PBL significantly enhances CT skills among high school students with varying cognitive styles, compared to the multimedia-assisted Direct Instruction approach.
[77]	The study found that the PhET simulation-assisted PBL model significantly improved students' CT skills, evidenced by substantial gains in standard scores in the implementation and modeling classes.
[78]	Significant increases were observed in the number of Learning Issues reports that incorporated collaborative CT, alongside more time spent on CT activities, enhancing both self-direction and expert identity fluidity in participants.
[79]	The study identified a significant relationship between CT and creativity, evidenced by the regression equation, demonstrating the efficacy of the integrated PBL model in enhancing both attributes in students.

A core strength of PBL is its student-centered approach, which contrasts with traditional, passive learning models. In PBL, learners take an active role in identifying, exploring, and solving problems. The iterative nature of this model, which involves continuous reassessment of information to generate solutions, hones CT skills by fostering deeper reasoning. PBL often presents ill-structured problems, pushing students to collaborate and engage in critical inquiry to find viable solutions [50], [78]. Research consistently shows that students participating in PBL develop stronger problem-solving and critical analysis abilities [48].

Collaboration is another key element of PBL that enhances CT. Working in groups, students are encouraged to articulate, defend their ideas, and consider alternative viewpoints. This process fosters critical dialogue, enabling learners to refine their arguments and approach problems from multiple perspectives [49], [52]. Such peer interactions play a pivotal role in advancing CT, as learners critically engage with diverse opinions, enhancing their individual analysis skills [58], [73].

PBL also aligns with authentic learning experiences, motivating students to engage in more critical, real-world problem-solving. This connection to practical challenges increases students' motivation to apply CT in various academic disciplines and professional contexts [53], [76]. The model’s emphasis on authenticity helps students develop transferable skills that are essential for real-world problem-solving, making PBL a valuable tool for preparing learners for future challenges [61].

Despite its benefits, PBL faces challenges in implementation, such as the need for well-designed problems and effective facilitation. Poorly structured problems or unbalanced group dynamics can limit CT development [55]. Facilitators play a crucial role in ensuring meaningful student participation and guiding critical discussions. Additionally, scalability and assessment remain challenges, particularly in resource-constrained environments.

Alternative assessment methods like open-ended questions or peer evaluations are more suited to PBL but can be difficult to implement widely [22]. However, the integration of technology, such as virtual simulations, offers promising solutions, enhancing engagement and scalability in PBL contexts [77].

3.3. The Learning Utilizing Virtual Technology to Improve Students' CT Skills

The final selection included 14 studies that explored the use of virtual technology in learning environments to enhance students' critical thinking (CT) skills. These studies highlight how virtual simulations and digital platforms provide interactive and immersive experiences that allow students to visualize abstract concepts, manipulate variables, and engage in problem-solving activities, all of which contribute to the development of CT. The integration of virtual technology creates a dynamic learning environment where students can practice analytical reasoning and critical evaluation in a simulated context. Table 3 presents the studies related to the use of virtual technology in improving students' CT skills.

The use of virtual technology in education has proven highly effective in enhancing students' CT skills. Virtual simulations and digital platforms enable active engagement with abstract concepts, allowing learners to manipulate variables and solve problems. This transition from passive to active learning significantly boosts CT [80], [81]. Through the analysis of 14 studies, it is evident that virtual technology enhances CT, overcoming traditional educational challenges, especially in scientific disciplines. Key features such as immersive learning environments bridge theoretical knowledge and practical application. For instance, spherical video-based immersive virtual reality (SV-IVR) reduces cognitive load and fosters critical analysis, improving CT skills [80]. Similarly, augmented reality (AR) helps visualize complex scientific concepts, strengthening students’ understanding and analytical abilities [82]. In remote learning, smartphone-based AR also improves CT, especially in subjects like physics [83].

Table 3. Studies related to the utilizing virtual technology to improve students' CT skills

Study	Findings
[80]	Students using SV-IVR reported lower mental effort and load, and displayed improved CT skills compared to those undergoing traditional teaching methods.
[84]	Analysis indicated a significant enhancement in students' future thinking skills, including problem-solving and envisioning, highlighting the effectiveness of the digital platform in a physics enrichment context.
[85]	Teaching with AR applications significantly boosted pupils' academic success and developed their CT skills, demonstrating enhanced understanding and application of nuclear physics concepts.
[83]	Students using smartphone-based Augmented Reality (AR) for distance learning demonstrated significantly higher CT scores, averaging 71.4 and 69.47, compared to non-AR users who scored 51.03 and 45.67, respectively.
[86]	The integration of virtual reality with PBL did not significantly enhance CT abilities compared to traditional methods, though improvements were noted in problem-solving and self-efficacy.
[87]	The study found significant differences in CT skills between students using interactive web modules and those using interactive videos, with both types of PhenoBL media proving effective in enhancing these skills.
[88]	The digital tools significantly enhance the CT skills of students, indicating a positive dynamic in rational thinking capabilities when using such technologies.
[89]	The study demonstrated that virtual simulations on the LMS platform significantly enhanced the reasoning skills of STEM students compared to traditional expository methods.
[90]	The study found that students utilizing VR laboratories demonstrated significantly improved CT skills compared to those using traditional labs.
[82]	The use of AR in teaching Physics significantly enhanced students' CT abilities and learning gains by facilitating better visualization of abstract concepts.
[91]	There was a noticeable improvement in students' CT skills with an overall N-gain of 0.57, categorizing it as medium, where the "interpretation" indicator showed the highest gains.
[92]	The study revealed that Edmodo-based interactive teaching materials significantly improved the CT skills of junior high school students, evidenced by a high average normalized gain (n-gain) of 0.71.
[81]	The virtual simulation method significantly improved the cognitive aspects of CT among students, who reported increased satisfaction, self-confidence, and positive attitudes towards the teaching method.
[93]	Students using the 3D visualization program demonstrated enhanced CT skills, as indicated by superior performance on chemical bonding tests compared to their peers in control groups.

Virtual simulations within learning management systems (LMS) also support CT development, particularly in STEM education. Previous study [89] shows virtual simulations integrated into LMS improved students' reasoning skills compared to traditional teaching methods. Virtual reality (VR) labs have also been shown to significantly enhance CT, providing 3D interactive environments that promote deeper engagement and higher-order thinking [90]. However, the implementation of virtual technology must be carefully designed to maximize its benefits. A study by [86] reveals that although VR simulations with PBL improved problem-solving skillsdid not significantly enhance CT compared to conventional methods. This suggests that effective integration of virtual tools into educational practices is crucial for optimal results in CT development. Virtual technology's flexibility also supports student engagement with complex, abstract problems. For example, virtual simulation systems in engineering education improved students' CT, especially in technical subjects like numerical control machining [81]. Students also reported greater self-confidence and satisfaction with their learning experiences, emphasizing the broader benefits of virtual tools in fostering a critical mindset.

In digital learning, online interactive modules also hold promise. It was found that interactive web modules and videos in chemistry courses significantly enhanced CT [87]. These tools allow students to interact directly with content, fostering deeper understanding and analytical skills. Virtual simulations during the COVID-19 pandemic, such as Android-based Physics Education Technology (PhET) simulations, also effectively promoted CT in remote learning environments [91]. Virtual technology has a substantial impact on CT development by providing interactive, immersive environments. The proper design and integration of these technologies are critical to fully realizing the potential in enhancing CT across disciplines. As educational methods evolve, virtual technology will continue to play a central role in developing CT skills [85], [88].

3.4. Designing the Innovative Learning Model

Based on the literature review, the framework for the innovative learning model was developed. The model integrates ethnoscience, Problem-based Learning (PBL), and virtual technology, drawing on the strengths of each approach.

This integrative model aims to provide a comprehensive approach to developing students' critical thinking (CT) skills in science education.

3.4.1. The Idea Framework of Model Development

In this study, the integration of ethnoscience and PBL is termed Ethno-PBL. The Ethno-PBL model integrated with assistive virtual technology represents an innovative approach to learning, aimed at enhancing students' CT skills. This model combines PBL within the context of ethnoscience, utilizing assistive virtual technology as an embedded tool to facilitate the learning process. By merging these elements, the model not only supports the exploration of authentic problems rooted in local traditions and culture but also leverages virtual simulations to visualize complex and abstract concepts.

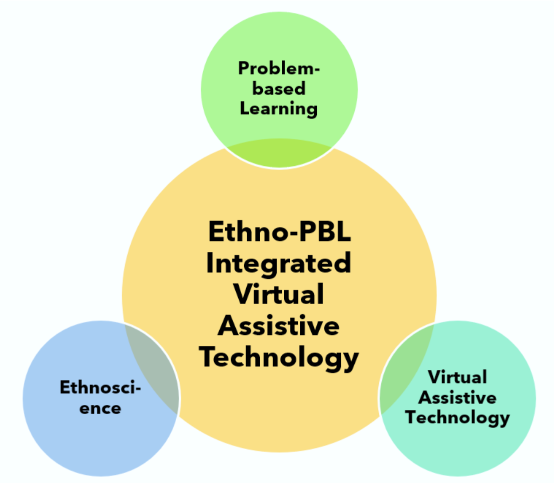

Figure 3. The idea framework of Ethno-PBL model integrated with assistive virtual technology

The Ethno-PBL model, enhanced with assistive virtual technology, is designed to address challenges in developing students' CT skills. It stems from the integration of three key elements: ethnoscience, PBL, and virtual assistive technology, which have been previously studied separately but are now brought together in this framework (see Figure 3). Ethnoscience offers culturally relevant, authentic learning contexts that can enhance scientific literacy and students' thinking skills [17]. However, the challenge lies in implementing ethnoscience within an innovative, interactive learning framework that actively cultivates students' CT abilities.

PBL, which centers around student engagement in solving open-ended problems, aligns well with the goal of developing CT. This approach forces students to think critically and reflectively as collaborating in teams to solve complex problems [26]. While PBL is effective, previous studies show that its effectiveness can be limited when students encounter abstract or difficult-to-understand content without adequate visualization tools [14].

To overcome this limitation, assistive virtual technology plays a critical role by helping students visualize abstract scientific concepts and process information more effectively, thereby boosting their critical analytical capabilities [31].

Previous studies also indicate that achieving high levels of CT competence among students can be challenging due to the lack of effective, interactive learning models that stimulate CT in complex contexts [94], [95]. The focus of PBL on contextual problem-solving and active student interaction necessitates further adaptation to maximize its effectiveness, especially when combined with digital learning technologies [96]. Research shows that integrating technology with PBL enhances CT skills, allowing for deeper cognitive engagement [97], [98]. Furthermore, the use of virtual technologies in science education has proven effective in enhancing concept mastery and preference for complex scientific theories, directly contributing to improved CT skills [31].

Assistive virtual technology, which originally served as a tool for learners with disabilities [99], has evolved into a critical visualization instrument within this Ethno-PBL model. Virtual simulations are widely used in science education to bridge the gap between abstract concepts and students' practical understanding. These technologies have shown to be highly effective in fostering new critical and analytical thinking skills among students [100], [101]. By integrating such technologies into Ethno-PBL, students gain access to rich, interactive learning resources that provide a more meaningful learning experience and directly enhance their CT skills. An example of assistive virtual technology is the Physics Education Technology (PhET) simulation, which has been extensively used in science education. PhET enables students to conduct virtual experiments and interactively explore scientific concepts, particularly useful when physical access to laboratories is restricted [102], [103]. The integration of PhET in the Ethno-PBL model allows for greater flexibility in learning, enabling students to access simulations online at any time. This aids in their understanding of abstract concepts while fostering the development of CT through exploration, analysis, and inference.

The incorporation of technology into science education not only enhances comprehension and retention of complex scientific concepts but also accommodates diverse learning styles and speeds, promoting personalized learning [104], [105]. Virtual technology's ability to promote collaborative learning and improve students' cognitive and socio-emotional aspects underscores its importance in science education [106]. In the Ethno-PBL model, the integration of technology creates a holistic, dynamic learning experience where human interaction and technology work together to provide comprehensive learning.

3.4.2. The Hypothetical Model of Ethno-PBL Integrated with Assistive Virtual Technology

Comprehensively, the hypothetical model illustrating the conceptual design of Ethno-PBL integrated with assistive virtual technology is presented in Figure 4.

The hypothetical learning model is adapted from the learning model development framework [107]. The structure of the learning model is characterized by its syntax (learning phases), social system, principles of reaction, support system, and effects of the model.

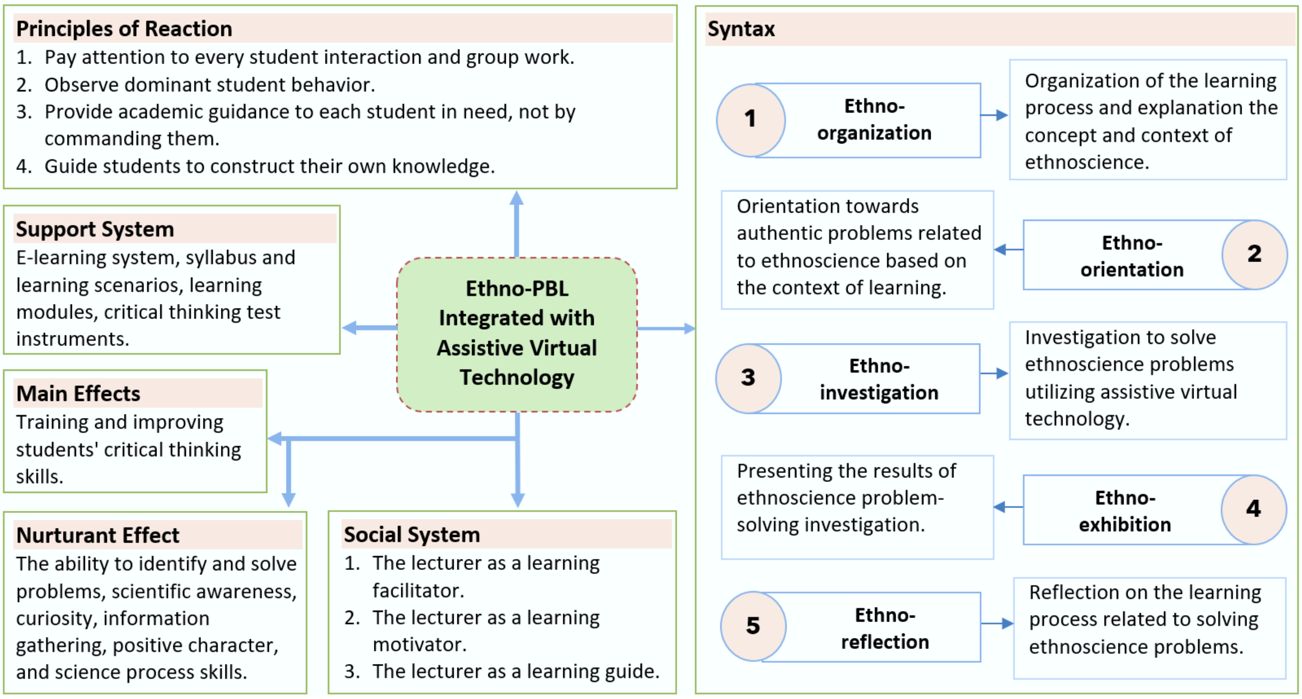

Figure 4. The hypothetical model of Ethno-PBL integrated with assistive virtual technology

The Ethno-PBL model integrated with assistive virtual technology consists of five stages: ethno-organization, ethno-orientation, ethno-investigation, ethno-exhibition, and ethno-reflection. It emphasizes the lecturer's role as a facilitator, guiding students through interactive group work and personalized support. The model's support system includes an e-learning platform, course outlines, modules, and CT skill tests, all aimed at improving students' CT. Unique features of the Ethno-PBL model include its integration of ethnoscience at every stage and its focus on developing students' CT abilities. This hybrid model works across all learning modes, with assistive virtual technology playing a crucial role in the ethno-investigation phase, facilitating planning, execution, and reporting of ethnoscientific investigations.

Figure 5 illustrates the phases of the Ethno-PBL model integrated with assistive virtual technology, starting with the first phase, ethno-organization. In this phase, the organization of the learning process is crucial in providing direction and explanations regarding ethnoscience concepts. The role of the instructor is to ensure that the learning objectives and processes are clearly communicated, while students are expected to pay full attention to these instructions.

Supported by Vygotsky's constructivist theory, this phase emphasizes that well-structured learning facilitates the mental development of learners [108]. Empirical studies also show that proper organization of the learning process fosters an optimal learning environment, which helps achieve the desired learning outcomes [109], [110]. Ethnoscience-based learning has been proven to encourage active student participation, enhancing scientific literacy and CT skills [111].

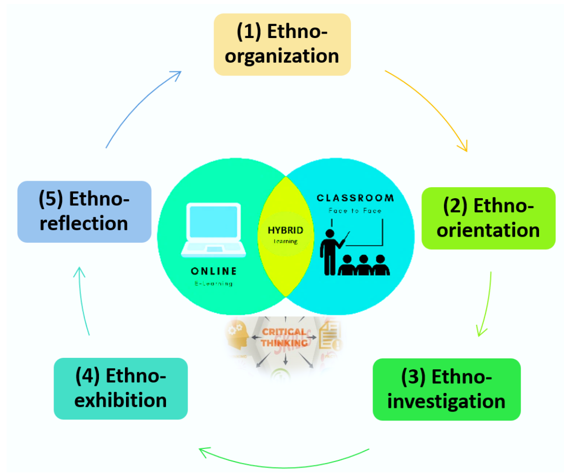

Figure 5. The phases of the Ethno-PBL model integrated with assistive virtual technology

The second phase, ethno-orientation, focuses on orienting students towards authentic problems related to ethnoscience within the context of the learning material. Here, the instructor guides students through authentic, culturally relevant problems and opens the floor for discussions. This aligns with constructivist principles, which state that learners build their understanding through active interaction with their environment by solving real-world problems [112]. Integrating cultural knowledge into the learning process makes learning more meaningful and relevant to students [17]. Empirical support for this phase suggests that authentic learning integrated with ethnoscience enhances learning experiences and improves CT [44], [113].

In the ethno-investigation phase, students actively engage in investigating and exploring ethnoscientific problems using assistive virtual technology. The role of the instructor here is to facilitate and encourage students to utilize technology in solving problems. Piaget's constructivist theory emphasizes the importance of learning through direct experience and interaction with the environment, particularly in problem investigation contexts [112]. Virtual simulation technology plays a vital role in helping students visualize abstract scientific concepts while overcoming accessibility barriers [14], [33]. Moreover, using virtual technology allows students to manipulate experimental parameters as needed, which enhances their CT skills [34], [89].

The ethno-exhibition phase requires students to present the results of their investigations into ethnoscientific problem-solving. In this phase, the instructor encourages students to share their investigation findings, a critical part of the learning process. Cognitive theory, as proposed by Bruner, posits that learning occurs through cognitive processes and the accurate processing of information [112]. This phase of presentation allows students to evaluate the evidence they have collected and promotes critical analysis, which is crucial for developing CT skills [114], [115]. Collaborative interaction and discussions of investigation results significantly contribute to improving students' CT [19].

Lastly, in the ethno-reflection phase, students are encouraged to reflect on their learning process, particularly in relation to solving ethnoscientific problems. This reflection phase serves as a tool for students to revisit the learning process and the problem-solving strategies employed. Constructivist principles affirm that successful learners are those who can think strategically and reflect on their learning experiences [112]. Reflection is a key component of CT as it involves deep and analytical thought processes [116], [117]. Empirical evidence supports the idea that reflection enhances learning outcomes, fosters CT, and leads to improved academic achievement [118].

Each phase in the Ethno-PBL model integrated with assistive virtual technology is grounded in solid theoretical and empirical foundations to support the development of CT skills. From the organization of learning, orientation towards authentic problems, to reflection, all are designed to facilitate the growth of CT. This model emphasizes the importance of cultural context in science learning and the role of technology as a supportive tool in creating a dynamic and adaptive learning experience, which ultimately contributes to more effective and meaningful learning.

4. Conclusion

The systematic literature review demonstrates that ethnoscience, problem-based learning (PBL), and virtual technology each make distinct contributions to developing students' critical thinking skills in science education. Ethnoscience embeds cultural relevance and authentic contexts, PBL fosters collaborative inquiry and reflective problem solving, and virtual tools enable interactive exploration of abstract concepts. Building on these complementary approaches, the Ethno-PBL model integrates authentic, culturally grounded challenges with immersive virtual experiences across five phases—organization, orientation, investigation, exhibition, and reflection—anchoring learning in constructivist principles that support students' critical thinking.

To move from conceptual design to practical impact, future research should rigorously test the Ethno-PBL model in diverse educational environments. Mixed-methods studies that combine quantitative measures of critical thinking gains with qualitative insights into student experiences will provide a comprehensive evaluation. Additional investigations into implementation fidelity, adaptability in resource-varied settings, and longitudinal tracking of critical thinking dispositions are needed to establish sustained impact. Finally, examining professional development strategies for educators and refining ethnoscience content for local cultural contexts will enhance relevance and scalability. By addressing these avenues, the Ethno-PBL framework can be refined and optimized to cultivate robust critical thinking skills in science learners.

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References:

[1]. Erikson, M. G., & Erikson, M. (2019). Learning outcomes and critical thinking–good intentions in conflict. *Studies in higher education*, *44*(12), 2293-2303. Doi:10.1080/03075079.2018.1486813

[2]. Liu, C., et al. (2023). Critical thinking disposition and academic achievement among Chinese high school students: A moderated mediation model. *Psychology in the Schools*, *60*(8), 3103-3113. Doi:10.1002/pits.22906

[3]. Bayram, A., et al. (2022). Nursing students' perceptions of nursing diagnoses, critical thinking motivations, and problem-solving skills during distance learning: A multicentral study. *International Journal of Nursing Knowledge*, *33*(4), 304-311. Doi:10.1111/2047-3095.12362

[4]. Xu, E., Wang, W., & Wang, Q. (2023). The effectiveness of collaborative problem solving in promoting students' critical thinking: A meta-analysis based on empirical literature. *Humanities and Social Sciences Communications*, *10*(1), 1-11. Doi:10.1057/s41599-023-01508-1

[5]. Merma-Molina, G., et al. (2022). Critical thinking and effective personality in the framework of education for sustainable development. *Education Sciences*, *12*(1), 28. Doi:10.3390/educsci12010028

[6]. Puig Mauriz, B., Blanco-Anaya, P., & Bargiela, I. M. (2023). Integrar el Pensamiento Crítico en la Educación Científica en la Era de la Post-verdad. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias*, 20(3), 3301. Doi:10.25267/Rev_Eureka_ensen_divulg_cienc.2023.v20.i3.3301

[7]. Susetyarini, E., & Fauzi, A. (2020). Trend of Critical Thinking Skill Researches in Biology Education Journals across Indonesia: From Research Design to Data Analysis. *International Journal of Instruction*, *13*(1), 535-550. Doi:10.29333/iji.2020.13135a

[8]. Lee, N. Y., Wang, Z., & Lim, B. (2024). The development of critical thinking: What university students have to say. *Teaching in Higher Education*, *29*(1), 286-299. Doi:10.1080/13562517.2021.1973412

[9]. Gilmanshina, E. A., & Gilmanshin, R. M. (2020). The assessment of critical thinking skills of gifted children before and after taking a critical thinking development course. *Thinking Skills and Creativity, 39*, 100780. Doi:10.1016/j.tsc.2020.100780

[10]. Trostek, J. R. (2020). Between the modelling and the engineering of learning: Preservice teachers' performance in course essays. *Journal of Further and Higher Education*, *44*(6), 781-794. Doi:10.1080/0309877X.2019.1600665

[11]. Ma, L., & Luo, H. (2021). Chinese pre-service teachers' cognitions about cultivating critical thinking in teaching English as a foreign language. *Asia Pacific Journal of Education*, *41*(3), 543–557. Doi:10.1080/02188791.2020.1793733

[12]. Fitriani, H., Asy'ari, M., Zubaidah, S., & Mahanal, S. (2019). Exploring the Prospective Teachersâ€™ Critical Thinking and Critical Analysis Skills. *Jurnal Pendidikan IPA Indonesia*, *8*(3), 379-390. Doi:10.15294/jpii.v8i3.19434

[13]. Verawati, N. N. S. P., et al. (2024). Analysis of Students' Critical Thinking Disposition in Science Learning. *Jurnal Pendidikan Fisika dan Teknologi*, *10*(1), 200-210. Doi:10.29303/jpft.v10i1.7127

[14]. El Kharki, K., Berrada, K., & Burgos, D. (2021). Design and implementation of a virtual laboratory for physics subjects in Moroccan universities. *Sustainability*, *13*(7), 3711. Doi:10.3390/su13073711

[15]. Acesta, A., & Sumantri, M. S. (2020). Development of Natural Science Learning Models Based on Multiple Inteligences to Improve Higher Order Thinking Skills in Elementary Schools. *Journal of Physics: Conference Series*, *1477*(4), 042036. IOP Publishing. Doi:10.1088/1742-6596/1477/4/042036

[16]. Sudarmin, S., et al. (2019). The development of PBL-based worksheets integrated with green chemistry and ethnoscience to improve studentsâ€™ thinking skills. *Jurnal Pendidikan IPA Indonesia*, *8*(4), 492-499. Doi:10.15294/jpii.v8i4.17546

[17]. Zidny, R., et al. (2021). Exploring indigenous science to identify contents and contexts for science learning in order to promote education for sustainable development. *Education Sciences*, *11*(3), 114. Doi:10.3390/educsci11030114

[18]. Wahyudi, W., et al. (2023). Hybrid Ethno-Project Based Learning Integrated With Virtual Assistive Technology to Enhance Students' Critical Thinking in Fundamental Physics Course. *TEM Journal*, *12*(4), 2006. Doi:10.18421/TEM124-11

[19]. Prayogi, S., et al. (2023). Dynamic Blend of Ethnoscience and Inquiry in a Digital Learning Platform (e-Learning) for Empowering Future Science Educators' Critical Thinking. *Journal of Education and e-Learning research*, *10*(4), 819-828. Doi:10.20448/jeelr.v10i4.5233

[20]. Lonergan, R., Cumming, T. M., & O'Neill, S. C. (2022). Exploring the efficacy of problem-based learning in diverse secondary school classrooms: Characteristics and goals of problem-based learning. *International Journal of Educational Research*, *112*, 101945. Doi:10.1016/j.ijer.2022.101945

[21]. Suárez-Cretton, X., & Castro-Méndez, N. (2022). Contribution of problem-based learning in Critical Thinking. *Revista Interuniversitaria de Formación Del Profesorado. Continuación de La Antigua Revista de Escuelas Normales*, *97*(36.3), 11–28. Doi:10.47553/rifop.v97i36.3.96182

[22]. Razak, A. A., et al. (2022). Improving critical thinking skills in teaching through problem-based learning for students: A scoping review. *International Journal of Learning, Teaching and Educational Research*, *21*(2), 342-362. Doi:10.26803/ijlter.21.2.19

[23]. Suhirman, & Prayogi, S. (2023). Problem-based learning utilizing assistive virtual simulation in mobile application to improve students' critical thinking skills. *International Journal of Education and Practice*, *11*(3), 351–364. Doi:10.18488/61.v11i3.3380

[24]. Anggraeni, D. M., et al. (2023). Systematic review of problem based learning research in fostering critical thinking skills. *Thinking Skills and Creativity*, *49*, 101334. Doi:10.1016/j.tsc.2023.101334

[25]. Yu, L., & Zin, Z. M. (2023). The critical thinking-oriented adaptations of problem-based learning models: a systematic review. *Frontiers in Education*, 8, 1139987. Doi:10.3389/feduc.2023.1139987

[26]. Liu, Y., & Pásztor, A. (2022). Effects of problem-based learning instructional intervention on critical thinking in higher education: A meta-analysis. *Thinking Skills and Creativity*, *45*, 101069. Doi:10.1016/j.tsc.2022.101069

[27]. Vandewaetere, M., Vandercruysse, S., & Clarebout, G. (2012). Learners' perceptions and illusions of adaptivity in computer-based learning environments. *Educational Technology Research and Development*, *60*, 307-324. Doi:10.1007/s11423-011-9225-2

[28]. Mohammed, D. Y. (2022). The web-based behavior of online learning: An evaluation of different countries during the COVID-19 pandemic. *Advances in Mobile Learning Educational Research*, *2*(1), 263-267. Doi:10.25082/AMLER.2022.01.010

[29]. Palvia, S., et al. (2018). Online education: Worldwide status, challenges, trends, and implications. *Journal of global information technology management*, *21*(4), 233-241. Doi:10.1080/1097198X.2018.1542262

[30]. Herodotou, C., et al. (2020). Blended and online learning: a comparative study of virtual microscopy in Higher Education. *Interactive Learning Environments*, *28*(6), 713-728. Doi:10.1080/10494820.2018.1552874

[31]. Bilad, M. R., Anwar, K., & Hayati, S. (2022). Nurturing prospective STEM teachers' critical thinking skill through virtual simulation-assisted remote inquiry in Fourier transform courses. *International Journal of Essential Competencies in Education*, *1*(1), 1-10. Doi:10.36312/ijece.v1i1.728

[32]. Diwakar, S., et al. (2015). Role of ICT-enabled virtual laboratories in biotechnology education: Case studies on blended and remote learning. In *2015 International Conference on Interactive Collaborative Learning (ICL)*, 915-921. Doi:10.1109/ICL.2015.7318149

[33]. El Kharki, K., Bensamka, F., & Berrada, K. (2020). Enhancing practical work in physics using virtual javascript simulation and LMS platform. *Radical solutions and eLearning: Practical innovations and online educational technology*, 131-146. Doi:10.1007/978-981-15-4952-6_9

[34]. De La Torre, L., et al. (2015). The ball and beam system: A case study of virtual and remote lab enhancement with moodle. *IEEE Transactions on Industrial Informatics*, *11*(4), 934-945. Doi:10.1109/TII.2015.2443721

[35]. Voogt, J., & Roblin, N. P. (2012). A comparative analysis of international frameworks for 21st century competences: Implications for national curriculum policies. *Journal of curriculum studies*, *44*(3), 299-321. Doi:10.1080/00220272.2012.668938

[36]. Yuan, R., & Liao, W. (2023). Critical thinking in teacher education: where do we stand and where can we go?. *Teachers and teaching*, *29*(6), 543-552. Doi:10.1080/13540602.2023.2252688

[37]. Schneider, M., & Preckel, F. (2017). Variables associated with achievement in higher education: A systematic review of meta-analyses. *Psychological bulletin*, *143*(6), 565. Doi:10.1037/bul0000098

[38]. Kozikoglu, I. (2019). Investigating Critical Thinking in Prospective Teachers: Metacognitive Skills, Problem Solving Skills and Academic Self-Efficacy. *Journal of Social Studies Education Research*, *10*(2), 111-130.

[39]. Prayogi, S., Yuanita, L., & Wasis. (2018). Critical Inquiry Based Learning: A Model of Learning to Promote Critical Thinking Among Prospective Teachers of Physic. *Journal of Turkish Science Education*, *15*(1), 43–56. Doi:10.12973/tused.10220a.

[40]. Page, M. J., et al. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *Systematic Reviews*, *10*(1), 89. Doi:10.1186/s13643-021-01626-4

[41]. Gall, M. D., Gall, J. P., & Borg, W. R. (2007). *Educational Research: An Introduction* (8th ed.). Pearson.

[42]. Adam, U. A., et al. (2024). Testing the potency of ethnoscience instruction on biology students' critical thinking ability. *The Journal of Educational Research*, *117*(4), 218-227. Doi:10.1080/00220671.2024.2373464

[43]. Verawati, N. N. S. P., et al. (2022). Inquiry-Creative Learning Integrated with Ethnoscience: Efforts to Encourage Prospective Science Teachers' Critical Thinking in Indonesia. *International Journal of Learning, Teaching and Educational Research*, *21*(9), 232–248. Doi:10.26803/ijlter.21.9.13

[44]. Prayogi, S., et al. (2022). Opportunities to stimulate the critical thinking performance of preservice science teachers through the ethno-inquiry model in an e learning platform. *International Journal of Learning, Teaching and Educational Research*, *21*(9), 134-153. Doi:10.26803/ijlter.21.9.8

[45]. Sumarni, W., & Kadarwati, S. (2020). Ethno-stem project-based learning: Its impact to critical and creative thinking skills. *Jurnal Pendidikan IPA Indonesia*, *9*(1), 11-21. Doi:10.15294/jpii.v9i1.21754

[46]. Arifin, S., et al. (2020). The effect of problem-based learning by cognitive style on critical thinking skills and students' retention. *JOTSE: Journal of Technology and Science Education*, *10*(2), 271-281. Doi:10.3926/jotse.790

[47]. Hidayati, N., et al. (2020). The relationship between critical thinking and knowledge acquisition: The role of digital mind maps-PBL strategies. *International Journal of Information and Education Technology*, *10*(2), 140-145. Doi:10.18178/ijiet.2020.10.2.1353

[48]. Lestari, P. D., Baiduri, B., & Ummah, S. K. (2024). Problem-based learning with iSpring assisted inquiry method on critical thinking skills. *Journal of Education and Learning (EduLearn)*, *18*(1), 148-153. Doi: 10.11591/edulearn.v18i1.21089

[49]. Marcinauskas, L., et al. (2024). Problem-based learning versus traditional learning in physics education for engineering program students. *Education Sciences*, *14*(2), 154. Doi:10.3390/educsci14020154

[50]. Pashchenko, T. V. (2024). Critical Thinking Development in Adult Learners through Problem-Based Learning in an Online Setting. *Voprosy obrazovaniya/Educational Studies Moscow*, (2). Doi:10.17323/vo-2024-16699

[51]. Naatonis, R. N., et al. (2024). Evaluation of Problem Based Gamification Learning (PBGL) Model on Critical Thinking Ability with Artificial Intelligence Approach Integrated with ChatGPT API: An Experimental Study. *Qubahan Academic Journal*, *4*(3), 485-520. Doi:10.48161/qaj.v4n3a919

[52]. Suprapto, N., Rizki, I. A., & Cheng, T. H. (2024). Profile of Students' Physics Critical Thinking Skills and Prospect Analysis of Project-Oriented Problem-Based Learning Model. *Journal of Educational and Social Research*, *14*(3), 134. Doi:10.36941/jesr-2024-0062

[53]. Amanda, F. F., et al. (2024). Enhancing critical thinking and problem solving skills by complexity science-problem based learning model. *REMIE: Multidisciplinary Journal of Educational Research*, *14*(1), 96-114. Doi:10.17583/remie.9409

[54]. Pertiwi, N. P., et al. (2024). Enhancing Critical Thinking Skills through STEM Problem-Based Contextual Learning: An Integrated E-Module Education Website with Virtual Experiments. *Journal of Baltic Science Education*, *23*(4), 739-766. Doi:10.33225/jbse/24.23.739

[55]. Nicholus, G., Nzabahimana, J., & Muwonge, C. M. (2024). Evaluating video-based PBL approach on performance and critical thinking ability among Ugandan form-2 secondary school students. *Cogent Education*, *11*(1), 2346040. Doi:10.1080/2331186X.2024.2346040

[56]. Schaller, M. D., et al. (2023). Training doctoral students in critical thinking and experimental design using problem-based learning. *BMC medical education*, *23*(1), 579. Doi:10.1186/s12909-023-04569-7

[57]. Susanti, M., et al. (2023). Problem-Based Learning for Improving Problem-Solving and Critical Thinking Skills: A Case on Probability Theory Course. *Journal of Education and Learning (EduLearn)*, *17*(4), 507-525. Doi:10.11591/edulearn.v17i4.20866

[58]. Santos-Meneses, L. F., Pashchenko, T., & Mikhailova, A. (2023). Critical thinking in the context of adult learning through PBL and e-learning: A course framework. *Thinking Skills and Creativity*, *49*, 101358. Doi:10.1016/j.tsc.2023.101358

[59]. Suradika, A., Dewi, H. I., & Nasution, M. I. (2023). Project-based learning and problem-based learning models in critical and creative students. *Jurnal Pendidikan IPA Indonesia*, *12*(1), 153-167. Doi:10.15294/jpii.v12i1.39713

[60]. Muhfahroyin, M., et al. (2023). Improving Critical Thinking of Low Ability Students through TPS and PBL Integration in Biology Learning. *Journal of Turkish Science Education*, *20*(4), 606-618. Doi:10.36681/tused.2023.034

[61]. Salazar, L. M., Díaz, M. H. R., & Slisko, J. (2023). Critical thinking development in physics courses by PBL in virtual collaboration environments. *International Journal of Innovation in Science and Mathematics Education*, *31*(4). Doi:10.30722/IJISME.31.04.003

[62]. Tursynkulova, E., Madiyarov, N., Sultanbek, T., & Duysebayeva, P. (2023, December). The effect of problem-based learning on cognitive skills in solving geometric construction problems: a case study in Kazakhstan. In *Frontiers in Education*, *8*, 1284305. Doi:10.3389/feduc.2023.1284305

[63]. Nunaki, J. H., et al. (2023). Encouraging students' critical thinking using problem-based book integrated daily problems and solutions about environmental pollution. *Journal of Curriculum and Teaching*, *12*(6), 218-229. Doi:10.5430/jct.v12n6p218

[64]. Taşoğlu, A. K., & Bakaç, M. (2023). Probleme dayalı öğrenme yaklaşımının öğrencilerin akademik başarı ve eleştirel düşünme becerilerine etkisi. *Milli Eğitim Dergisi*, *52*(238), 855-884. Doi:10.37669/milliegitim.1086365

[65]. Hidajat, F. A. (2023). A comparison between problem-based conventional learning and creative problem-based learning on self-regulation skills: Experimental study. *Heliyon*, *9*(9). Doi:10.1016/j.heliyon.2023.e19512

[66]. Amanda, F. F., et al. (2022). The correlation of critical thinking and concept mastery to problem-solving skills: The role of complexity science-problem based learning model. *Pedagogika/Pedagogy*, *146*(2), 80-94. Doi:10.15823/p.2022.146.4

[67]. Muvid, M. B., et al. (2022). Shaping socio-critical thinking of junior students using problem-based learning and inquiry strategy. *International Journal of Evaluation and Research in Education (IJERE)*, *11*(2), 780. Doi:10.11591/ijere.v11i2.21954

[68]. Marthaliakirana, A. D., et al. (2022). Problem-based learning with metacognitive prompts for enhancing argumentation and critical thinking of secondary school students. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(9), 1-15. Doi:10.29333/ejmste/12304

[69]. Cahyono, B., et al. (2021). Problem-Based Learning Supported by Arguments Scaffolding That Affect Critical Thinking Teacher Candidates. *Cypriot Journal of Educational Sciences*, *16*(6), 2956-2969. Doi:10.18844/cjes.v16i6.6480

[70]. Hidayati, N., Zubaidah, S., & Amnah, S. (2022). The PBL vs. digital mind maps integrated PBL: Choosing between the two with a view to enhance learners' critical thinking. *Participatory Educational Research*, *9*(3), 330-343. Doi:10.17275/per.22.69.9.3

[71]. Hursen, C. (2021). The effect of problem-based learning method supported by web 2.0 tools on academic achievement and critical thinking skills in teacher education. *Technology, Knowledge and Learning*, *26*(3), 515-533. Doi:10.1007/s10758-020-09458-2

[72]. Suryanti, N., & Nurhuda, N. (2021). The Effect of Problem-Based Learning with an Analytical Rubric on the Development of Students' Critical Thinking Skills. *International Journal of Instruction*, *14*(2), 665–684. Doi:10.29333/iji.2021.14237a

[73]. Çeliker, H. D. (2021). Problem-Based Scenario Method with Experiments: Determining the Prospective Science Teachers' Biology Self-Efficacy and Critical Thinking Tendency. *Science Education International*, *32*(1), 23-33. Doi:10.33828/sei.v32.i1.3

[74]. Mardi, M., Fauzi, A., & Respati, D. K. (2021). Development of Students' Critical Thinking Skills Through Guided Discovery Learning (GDL) and Problem-Based Learning Models (PBL) in Accountancy Education. *Eurasian Journal of Educational Research*, *95*(2021), 210–226. Doi:10.14689/ejer.2021.95.12

[75]. Suhirman, S., Prayogi, S., & Asy'ari, M. (2021). Problem-Based Learning with Character-Emphasis and Naturalist Intelligence: Examining Students Critical Thinking and Curiosity. *International Journal of Instruction*, *14*(2), 217–232. Doi:10.29333/iji.2021.14213a

[76]. Saputro, A. D., et al. (2020). Enhancing pre-service elementary teachers' self-efficacy and critical thinking using problem-based learning. *European Journal of Educational Research*, *9*(5), 765-773. Doi:10.12973/eu-jer.9.2.765

[77]. Putranta, H., Jumadi, & Wilujeng, I. (2019). Physics learning by PhET simulation-assisted using problem-based learning (PBL) model to improve students' critical thinking skills in work and energy chapters in MAN 3 Sleman. *Asia-Pacific Forum on Science Learning and Teaching*, *20*(1), 1–44.

[78]. Thompson, C. C. (2019). Advancing critical thinking through learning issues in problem-based learning. *Medical Science Educator*, *29*, 149-156. Doi:10.1007/s40670-018-00649-2

[79]. Hidayati, N., et al. (2019). Examining the Relationship between Creativity and Critical Thinking through Integrated Problem-based Learning and Digital Mind Maps. *Universal Journal of Educational Research*, *7*(9A), 171–179. Doi:10.13189/ujer.2019.071620

[80]. Al-Said, K., et al. (2024). The impact of video-based virtual reality training on critical thinking and cognitive load. *International Journal of Evaluation and Research in Education*, *13*(5), 32–39. Doi:10.11591/ijere.v13i5.28109

[81]. Li, Y., et al. (2020). Cultivation of the students' critical thinking ability in numerical control machining course based on the virtual simulation system teaching method. *IEEE Access*, *8*, 173584-173598. Doi:10.1109/ACCESS.2020.3025079

[82]. Faridi, H., et al. (2021). A framework utilizing augmented reality to improve critical thinking ability and learning gain of the students in Physics. *Computer Applications in Engineering Education*, *29*(1), 258-273. Doi:10.1002/cae.22342

[83]. Badriyah, N. L., Yusuf, M., & Efendi, A. (2023). Augmented Reality as a Media for Distance Learning in the Digital Era: Contribution in Improving Critical Thinking Skills. *International Journal of Information and Education Technology*, *13*(11), 1769–1775. Doi:10.18178/ijiet.2023.13.11.1988

[84]. Ibrahim, A. M., et al. (2024). Enhancing High School Students' Future Thinking Skills through Interactive Digital Platforms for Teaching Energy Issues. *International Journal of Interactive Mobile Technologies*, *18*(9). Doi:10.3991/ijim.v18i09.48879

[85]. Arymbekov, B., Turekhanova, K., & Turdalyuly, M. (2024). The Effect of Augmented Reality (AR) Supported Teaching Activities on Academic Success and Motivation to Learn Nuclear Physics among High School Pupils. *International Journal of Information and Education Technology*, *14*(5), 743-760. Doi:10.18178/ijiet.2024.14.5.2099

[86]. Song, Y. A., & Kim, M. (2023). Effects of a virtual reality simulation integrated with problem-based learning on nursing students' critical thinking ability, problem solving ability, and self-efficacy: A non-randomized trial. *Korean Journal of Women Health Nursing*, *29*(3), 229–238. Doi:10.4069/kjwhn.2023.09.12

[87]. Febliza, A., Afdal, Z., & Copriady, J. (2023). Improving Students' Critical Thinking Skills: Is Interactive Video and Interactive Web Module Beneficial?. *International Journal of Interactive Mobile Technologies*, *17*(3). Doi:10.3991/ijim.v17i03.34699

[88]. Meirbekov, A., Maslova, I., & Gallyamova, Z. (2022). Digital education tools for critical thinking development. *Thinking Skills and Creativity*, *44*, 101023. Doi:10.1016/j.tsc.2022.101023

[89]. Verawati, N. N. S. P., Ernita, N., & Prayogi, S. (2022). Enhancing the reasoning performance of STEM students in modern physics courses using virtual simulation in the LMS platform. *International Journal of Emerging Technologies in Learning (iJET)*, *17*(13), 267-277. Doi:10.3991/ijet.v17i13.31459

[90]. Ikhsan, J., Sugiyarto, K. H., & Astuti, T. N. (2020). Fostering Student's Critical Thinking through a Virtual Reality Laboratory. *International Journal of Interactive Mobile Technologies (iJIM)*, *14*(8), 183–195. Doi:10.3991/ijim.v14i08.13069

[91]. Hasyim, F., Prastowo, T., & Jatmiko, B. (2020). The Use of Android-Based PhET Simulation as an Effort to Improve Students' Critical Thinking Skills during the Covid-19 Pandemic. *International Journal of Interactive Mobile Technologies (iJIM)*, *14*(19), 31–41. Doi:10.3991/ijim.v14i19.15701

[92]. Wahyuni, S., Erman, E., Sudikan, S., & Jatmiko, B. (2020). Edmodo-Based Interactive Teaching Materials as an Alternative Media for Science Learning to Improve Critical Thinking Skills of Junior High School Students. *International Journal of Interactive Mobile Technologies (iJIM)*, *14*(9), 166. Doi:10.3991/ijim.v14i09.13041

[93]. Astuti, T. N., Sugiyarto, K. H., & Ikhsan, J. (2020). Effect of 3D Visualization on Students' Critical Thinking Skills and Scientific Attitude in Chemistry. *International Journal of Instruction*, *13*(1), 151-164. Doi:10.29333/iji.2020.13110a

[94]. MacDonald, A. (2020). Mathematics education beliefs and practices of Under 3s educators in Australia. *European Early Childhood Education Research Journal*, *28*(5), 758-769. Doi:10.1080/1350293X.2020.1817246

[95]. Romero Ariza, M., Quesada Armenteros, A., & Estepa Castro, A. (2024). Promoting critical thinking through mathematics and science teacher education: the case of argumentation and graphs interpretation about climate change. *European Journal of Teacher Education*, *47*(1), 41-59. Doi:10.1080/02619768.2021.1961736

[96]. Şendağ, S., & Odabaşı, H. F. (2009). Effects of an online problem based learning course on content knowledge acquisition and critical thinking skills. *Computers & education*, *53*(1), 132-141. Doi:10.1016/j.compedu.2009.01.008

[97]. Ismail, N. S., et al. (2018). The effect of Mobile problem-based learning application DicScience PBL on students' critical thinking. *Thinking Skills and Creativity*, *28*, 177-195. Doi:10.1016/j.tsc.2018.04.002

[98]. Mangiduyos, G. P., & Subia, G. S. (2021). Twenty-First (21st) century skills of college of education alumni. *Open Journal of Social Sciences*, *9*(9), 330-337. Doi:10.4236/jss.2021.99023

[99]. Smith, E. M. (2021). Assistive technology research: Evidence for a complex and growing field. *Assistive Technology*, *33*(4), 177-177. Doi:10.1080/10400435.2021.1958650

[100]. Bedetti, B., Bertolaccini, L., Patrini, D., Schmidt, J., & Scarci, M. (2018). Virtual simulation and learning new skills in video-assisted thoracic surgery. *Video-Assisted Thoracic Surgery*, *3*. Doi:10.21037/vats.2018.08.03

[101]. Zhang, N., et al. (2021). Development and application of digital assistive teaching system for anatomy. *Virtual Reality & Intelligent Hardware*, *3*(4), 315-335. Doi:10.1016/j.vrih.2021.08.005

[102]. Fan, X., Geelan, D., & Gillies, R. (2018). Evaluating a novel instructional sequence for conceptual change in physics using interactive simulations. *Education Sciences*, *8*(1), 29. Doi:10.3390/educsci8010029

[103]. Toli, G., & Kallery, M. (2021). Enhancing student interest to promote learning in science: The case of the concept of energy. *Education Sciences*, *11*(5), 220. Doi:10.3390/educsci11050220

[104]. Cowan, P., & Farrell, R. (2023). Using Virtual Reality to Support Retrieval Practice in Blended Learning: An Interdisciplinary Professional Development Collaboration between Novice and Expert Teachers. *Digital*, *3*(3), 251-272. Doi:10.3390/digital3030016

[105]. Villegas-Ch, W., & García-Ortiz, J. (2023). Enhancing learning personalization in educational environments through ontology-based knowledge representation. *Computers*, *12*(10), 199. Doi:10.3390/computers12100199

[106]. Pramila-Savukoski, S., et al. (2023). Competence development in collaborative hybrid learning among health sciences students: A quasi-experimental mixed-method study. *Journal of Computer Assisted Learning*, *39*(6), 1919-1938. Doi:10.1111/jcal.12859

[107]. Joyce, B. R., Weil, M., & Calhoun, E. (2009). *Models of Teaching*. Pearson/Allyn and Bacon Publishers.

[108]. Woolfolk, A. (2019). *Educational Psychology: Active Learning Edition* (14th ed.). Pearson.

[109]. Edgerton, E., & McKechnie, J. (2023). The relationship between student's perceptions of their school environment and academic achievement. *Frontiers in Psychology*, *13*, 959259. Doi:10.3389/fpsyg.2022.959259

[110]. Wang, C. C. (2021). The process of implementing problem-based learning in a teacher education programme: an exploratory case study. *Cogent Education*, *8*(1), 1996870. Doi:10.1080/2331186X.2021.1996870

[111]. Saija, M., & Tahya, D. (2023). Can the Ethnoscience-Based Inquiry Learning Model Improve Students' Science Process Skills? *Molluca Journal of Chemistry Education (MJoCE)*, *13*(1), 40–46. Doi:10.30598/MJoCEvol13iss1pp40-46

[112]. Arends, R. (2014). *Learning to teach* (10th ed). McGraw-Hill.

[113]. Zidny, R., & Eilks, I. (2022). Learning about pesticide use adapted from ethnoscience as a contribution to green and sustainable chemistry education. *Education Sciences*, *12*(4), 227. Doi:10.3390/educsci12040227

[114]. Dogruer, S. S., & Akyuz, D. (2020). Mathematical practices of eighth graders about 3D shapes in an argumentation, technology, and design-based classroom environment. *International Journal of Science and Mathematics Education*, *18*(8), 1485-1505. Doi:10.1007/s10763-019-10028-x

[115]. Sıburıan, J., Corebıma, A. D., & Saptasarı, M. (2019). The correlation between critical and creative thinking skills on cognitive learning results. *Eurasian Journal of Educational Research*, *19*(81), 99-114. Doi:10.14689/ejer.2019.81.6

[116]. Ennis, R. H. (2018). Critical thinking across the curriculum: A vision. *Topoi*, *37*, 165-184. Doi:10.1007/s11245-016-9401-4

[117]. Procter, L. (2020). Fostering critically reflective thinking with first-year university students: Early thoughts on implementing a reflective assessment task. *Reflective Practice*, *21*(4), 444-457. Doi:10.1080/14623943.2020.1773421

[118]. Akpur, U. (2020). Critical, reflective, creative thinking and their reflections on academic achievement. *Thinking Skills and Creativity*, *37*, 100683. Doi:10.1016/j.tsc.2020.100683

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