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A BIBLIOMETRIC STUDY of MODELS FOSTERING CRITICAL THINKING, COMMUNICATION, CREATIVITY, AND COLLABORATION SKILLS

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Abstract: This study aims to explore instructional models that foster 21st-century skills in secondary school physics education, focusing on critical thinking, communication, creativity, and collaboration. A bibliometric analysis was conducted on 142 publications from the past decade, utilising tools such as VOSviewer to identify dominant learning approaches, including Project-Based Learning (PjBL), guided inquiry, and STEM education. The results indicate that while STEM education significantly influences physics learning, specific research in this area remains limited. Key findings reveal the effectiveness of collaborative teaching methods, digital tools, and tailored interventions in enhancing students' practical application of these skills. This research provides valuable insights for educators and researchers seeking to cultivate essential physics education competencies, addressing the educational landscape's evolving demands.

Keywords: 21st-century-skills, STEM, physics, PjBL, bibliometric

INTRODUCTION

In the education landscape, "21st-century skills" have become essential for addressing the demands of a rapidly changing world. In 1997, the National Academy of Sciences in the United States reported outlined educational challenges for the upcoming century, emphasising critical skills necessary for life success [1]. Among these skills, the most important is having a sound background in science, technology, engineering and mathematics (STEM). Furthermore, soft skills such as cultural competency, critical thinking, collaboration, and problem-solving are recognised as vital components of modern education. Over subsequent decades, various reports have further refined these essential skills to prepare students for success in an increasingly competitive global marketplace. This evolution underscores the importance of academic knowledge and the pressing need for educators to integrate these skills into their curricula effectively.

Rotherham & Willingham [2] argue that while these skills are not new, the changing economy necessitates improved curricula, enhanced teaching methods, and more effective assessments. Larson & Miller [3] emphasise that these competencies must be woven into all aspects of the curriculum rather than taught in isolation. The learning environment significantly influences students' skill development. Research by Khoiri et al. [4] indicates that while rural students tend to excel in collaborative tasks, urban students outperform their peers in creativity and communication; however, no significant differences were observed in critical thinking abilities across these groups. Consequently, the National Education Association has identified critical thinking, creativity, communication, and collaboration—collectively known as the "4Cs"—as essential competencies for modern education (National Education Association). Critical thinking is defined by Sudarmin [5] as a reflective process that engages cognitive resources to make informed decisions aimed at achieving specific objectives. Understanding these distinctions is crucial for tailoring educational strategies to meet diverse student needs effectively.

Sihotang et al. [6] describe critical thinking as an active and thorough consideration of beliefs or knowledge supported by strong reasoning and sound conclusions. Suryati [7] emphasises that a fundamental aspect of critical thinking lies in providing justifiable reasons that underpin conclusions drawn from the analysis. This understanding underscores the importance of teaching students to reach the findings and articulate and defend their reasoning processes effectively. Conversely, creative thinking involves examining problems or situations from multiple perspectives—a skill developed through unstructured methods like brainstorming and structured approaches such as heuristic programs [8]. According to Meika & Sujana [9], creative thinking encompasses four dimensions known as "the Four P's of Creativity": Person (individuals with unique ideas), Product (the creation of original and valuable outputs), Process (reflective thinking skills including fluency and originality), and Press (external factors that stimulate creative thought). This multifaceted view highlights how creativity can be nurtured through targeted educational strategies. Creativity as a person means that humans have unique thoughts. Creativity as a product can produce new, original and valuable creations. Creativity as a process of reflecting thinking skills includes fluency, flexibility, originality, and elaboration. Creativity as a press is a factor that encourages creative thinking.

Collaboration is a cooperative process where individuals work together harmoniously while coordinating their efforts to achieve shared goals through positive interdependence within a group [10]. Belousova [11] further elaborates on this concept by stating that collaboration fundamentally involves individual interaction. This interaction fosters teamwork and enhances individual accountability within group settings. These revisions enhance clarity by addressing weaknesses identified earlier while maintaining coherence

within each paragraph's context. Every human has a unique personality, seen in their daily activities. By interacting, someone will realise themselves to discover and develop new things, channelling the positive things they have to their collaborative partner. According to research Warsah et al. [12], using collaboration skills in learning has been proven to positively and significantly impact student's critical thinking abilities because collaborative learning requires emotional awareness, learning motivation, and cognitive and open-mindedness.

In the meantime, Communication skills encompass the ability to effectively convey thoughts, ideas, knowledge, and new information using various modalities—including oral presentation, written communication, symbols, graphics, or numerical data [13]. Learning activities are inherently intertwined with communication; thus, the quality of communication directly influences student engagement during the learning process. Maryanti et al. [14] suggest that poor communication can decrease student motivation regarding their studies. These revisions enhance clarity by addressing weaknesses identified earlier while maintaining coherence within each paragraph's context. Teacher communication skills are essential in student academic achievement [15]. Bao and Koenig asserted that future research in the twenty-first century should incorporate well-defined education and research objectives, including reasoning, creativity, and open problem-solving skills [16].

While previous research has explored the integration of 21st-century skills in education and the use of bibliometric analysis in various fields, there is a need for a comprehensive analysis of the specific trends and dominant instructional models in physics education. This study aims to fill this gap by providing a bibliometric analysis of publications in physics education, focusing on the instructional models used to foster 21st-century skills. This analysis offers valuable insights into the current state of research and identifies potential areas for future investigation, thereby informing educators and researchers in their efforts to cultivate these essential skills in physics education.

The remainder of this paper is structured as follows. The next section reviews relevant literature on 21st-century skills, learning models, and bibliometric analysis. This is followed by a description of the methodology used, including the data collection and analysis procedures. The results of the bibliometric analysis will then be presented, followed by a discussion of the findings and their implications. Finally, the conclusion summarises the key findings and provides recommendations for future research

RESEARCH METHODS

This study employed a bibliometric analysis to systematically map the landscape of scholarly literature on instructional models enhancing 21st-century skills in physics education.

1. Data Collection:

   The data collection process commenced with a search from 2013 to 2023 from scopus.com. The first search was delimited by two key terms, "21st-century skills" and "education", and was restricted to only articles. The initial search yielded a total of 1,459 publications. Subsequently, the search was further narrowed down to the field of physics and astronomy, resulting in 142 publications relevant to the scope of the study. For each document retained, the researchers extracted bibliometric metadata encompassing publication year, citation count, affiliations, country of origin, journal details, cited references, document title, abstract, and keywords.
2. Data Analysis

   The subsequent data analysis involved frequency calculations utilising VOSViewer version 1.6.20. This software is one of the AI tools Ludo Waltman and Nees Jan van Eck developed at Leiden University's Center for Science and Technology Studies (CWTS). Documents saved in RIS type are then imported into VOSViewer to visualise the document according to the needs. The 142 publications were then subject to a detailed manual analysis, focusing on aspects such as authorship, utilised pedagogical models, enhanced aspects of 21st-century skills, research outcomes, studied objects, countries of origin, and citation counts. This in-depth analysis aimed to uncover patterns, identify potential areas of novelty and provide insights into the current state of research on the specified topic. By employing rigorous bibliometric methods and leveraging advanced visualisation tools, this study seeks to contribute to a comprehensive understanding of the evolving landscape of educational research to foster 21st-century skills, particularly within the domain of physics education.

RESULT AND DISCUSSION

The analysis of the dataset, comprising 246 relevant items on 21st-century skills, reveals a diverse research landscape categorised into 11 distinct clusters, each differentiated by varying colours, forming a collaborative network with a total of 4,630 links and a cumulative link strength of 10,886 based on Figure 1.

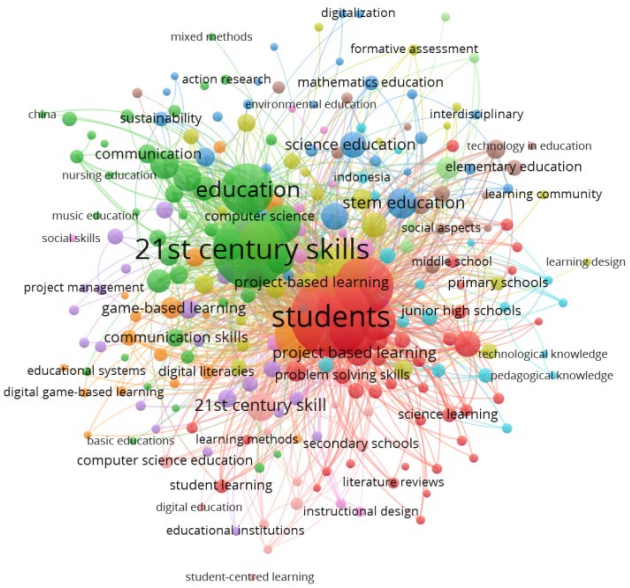

Figure 1. The 1st searching topics correlation based on "21st century skills & education" keywords

Based on Figure 1, the most prominent research areas related to 21st-century skills are clustered around two central themes. In VOSviewer bibliometric analysis, a cluster refers to a group of related items that share common characteristics or themes, such as publications, authors, or keywords. Cluster 1 focuses on studies involving students, while Cluster 2 concentrates on their skills. This evidences these respective clusters' most significant and interconnected circles. Research on 21st-century skills is evenly distributed across various educational domains, including technical education, science education, mathematics education, education policy, computer science education, physics education, nursing education, and music education. The studied subjects encompass elementary to high school students, university students, and teachers.

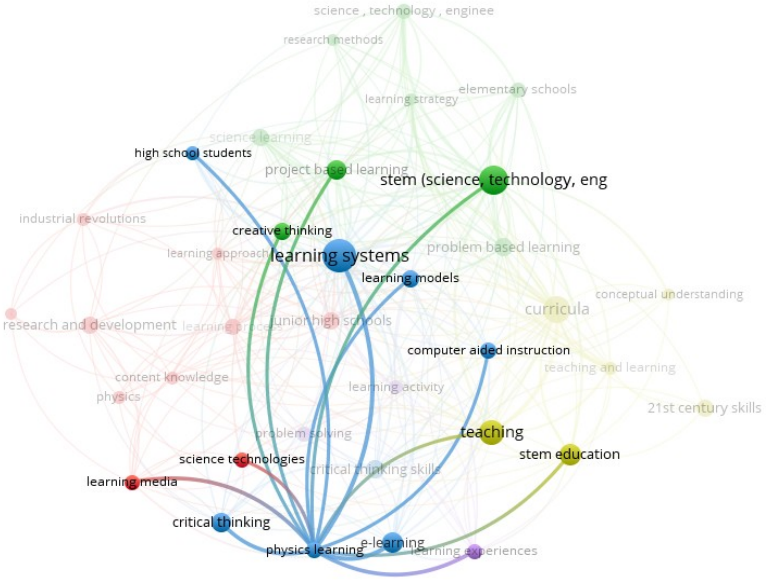

Figure 2. The topic research's correlation of 21st-century skills in physics education, particularly

Examining the research landscape, specifically within the realm of physics education, from Figure 2, studies addressing 21st-century skills in this context are relatively scarce compared to other educational fields. However, it is shown that physics education is prominently linked to two competencies of 21st-century skills: critical thinking and creative thinking. These two skills are still in the early stages of exploration, as indicated by the comparatively smaller circles compared to others.

To enhance 21st-century skills, researchers frequently employ instructional models. Project-based learning, problem-based learning (PBL), and Science, Technology, Engineering, and Mathematics (STEM) are the most extensively researched models associated with physics learning and 21st-century skills. As Stehle and Peters-Burton propose that inclusive STEM high schools create atmospheres conducive to fostering the growth of 21st-century skills [17].

This discussion sheds light on the existing research landscape, highlighting the predominant clusters, interconnectedness, and thematic concentrations within the broader context of 21st-century skills. It also underlines the need for further exploration of these skills within the domain of physics education, emphasising the significance of models like project-based learning and STEM in shaping the educational trajectory towards fostering these crucial skills. Among the four 21st-century skills, research on critical and creative thinking skills predominates, followed by studies of communication and collaboration skills.

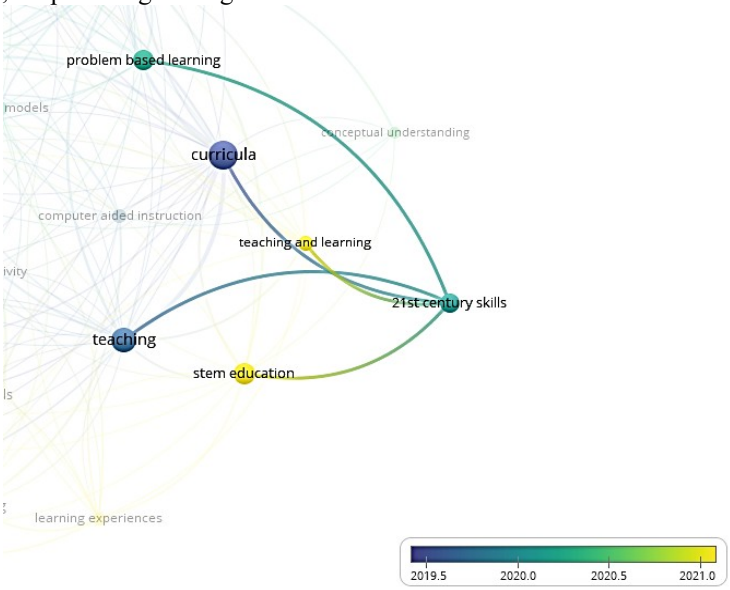

Figure 3. Overlay visualisation in physics education subject

In terms of recent trend research topics, Figure 3 illustrates that research on 21st-century skills is supported by instructional models such as PBL, curricula, and teaching processes, with the latest trend being the STEM method. However, in other clusters, Project-Based Learning (PBL) is strongly associated with 21st-century skills, specifically critical thinking and creative thinking, as evident in Figure 4. PBL is often elaborated by incorporating learning media and science technologies to enhance students' proficiency in learning physics.

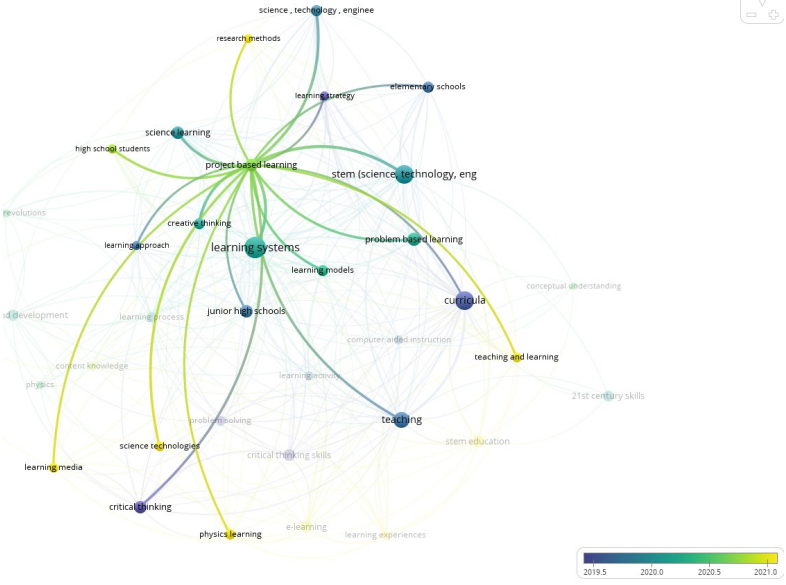

Figure 4. Project-based learning to enhance 21st-century skills

The reviewed studies collectively from Table 1 contribute to understanding diverse strategies to enhance STEM competencies and 21st-century skills in educational settings worldwide, especially in Indonesia. The findings suggest that while some initiatives, like the STEMC learning approach in Aceh, Indonesia, show promise in developing holistic skills, others, such as the inquiry learning model in Indonesia, reveal moderate gains in critical thinking abilities among elementary school students [18]. Challenges persist, as evidenced by identified weaknesses in the application of technology by science

teachers in Bandung, Indonesia, Hikmawati & Gaffar [19] emphasising the need for targeted interventions.

Furthermore, the studies advocate for a holistic approach, incorporating cultural elements into education, as seen in the integrated science and culture education model in Malang, Indonesia [20], [21]. This approach, coupled with the effective use of technology, is showcased in the TPACK application among mathematics teachers in Indonesia. While there is notable progress, continuous support for pre-service teachers, as recommended in Thailand, remains crucial for sustainable development [22]. The research emphasises the importance of context-specific interventions, technological integration, and ongoing support systems in nurturing well-rounded skills for educators and students in diverse educational landscapes.

The presented studies reflect a multifaceted approach to improving STEM competencies and 21st-century skills among educators and students across diverse educational contexts. Notably, the impact of STEM teaching during the COVID-19 pandemic in Thailand suggests the potential of professional learning communities to enrich both teacher and student competencies [23]. Similarly, research on chemistry teachers' application of 21st-century skills in Indonesia shows a commendable average application level, emphasising the importance of skill integration in subject-specific domains. Furthermore, the incorporation of innovative technologies such as Android, VR, AR, and coding in ICT learning in Greece demonstrates an evolving trend in educational strategies [24].

Additionally, the studies underscore persistent challenges, such as the need for scaffolding strategies to enhance scientific argumentation skills among biology teacher students in Indonesia and the identified weaknesses in community activities for science teachers in Bandung [19]. Recommendations include leveraging project-based learning, digital teaching materials, and e-modules to address these challenges and foster critical thinking, creativity, and collaboration. The research highlights the significance of tailored educational interventions, technological integration, and collaborative learning models in advancing STEM competencies and 21st-century skills in diverse academic settings.

Table 1. Summary of Physics and 21st-Century Skills Studies

No	Learning Model	Aims	Results	Reference	Education Focus	Country
1.	Impact of STEM Teaching and STEM Competencies related to the COVID-19 pandemic on the subject of work and energy	STEM Competencies & 21st-century skills	Four teachers did STEM teaching competencies at the average level, and three were below average. 64.4% have STEM competencies at the Growing. 24.5% at the Perfect. This implies that a professional learning community can help enrich STEM competencies, including 21st-century skills for teachers and students.	[23]	7 teachers & 45 students from an Islamic private high school	Thailand
2.	Examining the application of chemistry teachers' 21st-century skills in learning activities at school	Improving teachers' 21st-century skills	The average application of 21st-century skills is very good, with an average percentage of 81.86%.	[25]	80 alumni from the Chemistry Education Department of Universitas Islam Negeri Syarif Hidayatullah	Jakarta, Indonesia
3.	STEM in ICT learning using Android, VR, AR, and coding	Critical Thinking	The trend in ICT education involves using Android, VR, AR, and coding. The learning strategies include distance learning, programming teaching, and STEM.	[24]	Students	Greece
4.	Proposing scaffolding strategies to improve the	Scientific Argumentation Skills (SAS)	The number of components of argumentation for prospective biology	[19]	20 biology education students	Bandung, Indonesia

No	Learning Model	Aims	Results	Reference	Education Focus	Country
	quantity and quality of scientific argumentation skills (SAS)		teachers is still small. Their capacity to provide data, assurances, and support claims is also small. Hence, different types of scaffolding can be explored for further research.			
5.	Launching the "Science, Technology, Engineering, Mathematics, and Character (STEMC)" learning approach	Critical thinking, computational thinking, collaboration, communication, creativity, and character	Developing "STEMC" modules for senior high school and joining up with "State Owned Enterprises (BUMN)" in teacher professional development programs to enhance students' scientific abilities, perseverance, and motivation. STEM Center at Syiah Kuala University also plans to implement STEMC in Indonesia.	[18]	High school	Aceh, Indonesia
6.	Analysis of biotechnology learning processes. Learning to equip prospective biology teacher students	Ability to apply, develop, and disseminate knowledge and technology professionally	The UNPAS Biology Education Study Program still uses classical learning methods with a teaching-centered learning system. However, instructors are already using scientific methods, the PPA model, and Microsoft PowerPoint with animation videos, indicating the potential for improving the quality of the learning process.	[26]	38 students and 2 instructors	Bandung, Indonesia
7.	Integrated Science and Culture Education	21st Century Skills	Enhances 21st-century skills. Three strategies for developing integrated science and culture education are general, embedded, and blended learning. These strategies have been utilised to develop the Problem-Based Learning model Dalihan Na Tolu by the Batak culture, the RANDAI Learning Model by the Minangkabau culture, and the Tudang Sipulung model by the Bugis Makassar culture.	[20]	Junior high school students	Malang, Indonesia
8.	Technological Pedagogical	21st Century Skills & Digital	The role of teachers is highlighted in developing	[27]	Mathematics Teachers	Indonesia

No	Learning Model	Aims	Results	Reference	Education Focus	Country
	Content Knowledge (TPACK)	Literacy improvement	these competencies of 21st Century Skills from early education, with a focus on the implementation of technological pedagogical content knowledge (TPACK)			
9.	STEM & the Use of Arduino Applications for Experiments	Improving 21st Century Skills utilizing STEM education	Its emphasis on practicality and affordability showcases the potential for widespread classroom application, contributing significantly to STEM education and 21st-century skill development.	[28]	Physics Education	Turkey
10.	Profile of Community Activities for Science Teachers, Strengths to Limitations	Descriptions of activity in the Science Teacher Community, from superiority to restrictions related to developing 21st-century skills.	Respondents demonstrated weak lines in the subject (particularly in physics), pedagogical practices about developing 21st-century skills, and management, along with shortcomings in utilising information technology (IT).	[29]	38 science teachers in the city	Bandung, Indonesia
11.	Descriptive research based on Questionnaire	Gathering Student Perspectives on Science Learning Media to prepare student with 21st-Century Skill	Students need science learning media to help them get to know science materials, mainly tricky topics such as the human digestive system, the classification of living things, and the human muscular and skeletal systems. Students need an integrated science education learning media package. Visual and audiovisual media are used in science learning. In particular, students hope multimedia can be used in some science topics.	[30]	Junior high school	Yogyakarta, Indonesia
12.	Need for Suitable Teaching Materials for the 21st Century	Developing digital teaching materials through analysis of physical learning materials, curriculum analysis, and student analysis.	Digital e-module teaching materials are developed using the Creative Problem Solving model to improve 21st-century skills.	[31]	54 students	Padang, Indonesia

No	Learning Model	Aims	Results	Reference	Education Focus	Country
13.	E-learning for 21st Century Skills	Provides opportunities to enhance 21st-century skills through e-learning.	E-learning is recommended for meeting diverse student needs and improving motivation, learning experience, and outcomes. It also provides opportunities to enhance 21st-century skills.	[32]	Senior high school and university students	Jakarta, Indonesia
14.	Integrated Science Teaching Material based on the CPS Model	Critical thinking, creative skills, and anti-corruption character are emphasised.	The Creative Problem Solving model is recommended to enhance student creativity and instil anti-corruption values in the classroom. The Creative Problem Solving model enhances student creativity by guiding them through systematic problem-solving steps. Anti-corruption values are embedded in the classroom to contribute to a corruption-free Indonesia.	[33]	Junior high school students	Padang, Indonesia
15.	STEM Teaching Capacity assessment	Prospective teachers to conceptualise STEM aspects	Prospective teachers need further support in designing and teaching STEM lessons, improving assessment skills, and embracing diversity.	[34]	57 pre-service chemistry teachers	Vietnam
16.	E-Module with STEM PBL learning model for Critical Thinking	Students who lack critical thinking skills in each aspect.	Develop an electronic module based on STEM PBL to improve students' critical thinking skills.	[35]	1 chemistry teacher and 75 students	Solo, Indonesia
17.	Project Based Learning	Improves 21st-century skills and learning outcomes using Project-based learning	The longer the project duration, the better the improvement in 21st-century skills and learning outcomes.	[21]	Vocational high school students	Malang, Indonesia
18.	Describing Students' Problem-Solving Ability in Sine Rule Problems	Some students that is struggle to comprehend and plan problem-solving methods.	Students need improvement in comprehending and planning effective problem-solving methods.	[36]	34 senior high school students	Bandung, Indonesia
19.	STEM Competence in Pre-Service Science Teachers	Pre-service teachers	Recommendations include continuous support for pre-service teachers in integrating STEM and improving their teaching practices.	[22]	10 pre-service science teachers	Thailand
20.	Creative Learning Cycle Method for 21st-Century	The creative learning cycle, developed by	The creative learning cycle method significantly enhances	[37]	Primary school students	Bandung, Indonesia

No	Learning Model	Aims	Results	Reference	Education Focus	Country
	Skills enhancement	Mitchel Resnick, to increase 21st-century skills.	21st-century skills by 38.1%. Five stages include Imagine, Reflect, Share, Play, and Create.			
21.	Integrating Computational Thinking and Robotic Education into PBL	Project-based learning using ScratchTM programming improves 21st-century skills, specifically computational thinking.	Implementing project-based learning with ScratchTM programming enhances 21st-century skills and computational thinking.	[38]	160 high school students	Spain
22.	Guided Inquiry Learning Model	Enhancing senior high school students' 21st-century skills in learning physics.	A guided inquiry learning model is recommended for improving high school students' 21st-century skills in physics subject.	[39]	High school students	Padang, Indonesia
23.	RnD teaching medium for Improving 21st Century Skills	enhancing critical thinking, collaboration, creativity and communication skills by utilising E-books	The developed e-books in schools could improve students' 21st-century skills.	[40]	High school students	Padang, Indonesia
24.	Problem-Based Learning Integration for 21st Century Skills	Improving students' 21st-century skills.	Integration of PBL in teaching and learning sessions significantly enhances 21st-century skills.	[41]	University students	Malaysia
25.	STEM Project-Based Learning Student Worksheet	helping students master 21st-century skills.	The STEM-PBL student worksheet on renewable energy is developed to help students in master 21st-century skills.	[42]	High school students	Jakarta, Indonesia
26.	RnD TPACK in Physics Textbook with Augmented Reality	TPACK-based physics textbook with AR to improve skills proficiency and TPACK implementation.	TPACK-based physics textbook with AR is recommended for enhancing 4C skills and TPACK implementation with 89% 4C skills proficiency and 94% TPACK implementation.	[43]	High school students	Jakarta, Indonesia
27.	Project-Based Learning for Communication and Collaborative Skills	Improving collaborative and communication skills so that activeness increases	Implementing project-based learning enhanced student activeness, especially in communication and collaboration skills.	[44]	High school students	Indonesia
28.	STEM PjBL Approach for Creative Thinking	The STEM PjBL approach to increasing student creativity.	STEM PjBL approach successfully enhances the creative thinking skills of senior high school students. The STEM PjBL Implementation shows a significant	[45]	High school students	Lampung, Indonesia

No	Learning Model	Aims	Results	Reference	Education Focus	Country
			increase in creative thinking skills.			
29.	A Literature Review STEM Education in Indonesia	STEM education in Indonesia	Provides an overview of STEM education in Indonesia, including various models applied and their effectiveness on student outcomes and 21st-century skills.	[46]	Education	Indonesia
30.	Project-Based Learning in Science Learning	21st-century skills improvement technique	The results of the journal analysis show that project-based learning (PjBL) is identified as an effective model for improving student critical thinking and learning outcomes in science education.	[47]	Education	Indonesia
31.	Project-Based Science Practicum Model	21st-century skills	A model of science practicum based on daily science projects has been developed and validated and can instil 21st-century skills in junior high school students.	[48]	Junior High School	Semarang, Indonesia
32.	Inquiry Learning Model for Elementary School	Critical Thinking improvement	the inquiry learning model enhances the critical thinking abilities of elementary school students in the concepts of Earth and the Universe.	[49]	Elementary school	Indonesia
33.	Free Inquiry Learning Model	21st Century Skills	Through field trip activities, the free inquiry learning model can shape the 21st-century competencies needed for a prospective biology teacher.	[50]	Biology teacher	Indonesia

The research landscape on 21st-century skills reveals intriguing insights into the efforts to cultivate these skills across different educational levels. According to Waslaluddin [37], the Creative Learning Cycle, a method developed by Mitchel Resnick, demonstrated a remarkable 381% improvement in 21st-century skills when implemented. This cycle involves five stages: Imagine, Reflect, Share, Play, and Create. Notably, this research, which was conducted in Bandung, Indonesia, has been cited by two researchers, showcasing its relevance and potential impact.

Table 1 provides a comprehensive overview of endeavours to enhance 21st-century skills at various educational levels, from elementary to high school, university students, prospective teachers, and teachers. Diverse instructional models, including STEM, Problem-Based Learning (PBL), Project Based Learning (PjBL), guided inquiry, free inquiry, creative problem solving, Creative Learning Cycle, STEMC, and culturally-based learning, have proven effective in fostering 21st-century skills.

Among these models, STEM emerges as the most widely employed approach, particularly in enhancing the skills of both students and teachers. However, the study by Trang et al. [34] suggests that while most prospective teachers conceptualise STEM aspects, they may face challenges in effectively designing and implementing STEM teaching methods. This necessitates the development of specific guidance on designing and implementing STEM teaching methods to enhance conceptual understanding and practical application.

Furthermore, establishing teacher communities in Thailand and Indonesia has proven beneficial in enriching 21st-century skills for students and teachers. These

communities facilitate communication and knowledge sharing, contributing to improving skills [23], [29].

In the Indonesian context, STEM is integrated into various learning models, including PjBL, inquiry-based learning, PBL, Android Arduino-based learning, digital-based learning [28], and student books. Research indicates the effectiveness of STEM in improving students' learning outcomes, including scientific literacy, critical and creative thinking, attitudes, higher-order thinking Skills (HOTS), achievements, problem-solving, and 21st-century skills [46]. Besides, Sari et al. [40] found that e-books can significantly improve critical thinking, creativity, collaboration, and communication as integral components of 21st-century skills.

Analysing and synthesising various studies [47] suggest that Project-Based Learning (PjBL) stands out as an appropriate model to address the dare of the 21st century. PjBL has consistently demonstrated the ability to enhance student learning outcomes and problem-solving skills and foster critical thinking. Additionally, PjBL has been associated with improving communication and collaboration skills [44]

CONCLUSION

This study emphasises the importance of innovative instructional models to enhance 21st-century skills for secondary school students, particularly in physics education. The bibliometric analysis of 142 publications identified Project-Based Learning (PjBL), guided inquiry, and STEM education as practical approaches for fostering critical thinking, creativity, collaboration, and communication skills. The study shows that collaborative teaching strategies greatly enhance students' teamwork and problem-solving abilities while integrating digital tools enhances engagement and learning outcomes. The findings of this study demonstrated that the significance of project-based learning and STEM education highlights the importance of these approaches in fostering 21st-century skills. Thus, physics educators should consider incorporating these models into their teaching practices, providing students opportunities to develop 21st-century skills.

Secondly, the study suggests that future research explore the effectiveness of different instructional models for specific physics topics or investigate the long-term impact of 21st-century skills interventions on student outcomes. Based on these implications, this study recommends that Physics teachers receive professional development on implementing project-based learning and STEM education. Besides, educational institutions should provide resources and support for teachers to integrate 21st-century skills into their curriculum, and future research could focus on developing and evaluating interventions to foster 21st-century skills in physics education.

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