INSECTA Vol. 7 No. 2, 2026, pp. 22 - 33

Available online at
INSECTA
Integrative Science Education and Teaching Activity Journal
Journal homepage : https://jurnal.iainponorogo.ac.id/index.php/insecta

Article

Designing the Quality of Physics Graduates: A Systematic Exploration of Basic Physics Practicums Aligned with 21st Century Competencies

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Article Info
Article history:
Received: March 8, 2026
Accepted: April 25, 2026
Published: May 31, 2026

Keywords:
21st century competencies;
Basic physics practicum;
Graduate competencies

ABSTRACT
Physics education programs must produce graduates capable of transforming scientific principles into innovative solutions. However, a significant gap exists in the systematic integration of laboratory design, standardized 21st-century competency assessments, and SDG 4-relevant outcomes. This study addresses this fragmentation by exploring basic physics laboratory models through a Systematic Literature Review (SLR) and bibliometric analysis of 22 selected articles from 2015–2025. Findings confirm a paradigm shift toward competency-based teaching, with research interest in technology integration peaking in 2023. The analysis identifies that inquiry-based models, such as the Higher Order Thinking Laboratory (HOT Lab), are most effective for fostering graduate work-readiness by prioritizing critical thinking and problem-solving. Furthermore, the study highlights the indispensable role of laboratory assistants as pedagogical agents whose 4C competencies significantly catalyze students' experimental comprehension. The study's primary novelty is the formulation of the "Triple-Aligned Architecture," a framework ensuring that instructional objectives, digital technology integration, and evaluations systematically converge on three pillars: 21st-century skills, professional competencies, and sustainability. This architecture provides a strategic roadmap for institutions to transform laboratories into innovation hubs that produce adaptive graduates with measurable global impact and readiness for the digital era.

INTRODUCTION

Physics education in higher education plays a strategic role in preparing graduates to navigate complex global challenges through the mastery of disciplinary knowledge and higher-order competencies. Contemporary educational paradigms, particularly within the framework of Sustainable Development Goal 4 (SDG 4), emphasize the necessity of fostering 21st-century skills such as critical thinking, creativity, and problem-solving to ensure inclusive and quality education. In this context, basic physics practicums serve as a fundamental pedagogical bridge between theoretical concepts and empirical practice, providing an essential environment for developing scientific reasoning and data analysis skills. Research indicates that inquiry-oriented laboratory designs significantly enhance these competencies by engaging students in collaborative investigation and active experimentation (Bakri, Luthfiya, 2023; Bao & Koenig, 2019). However, the realization of these pedagogical objectives necessitates a synergy between instructional design and field implementation.

The effectiveness of laboratory learning is not inherent and depends heavily on instructional alignment and the quality of facilitation. Recent studies have highlighted the pivotal role of laboratory assistants as pedagogical agents, showing that their 4C competencies (critical thinking, creativity, collaboration, and communication) significantly predict students' experimental comprehension (Agustina et al., 2025). Furthermore, the integration of technology and innovative models, such as the Higher Order Thinking Laboratory (HOT Lab), has been identified as a key driver for enhancing 21st-century learning outcomes in physics (Sultan et al., 2023). While these advancements provide a foundation for modernizing the laboratory environment, current scholarship remains focused on isolated instructional dimensions rather than systemic integration.

Current scholarship in physics education has extensively explored specific facets of laboratory-based learning. For instance, research by Bakri demonstrated that modern physics practicums successfully foster creativity and critical thinking through specialized instructional designs (Bakri, Luthfiya, 2023). While Sultan introduced the Higher Order Thinking Laboratory (HOT Lab) model to shift practicum activities toward 21st-century standards (Sultan et al., 2023). Additionally, empirical evidence from Agustina emphasizes the critical impact of laboratory assistants soft skills on students experimental comprehension, highlighting a significant correlation between assistant competency and student success (Agustina et al., 2025). The synthesis of these studies reveals a critical interdependence where pedagogical blueprints and human resource capacity must converge to meet global educational standards.

However, a critical gap remains in the holistic synthesis of these instructional components. While Tugirin provided a Systematic Literature Review (SLR) on critical thinking skills in physics education, their analysis primarily focused on learning models and instruments within the Scopus database without deeply integrating the "Triple-Aligned Architecture" a framework that converges 21st-century skills, professional competencies, and sustainability (SDG 4) (Tugirin, 2025). Previous SLR studies often lack a systematic focus on the integration of laboratory design with standardized competency assessments and specific SDG outcomes, frequently neglecting the instructional role of laboratory assistants in a broader sustainability framework. By addressing this fragmentation through a Systematic Literature Review and bibliometric analysis, this study formulates a comprehensive roadmap to transform basic physics laboratories into innovation hubs that ensure graduate work-readiness and global impact.

METHODS

Research Design

This study employs a Systematic Literature Review (SLR) methodology, designed to provide a transparent, reproducible, and comprehensive synthesis of primary research. The process strictly adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. To ensure a focused investigation, the research is guided by three core questions integrated into a systematic inquiry. First, it identifies the prevailing models of basic physics practicums documented in the literature between 2015 and 2025. Second, it examines how these laboratory models align with 21st-century competencies and the outcomes of Sustainable Development Goal 4 (SDG 4). Finally, the study evaluates the specific impact of laboratory assistants' competencies on student learning outcomes, positioning them as critical pedagogical agents in the laboratory environment.

Search Strategy and Data Sources

A comprehensive literature search was conducted across international databases, including Science Direct and Google Scholar, supplemented by reputable national journals (Sinta 1, 2, and 3). The search utilized a combination of specific keywords and Boolean operators: (“basic physics lab” OR “physics practicum” OR “21st century skills” AND “graduate competencies”) applied to titles, abstracts, and keywords.

Eligibility Criteria (PICO Framework)

The selection of studies was governed by the PICO (Population, Intervention, Comparison, and Outcome) framework. The inclusion and exclusion criteria are summarized in table 1 below to ensure a systematic selection process.

Table 1. Inclusion and Exclusion Criteria based on PICO

Criteria	Inclusion Criteria	Exclusion Criteria
Population (P)	Undergraduate students enrolled in basic physics practicums.	K-12 students or non-physics laboratory contexts.
Intervention (I)	Implementation of innovative learning models (e.g., Inquiry, HOT Lab, STEAM etc).	Conventional, verification-only laboratory models without innovation.
Comparison (C)	Studies providing measurable effectiveness data or comparing innovative vs. conventional models.	Descriptive studies without empirical data or comparative analysis.
Outcome (O)	Measurement of 21st-century competencies, graduate work-readiness, or SDG 4 impacts.	Studies focusing solely on theoretical knowledge without skill assessment.
Context	Peer-reviewed articles, open access, published between 2015–2025.	Book chapters, conference abstracts, or non-open access articles.

Data Quality Appraisal: Adapted CASP

To ensure the methodological rigor of the included studies, an adapted Critical Appraisal Skills Programme (CASP) instrument was employed. The instrument was modified by adding specific scoring weightage to the primary domains of internal validity and pedagogical relevance. The appraisal of internal validity focused on assessing the robustness of experimental designs and the consistency of measurement tools , whereas pedagogical relevance evaluated how explicitly each study aligned with SDG 4 outcomes and the Triple-Aligned Architecture framework. Each article was scored by two independent reviewers to ensure that only studies achieving a "High" or "Moderate" quality rating progressed to the final synthesis phase, thereby maintaining the trustworthiness of the findings.

Data Analysis and Synthesis Process

The analysis followed a multi-staged approach to ensure depth and clarity, beginning with a thematic synthesis that involved a three-step process. This process commenced with the line-by-line coding of the "Results" and "Discussion" sections of primary studies, followed by the development of descriptive themes by grouping related codes, such as technology integration and soft skill development, and concluded with the generation of analytical themes to provide a new conceptual understanding of the data. Subsequently, a narrative synthesis was conducted through the construction of a textual summary to explore relationships within and between studies, specifically focusing on the comparative impact of different practicum models like HOT Lab versus Inquiry on 21st-century competencies. To complement this qualitative synthesis, bibliometric visualization was performed using VOSviewer for co-occurrence analysis and thematic clustering. This quantitative phase served to visualize conceptual interconnections and validate the emergence of the "Triple-Aligned Architecture" framework.

Trustworthiness and Reliability

To ensure the reliability of the selection and analysis process, this study implemented investigator triangulation. Two researchers independently screened the titles, abstracts, and full texts against the PICO criteria. Any discrepancies in study selection or CASP scoring were resolved through a consensus meeting or by consulting a third senior researcher. This rigorous peer-debriefing process minimizes individual bias and ensures that the final synthesis is a credible representation of the current literature.

RESULTS AND DISCUSSION

The diagram below illustrates the study selection flow from initial identification to final inclusion, in accordance with PRISMA guidelines. The Systematic Literature Review (SLR) process began with the primary study identification phase based on predetermined keywords. In this phase, searches in the database yielded a total of 209 relevant articles, with 200 articles identified through Google Scholar and 9 articles through Science Direct, as shown in figure 1. After the identification process, a screening phase was conducted to assess the eligibility of the studies. Of the total articles identified from Google Scholar, 183 articles were excluded because they did not meet the inclusion criteria or were duplicates, leaving 17 articles for further review. Meanwhile, from Science Direct, 4 articles were excluded, leaving 5 relevant articles for further selection.

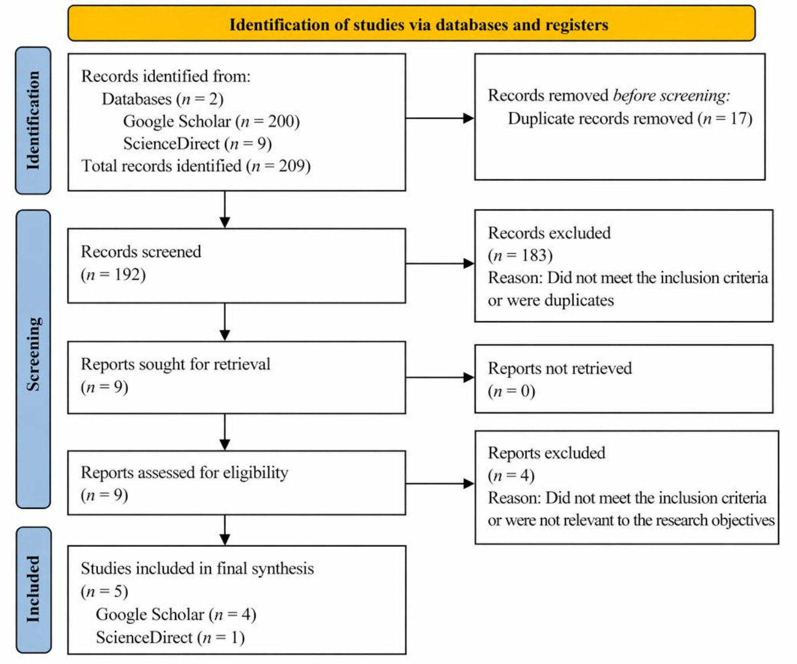

Figure 1. PRISMA Flow Diagram of Study Selection

Based on the results of an objective and systematic SLR process, the following flowchart of research article screening using the PoP (Publish or Perish) application shows data extracted from 2015 to 2025. In addition, the screening data extracted using the Publish or Perish (PoP) application shows significant variations in annual publication trends related to this topic between 2015 and 2025 in figure 2. The results show that article publications from Google Scholar and Science Direct began to show an upward trend in 2021 and peaked in 2023, reflecting increased academic interest in integrating physics curricula with sustainability issues and 21st-century competencies following the adoption of the SDGs agenda. This global trend is reflected in regional academic discourses that emphasize the necessity of modernizing science labs to meet contemporary educational standards. In this context, bibliometric evidence indicates that contemporary research in science education increasingly prioritizes virtual laboratories as a pivotal tool for enhancing science process skills and student motivation within digital learning environments (Yanti et al., 2023). This data confirms the relevance of the 2015-2025 time frame set in the research protocol.

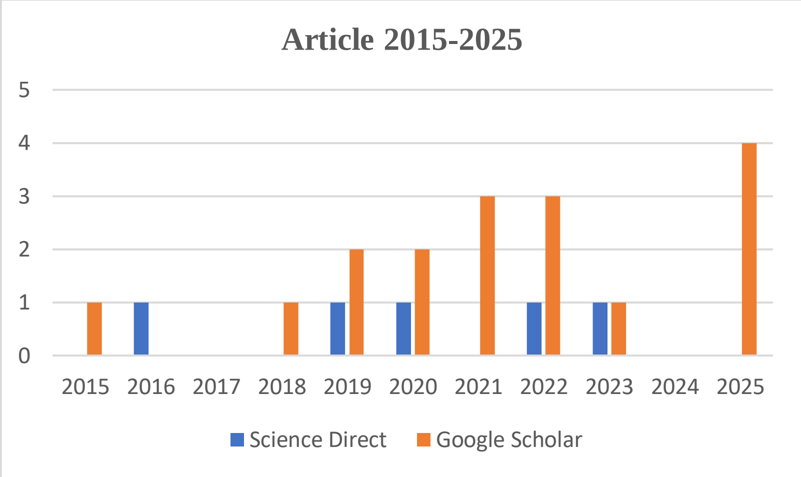

Figure 2. Article screening through PoP (Publish or Perish)

To clarify the results of filtering articles through PoP in graph 1, the following table includes data from "Scholar" and is available in open access for the period 2015-2025.

Table 2. List of Articles by "Scholar" through PoP

No	Author	Year	Title	Source
1	Shukran Abdul Rahman and Koo Yew Lie	2015	Graduate competencies: Issues and solutions of graduate employability in Malaysia	Technology and Workplace Skills for the Twenty
2	Prikshat Verma, et al.	2018	Graduate work-readiness challenges in the Asia-Pacific region and the role of HRM	Equality, Diversity and Inclusion An International Journal
3	Humberto Oraison, et al.	2019	Does university prepare students for employment?: Alignment between graduate attributes, accreditation requirements and industry employability criteria	Journal of Teaching and Learning for Graduate Employability
4	Ummi Nu Laila Sulistyani	2019	2013 Curriculum Evaluation: a Comparison to Language Curriculum Design and 21st Century Learning Skills	Jurnal Pendidikan Humaniora
5	A Mustikasari, Wiyanto, et al	2020	A conceptual model of the integrated science learning quality assurance	Journal of Physics: Conference Series
6	Sinta Oktavia and Utari Prisma Dewi	2020	Description of Integrated Science Process Skills in Physics Education Students in Convex Mirror Practicum	FORMATIF: Jurnal Ilmiah Pendidikan MIPA
7	J Firmansyah and A Suhandi	2021	Critical thinking skills and science process skills in physics practicum	Journal of Physics: Conference Series
8	DA Putra, R Setiani, et al.	2021	The Effect of ARICESA on Achievement Motivation and Understanding of Basic Science Concepts for Prospective Teacher Students	Journal of Physics: Conference Series
9	Mary Sabry, et al.	2021	Student learning outcomes from work placement: A systematic literature review	REES AAEE 2021 conference: Engineering Education Research Capability Development

No	Author	Year	Title	Source
10	Sandra Santos, Carla Freire, et al.	2022	The Adaptable Graduate: Competencies for the Future of Work	Portuguese Foundation for Science and Technology (FCT)
11	Fitri Annisaa and Bertha Yonata	2022	Using flipped classroom approach to promote critical thinking skills on reaction rate topic	Jurnal Pijar Mipa
12	Duden Saepuzaman, et al.	2022	Analysis of HOTS Instrument for Prospective Physics Teacher Using Generalized Partial Credit Model	JURNAL IDEAS: Pendidikan, Sosial dan Budaya
13	Donal Nababan, et al.	2023	Web-Based Learning Media for Distance Education: A Review	JPPIPA: Jurnal Penenelitian Pendidikan IPA
14	Ma Teresa Silos Alvarez and Sheila Y. Guinat	2025	Enhancing curriculum development: a comprehensive framework for undergraduate competencies	International Journal of Evaluation and Research in Education (IJIRE)
15	Mochamad Kamil Budiarto, et al.	2025	Effect of ICT-Based Learning Media on Student Learning Outcomes: A Scoping Review.	Journal of Learning for Development
16	Parinda Phanphech and Thanakarn Kumphai	2025	Development of an Electrical Technology Curriculum for Bachelor's Degree Programs within the Outcome-Based Education (OBE)	2025 10th International STEM Education Conference (iSTEM-Ed)
17	Riswanto et al.	2025	Evaluating The Utilization of Physics Laboratories in High Schools: A Case Study at SMAN 5 Metro	Jurnal Pendidikan Fisika dan Teknologi

Designing high-quality physics graduates requires continuous curriculum review to remain relevant to the dynamics of society and the demands of the 21st-century workplace (Nur & Sulistyani, 2019). This is in line with the 21st Century Learning Design framework, which emphasizes work readiness as the main indicator of graduate quality, a challenge that is still prominent in the Asia-Pacific region (Verma et al., 2018). In the context of science higher education, graduate quality is not only determined by mastery of disciplinary concepts, but also by the ability to apply this knowledge in a professional practice context and its contribution to sustainable development (Sabry et al., 2021). In line with this, physics education is seen as having a strategic role in supporting the achievement of the Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education), through learning designs that explicitly develop critical thinking, collaboration, and technological literacy skills (Prayogi et al., 2024).

However, various studies show that ensuring the quality of learning, particularly through basic physics practicums, still faces a number of obstacles. Nazar's research confirms that the quality of higher education is highly dependent on the integration of curriculum, pedagogy, and graduate competency outcomes, while weak contextual learning design can hinder the contribution of education to the SDGs (Nazar et al., 2018). In the context of physics, the use of laboratories is reported to still be suboptimal, which has an impact on low student engagement and difficulties in linking theoretical concepts with empirical experiences (Prayogi et al., 2024). These findings are in line with the results of the study synthesis shown in the VOSViewer bibliometric analysis in Figure 2, which shows that most studies emphasize the need to transform practicums from mere concept verification to a vehicle for the integrated development of 21st-century competencies.

In response to these challenges, various studies emphasize the importance of redesigning basic physics practicums that are oriented towards developing Higher Order Thinking Skills (HOTS) and 21st century skills. Research conducted by Firmansyah and Suhandi shows that physics practicums can train critical thinking skills and science process skills in an integrated manner (Suhandi, 2021). The transition from traditional laboratory setups to more dynamic frameworks is essential for fostering high-level cognitive engagement. This finding aligns with evidence showing that the implementation of an online guided inquiry laboratory model, supported by interactive simulations such as PhET, has been shown to exert a significant positive influence on students' critical thinking abilities by fostering active engagement in scientific investigation (Rohana et al., 2022). Meanwhile, the STEAM-based approach and sustainability context have been proven to improve critical thinking skills and student awareness of global issues (Indahwati et al., 2023).

In addition, the integration of digital technology and artificial intelligence is increasingly seen as a factor supporting graduate quality, both in improving learning access and personalizing competency development (Alsagri & Saquib, 2024). This trend is reinforced by the results of bibliometric analysis presented in the PoP Figure and VOSviewer visualization, which show the dominance of the themes of technology, 21st-century competencies, and SDG 4 in recent physics education research (Dawana et al., 2024). Thus, the results of this SLR confirm that systematically designed basic physics practicums that integrate inquiry pedagogy, HOTS, digital technology, and sustainability orientation are strategic keys in designing the quality of physics graduates who are superior and relevant to the demands of the 21st century.

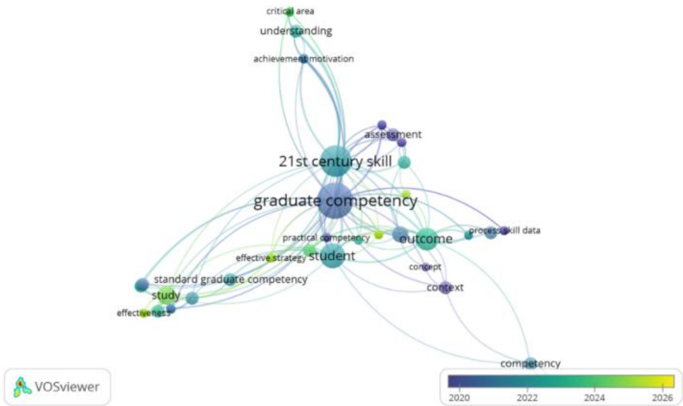

Figure 3. Bibliometric Analysis of VOSviewer Scholar Articles

Bibliometric analysis using VOSviewer on the articles included in Figure 3 and Table 2 shows strong and interrelated thematic clustering that clearly validates the focus of this SLR research. The main clusters are centered on the concepts of “21st century skills” and “graduate competency,” indicating that the core of current physics education research is on outcomes and graduate capabilities. This dense interconnection underlines a paradigm shift from content-based teaching to competency-based teaching. While in the 20th century professional success was largely determined by mastery of specific content knowledge, success in the 21st century depends on the individual's ability to effectively utilize that knowledge in changing situations. Therefore, basic physics practicums are seen as a fundamental medium for producing graduates who are not only proficient in technical skills (hard skills), but also have transferable skills or soft skills, which are now highly sought after by organizations and the global job market. These competencies, which include a combination of knowledge, skills, and attitudes, enable graduates to act effectively in dynamic work contexts (Hawkins & Jacob, 2015; Santos et al., 2022).

Therefore, basic physics practicums are seen as a fundamental medium for producing graduates who are not only proficient in technical skills (hard skills), but also have transferable skills or soft skills, which are now highly sought after by organizations and the global job market. This fact is reinforced by findings that physics practicums are significantly effective in training scientific process skills, which are the hard skills that form the foundation for the development of critical thinking skills (Suhandi, 2021). These developed competencies, which include a combination of knowledge, skills, and attitudes, enable graduates to act effectively in dynamic work contexts.

The dense interconnectedness of clusters in bibliometric analysis reinforces the central role of basic physics practicums as a fundamental platform for developing skills and competencies. The terms “laboratory” and “graduate competency” are intertwined, empirically demonstrating that the models synthesized in this study are oriented toward the transfer of skills that are direct and applied in nature. Furthermore, the keywords surrounding the core cluster, such as “understanding,” “motivation,” and “effectiveness,” highlight that the quality of learning is no longer measured solely from a purely cognitive perspective. In line with the definition in this era, competency is defined as a combination of knowledge (understanding), skills, and attitudes (motivation) that enable a person to act effectively in a work context.

Thus, effective practicum models must be methodologically proven to increase effectiveness and maintain student motivation, while balancing substantive knowledge mastery with adaptability, in line with the pillars of “learning to be” and “learning to do.” This focus ensures that graduates possess the adaptive skills (transferable skills) that are essential for professional success in the 21st century (Hawkins & Jacob, 2015). This is fundamental because research shows that graduates' work readiness is highly dependent on possessing the practical competencies, critical thinking, and problem-solving skills required by industry, which employers often prioritize over the ethical and cultural attributes emphasized by accreditation bodies and universities (Oraison et al., 2019). This focus ensures that graduates possess the adaptive skills (transferable skills) that are essential for 21st-century professional success.

Furthermore, based on VOSviewer bibliometric analysis, it was revealed that the included practicum models sought to integrate real challenges in the 21st century. This pattern of interrelationships between terms will form the empirical foundation for formulating a comprehensive triple-aligned architecture. This integration requires a practicum design that not only covers core skills, such as critical thinking and problem solving, which are fundamental parts of 21st century skills, but also covers aspects of sustainability and professional ethics that are essential for graduate competence. This is because success in the 21st century is not only determined by mastery of specific content knowledge, but also by the individual's ability to apply that knowledge effectively in changing and complex situations. Therefore, the proposed architecture will ensure that every component of the practicum, from instructional objectives to evaluation, systematically supports these three pillars. The ability to articulate scientific findings and defend logical conclusions is no longer an optional skill but a core requirement for physics graduates within this framework. Supporting this view, argumentation skills represent a fundamental component of 21st-century competencies, as they are intrinsically linked to a student's capacity for critical thinking and the effective communication of complex scientific concepts (Fadly, 2020). This is in line with the learning pillars of “learning to live together” and “learning to be” which emphasize the development of social understanding, responsibility, and self-potential (Hawkins & Jacob, 2015; Oraison et al., 2019).

To clarify the results of article screening through PoP in graph 1, the following table includes data from ScienceDirect and is available in open access for the period 2015-2025.

Table 3. list of articles by “science direct” through PoP

No	Author	Year	Title	Source
1	C. Zhang, B. Wijnen and J. M. Pearce	2016	Open-Source 3-D Platform for Low-Cost Scientific Instrument Ecosystem	Journal of Laboratory Automation
2	Veeraporn Siddoo, et al.	2019	An exploratory study of digital workforce competency in Thailand	Heliyon

No	Author	Year	Title	Source
3	Joshua M. Pearce	2020	Economic savings for scientific free and open source technology: A review	HardwareX
4	Francesco Smaldone, et al.	2022	Employability skills: Profiling data scientists in the digital labour market	European Management Journal
5	Alma C. Asuncion, et al.	2023	Weaving gaps in garments education technology: Crafting a skill-based E-toolkit based on Taba's curriculum development model	Social Sciences & Humanities Open

A synthesis of findings from the five articles sourced from ScienceDirect confirms that designing the quality of physics graduates must focus on transforming the design of basic practicums to align with 21st-century competency requirements. The skills gap faced by graduates when entering the workplace indicates a deficit in practice and difficulties in operating equipment (Asuncion et al., 2023). The research also highlights the failure of content-based learning models. Therefore, research in this field emphasizes industry responsiveness through the development of digital literacy and innovative capabilities.

This is achieved through the adoption of open-source hardware technology and low-cost 3D platforms. It can radically “inspire the creation of a wide range of specialized instruments that can be shared and replicated digitally around the world” (Pearce, 2020; Zhang et al., 2016). In this way, technical skills and practices can be trained on an ongoing basis. This transformation is crucial because higher education leaders are required to “accelerate plans to produce graduates with the quality and preparation necessary to meet the needs of the workplace” (Siddoo et al., 2019). This is especially true in the context of evolving professional roles that demand the ability to analyze increasingly complex and heterogeneous big data (Smaldone et al., 2022). Overall, these findings validate a systematic framework oriented towards applied skills (skill-based material), making basic physics practicums a crucial medium for producing graduates who not only master concepts but also possess analytical-digital competencies that are ready to adapt to the global job market.

Figure 4. Bibliometric Analysis of VOSviewer Science Direct Articles

The bibliometric analysis of articles sourced from ScienceDirect in Figure 4 shows thematic clusters that are more focused on the integration of “technology” with ‘scientist’ and “application.” These clusters underline the research trend in more indexed journals, which tend to emphasize the aspects of technology implementation and innovation in practical work to produce scientists who are ready to apply physics. Although the term “21st century skills” is not an explicit central cluster in this visualization, the focus on technology and application implicitly supports the demands of 21st century competencies and the context of sustainability. Furthermore, this cluster fulfills the “learning to do” pillar of learning, which focuses on acquiring practical skills and ways of applying knowledge to solve problems. Thus, the use of technology in physics practicums is seen as a fundamental prerequisite for training graduates in the use of hard skills that can be implemented in real-world applications (Hawkins & Jacob, 2015).

This requirement is particularly relevant in the era of society 5.0, where universities are required to produce graduates who not only master knowledge but are also proficient in digital literacy and problem-solving skills (Andayani, 2023). Thus, the use of technology in physics practicums is seen as a fundamental prerequisite for training graduates in the use of hard skills that can be implemented in real-world applications, while also equipping them with the basic skills to compete in a super-smart society. The use of technology in physics practicums, as demonstrated by this cluster, plays an important role in shaping the graduate competencies needed in the digital era. This reflects the need for graduates who are able to utilize big data, simulations, and modern instrumentation to solve complex problems. This pattern distinguishes the focus from the google scholar cluster, which emphasizes the improvement of soft skills and motivation, while “science direct” focuses on tools (technology) and the real impact (application) of physics education.

The relevance to the “science direct” cluster shows that practical work should be designed as an incubation process for innovation. A scientist produced from technology-based practicums will automatically possess technical and computational skills, which are key prerequisites for 21st century competencies. Therefore, practicum modules that explicitly integrate technology and assign impactful projects ensure relevant contributions to real world problem solving. Overall, the pattern of interrelationships between terms from both databases will form a strong empirical foundation. The synthesis of these two focuses the development of comprehensive cognitive and affective skills alongside mastery of applied technological tools can produce physics graduates with real and sustainable impact.

While the integration of advanced technologies such as open-source hardware and digital toolkits provides the technical infrastructure for modernizing physics practicums, the role of laboratory assistants as instructional mediators remains indispensable. The successful operation of these innovative tools is not merely a matter of technical availability but depends heavily on the pedagogical facilitation provided by human agents. As highlighted by recent empirical evidence, the “4C” competencies (critical thinking, creativity, collaboration, and communication) of laboratory assistants act as a critical catalyst, ensuring that students do not just operate equipment but achieve a deeper experimental comprehension. Therefore, the digital transformation of the laboratory must be accompanied by the professional development of assistants, positioning them as essential guides who bridge the gap between complex technological applications and the achievement of 21st-century learning outcomes (Agustina et al., 2025; Lehesvuori, 2023; Sultan et al., 2023).

CONCLUSION

Based on the systematic review and data exploration that has been conducted, it can be concluded that designing the quality of Physics graduates in line with the demands of 21st century competencies requires a fundamental transformation of the curriculum architecture and the implementation of basic physics practicums. The results of the analysis confirm the urgent need to continuously update the curriculum in order to meet the rubrics of 21st-century learning design and address the gap between graduate competencies and professional readiness.

This transparency shows that the quality of Physics graduates is measured not only by their mastery of basic scientific concepts and motivation to achieve, but also by their ability to apply Higher Order Thinking Skills (HOTS) and integrated science process skills. To achieve this, laboratory learning practices must be reoriented from conventional methods, which tend to be suboptimal, to guided inquiry-based approaches that have been proven effective in facilitating the development of critical skills and problem solving explicitly.

In addition to pedagogical aspects, the integration of digital technology, particularly web-based learning media, is imperative to overcome barriers to accessing materials and ensure a deeper understanding of concepts. Synergistically, the transformation of laboratory learning also necessitates the enhancement of laboratory assistants competencies as pedagogical agents. Their 4C skills are pivotal in catalyzing students experimental comprehension and bridging the gap between theoretical knowledge and practical application. Furthermore, it is important for study programs to integrate structured work experience to facilitate the transition from the academic environment to the world of work, which will ultimately improve the employability of graduates. Thus, reorienting basic physics practicums into a means of developing multidimensional competencies encompassing pedagogy, technology, and human resource excellence is key to producing professional physics graduates who are ready to innovate in the 21st century.

REFERENCES

Agustina, R. D., Putra, R. P., Chusni, M. M., & Umri, Z. (2025). 4C Competencies of Laboratory Assistants : A Catalyst for Improved Experimental Comprehension in Physics Education. *International Journal of Education and Teaching Zone (IJETZ)*, *4*(2), 106–125.

Alsagri, H. S., & Saquib, S. (2024). Discover Sustainability Evaluating the role of Artificial Intelligence in sustainable development goals with an emphasis on “ quality education .” *Discover Sustainability*. https://doi.org/10.1007/s43621-024-00682-9

Andayani, W. M. dan B. S. (2023). Professional Educator in the Era of Society 5 . 0 : Primary Education Alumni Competence. *Journal of Higher Education Theory and Practice*, *23*(10), 6–16.

Asuncion, A. C., Vera, A. De, Macalipis, J. G., Mae, C., Borromeo, T., Rivera, J. C., & Limon, M. R. (2023). Social Sciences & Humanities Open Weaving gaps in garments education technology : Crafting a skill-based E -toolkit based on Taba ’ s curriculum development model. *Social Sciences & Humanities Open*, *8*(1), 100656. https://doi.org/10.1016/j.ssaho.2023.100656

Bakri, Luthfiya, R. and W. (2023). The Modern Physics Practicum : Students creatively and critically thinking in the 21st-century competencies The Modern Physics Practicum : Students creatively and critically thinking in the 21st-century competencies. *Journal of Physics: Conference Series*. https://doi.org/10.1088/1742-6596/2596/1/012079

Bao, L., & Koenig, K. (2019). Physics education research for 21st century learning. *Disciplinary and Interdisciplinary Science Education Research*, *1*(1), 1–12. https://doi.org/10.1186/s43031-019-0007-8

Dawana, I. R., Prahani, B. K., Hariyono, E., & Ghofur, M. A. (2024). Utilisation of augmented reality technology in physics education : A bibliometric analysis and its impact on Sustainable Development Goals (SDGs). *E3S Web of Conferences*, *04006*.

Fadly, W. (2020). Integrative Science Education and Teaching Activity Journal Looking at a Portrait of Student Argumentation Skills on the Concept of Inheritance (21st Century Skills Study). *INSECTA: Integrative Science Education and Teaching Activity Journal*, *I*(1), 17–33.

Hawkins, J. N., & Jacob, W. J. (2015). *Technology and Workplace Skills for the Twenty-First Century*. Palgrave Macmillan.

Indahwati, S. D., Rachmadiarti, F., Hariyono, E., & Prahani, B. K. (2023). Integration of independent learning and physics innovation in STEAM-based renewable energy education to improve critical thinking skills in the era of Society 5 . 0 for Sustainable Development Goals (SDGs) 2030. *E3S Web of Conferences*, *01010*.

Lehesvuori, S. et al. (2023). Student-centredness in physics laboratory teaching sessions. *Learning, Culture and Social Interaction*, *43*(October). https://doi.org/10.1016/j.lcsi.2023.100773

Nazar, R., Chaudhry, I. S., Ali, S., & Faheem, M. (2018). ROLE OF QUALITY EDUCATION FOR SUSTAINABLE DEVELOPMENT GOALS (SDGS). *PEOPLE: International Journal of Social Sciences*, *4*(2), 486–501.

Nur, U., & Sulistyani, L. (2019). 2013 Curriculum Evaluation : a Comparison to Language

Curriculum Design and 21st Century Learning Skills. *Jurnal Pendidikan Humaniora*, *7*(4), 157–165.

Oraison, H., Konjarski, L., & Howe, S. (2019). Does university prepare students for employment ? Alignment between graduate attributes , accreditation requirements and industry employability criteria. *Journal of Teaching and Learning for Graduate Employability*, *10*, 173–194.

Pearce, J. M. (2020). HardwareX Economic savings for scientific free and open source technology : A review. *HardwareX*, *8*, e00139. https://doi.org/10.1016/j.ohx.2020.e00139

Prayogi, S., Nyoman, N., & Putu, S. (2024). Physics Learning Technology for Sustainable Development Goals (SDGs): A Literature Study. *International Journal of Ethnoscience and Technology in Education (IJETE)*, *1*(2), 155–191.

Rohana, I., Suana, W., Nyeneng, I. D. P., & Herlina, K. (2022). Integrative Science Education and Teaching Activity Journal The Effect of Online Guided Inquiry Laboratory toward Students ' Critical Thinking Ability. *INSECTA: Integrative Science Education and Teaching Activity Journal*, *3*(1), 70–80.

Sabry, M., Gardner, A., & Hadgraft, R. (2021). Student Learning Outcomes from Work placement : A Systematic Literature Review. *Research in Enginerring Education Network (REEN)*, 725–735.

Santos, S., Freire, C., Barbosa, I., & Figueiredo, H. (2022). The Adaptable Graduate: Competencies for the Future of Work. *Portuguese Foundation for Science and Technology (FCT)*, 1–28.

Siddoo, V., Sawattawee, J., Janchai, W., & Thinnukool, O. (2019). Heliyon An exploratory study of digital workforce competency in Thailand. *Heliyon*, *5*(August 2018), e01723. https://doi.org/10.1016/j.heliyon.2019.e01723

Smaldone, F., Ippolito, A., Lagger, J., & Pellicano, M. (2022). Employability skills : Profiling data scientists in the digital labour market. *European Management Journal*, *40*(5), 671–684. https://doi.org/10.1016/j.emj.2022.05.005

Suhandi, J. F. dan A. (2021). Critical thinking skills and science process skills in physics practicum Critical thinking skills and science process skills in physics practicum. *International Conference on Mathematics and Science Education (ICMScE) IOP Publishing*. https://doi.org/10.1088/1742-6596/1806/1/012047

Sultan, A. D., Kurniawan, R., & Nurfadillah, N. (2023). Design and Analysis of the Basic Physics Practicum Model Based on the Higher Order Thinking Laboratory as a Model for 21st Century Learning Practicum. *European Online Journal of Natural and Social Sciences*, *12*(2), 233–240.

Tugirin, et al. (2025). A Systematic Literature Review on Critical Thinking Skills in Physics Education To cite this article : A Systematic Literature Review on Critical Thinking Skills in Physics Education. *International Journal of Education in Mathematics, Science and Technology*, *13*(5), 1268–1282.

Verma, P., Nankervis, A., Connell, J., & Burgess, J. (2018). Graduate work-readiness challenges in the Asia-Pacific region and the role of HRM. *Equality, Diversity and Inclusion: An International Journal*, *37*(2), 121–137. https://doi.org/10.1108/EDI-01-2017-0015

Yanti, M., Rahayu, D. S., & Rizal, H. P. (2023). Integrative Science Education and Teaching Activity Journal Analysis of the Potential of Virtual Lab Research Development in Science Learning with the Bibliometric method. *INSECTA: Integrative Science Education and Teaching Activity Journal*, *4*(1), 29–38.

Zhang, C., Wijnen, B., & Pearce, J. M. (2016). Open-Source 3-D Platform for Low-Cost Scientific Instrument Ecosystem. *SLAS-TECHNOLOGY*, *21*(4), 517–525. https://doi.org/10.1177/2211068215624406