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A Review: Research Trends on Development of a Sensor-Based Linear Motion Kit with Problem-Based Learning Model to Improve Problem-Solving and Critical Thinking Skills

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Abstract: This study aims to synthesize and map research trends related to the development of sensor-based linear motion kits integrated with a Problem-Based Learning (PBL) model to enhance students' problem-solving and critical thinking skills in physics education. A Hybrid Systematic Literature Review (SLR) and Bibliometric Review was employed following PRISMA guidelines. Articles published between 2020 and 2025 were retrieved from Scopus and SINTA databases. Articles focusing on sensor-based kits and PBL in high school or university physics were included. After identification, screening, eligibility, and inclusion processes, 30 relevant studies were analyzed. Bibliometric techniques were used to identify publication trends, keyword co-occurrence, and thematic clusters, while qualitative synthesis examined pedagogical approaches and learning outcomes. The findings indicate a growing research interest in sensor-supported physics learning and PBL integration. Studies consistently report that sensor-based linear motion kits embedded in PBL environments effectively support real-time data interpretation, experimental reasoning, and collaborative inquiry, leading to significant improvements in problem-solving and critical thinking skills. However, gaps remain in the integration of low-cost, curriculum-aligned sensor kits and in long-term empirical validation. This review highlights the pedagogical potential of integrating sensor-based linear motion kits with PBL and provides evidence-based insights to guide future research and instructional design in physics education.

Keywords: Critical Thinking; Physics education; Problem based learning; Problem solving; Sensor-based linear motion kit

Introduction

Physics education in the 21st century requires a fundamental transformation from knowledge transmission–oriented instruction to learning approaches that emphasize the development of higher-order thinking skills. Competencies such as problem-solving and critical thinking are considered essential skills for students to effectively address the complexity of scientific and technological challenges in real-life contexts (OECD, 2021; Facione, 2020). However, numerous studies have reported that physics instruction in schools remains predominantly conventional, focusing on formula memorization and teacher-centered delivery, which limits students' conceptual understanding and critical thinking development (John, 2006; Suryani & Rahayu, 2022).

One of the physics topics that frequently presents conceptual difficulties for students is linear motion. Concepts such as velocity, acceleration, and the relationships among kinematic variables are inherently abstract and require empirical experiences to be meaningfully understood (Lilian et al., 1987). Previous studies indicate that students often develop misconceptions in linear motion due to the lack of authentic, data-driven laboratory activities that connect

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theory with observable phenomena (David et al., 1992; Sitohang & Tanjung, 2025). In response to these challenges, the development of sensor-based instructional kits has emerged as a promising solution in physics education. Sensor-based physics kits enable students to conduct direct measurements of motion phenomena using real-time data, thereby promoting contextual and evidence-based learning experiences (Maryani et al., 2023; Nugraha & Wahyudi, 2024). Empirical findings suggest that learning activities supported by microcontroller-based sensors—such as Arduino systems, ultrasonic sensors, and accelerometers—significantly enhance students' understanding of kinematics concepts as well as their data analysis skills (Finkelstein et al., 2005; Çoban & Erol, 2021; Çoban & Salar, 2023).

Nevertheless, the effectiveness of sensor-based learning tools is highly dependent on the instructional model applied. Without appropriate pedagogical design, technology integration may only function as a demonstration tool and fail to foster higher-order thinking skills (Cindy et al., 2007). Therefore, the integration of technology must be aligned with student-centered learning models that actively engage learners in inquiry and reasoning processes. One such model that has been widely recognized for its effectiveness is Problem-Based Learning (PBL). Problem-Based Learning emphasizes learning through authentic and ill-structured problems that require students to analyze situations, formulate hypotheses, collect and interpret data, and evaluate solutions through reflective thinking (Hmelo-Silver, 2004; Muliyadi, 2017). A substantial body of Scopus-indexed research has demonstrated that PBL consistently improves students' critical thinking and problem-solving abilities in science and physics education (Yew & Goh, 2020; Le et al., 2023). PBL implementation in physics learning positively affects students' critical thinking skills, conceptual understanding, and scientific attitudes (Doyan et al., 2023; Hmelo-Silver, 2004; Susilawati et al., 2025).

The integration of sensor-based linear motion kits with the PBL model has strong potential to create a learning environment aligned with the STEM (Science, Technology, Engineering, and Mathematics) education framework. STEM-oriented problem-based learning encourages students to connect theoretical concepts with technological applications and engineering processes, thereby strengthening knowledge transfer and higher-order cognitive skills (Bybee, 2020; Le et al., 2023). Previous studies indicate that STEM–PBL approaches in physics learning significantly enhance students' analytical reasoning, evaluation skills, and decision-making abilities compared to conventional instructional approaches.

Several studies have focused on developing physics instructional materials, such as PBL-based modules, PhET-assisted e-modules, and conventional kinematics teaching aids. However, most of these studies have not specifically developed sensor-based linear motion kits fully integrated with the PBL syntax, nor have they simultaneously examined their effects on problem-solving and critical thinking skills (Hmelo-Silver, 2004; Diana, 2012). Moreover, empirical research investigating the systematic implementation of such kits within secondary school physics learning contexts remains limited (Muliyadi et al., 2023; Sitohang & Tanjung, 2025).

Based on these research gaps, a systematic review of the development of this kit is necessary to map what already exists and what is missing. Consequently, this study is expected to contribute both theoretically and practically to the advancement of innovative physics learning by providing evidence-based instructional tools that effectively enhance students' problem-solving and critical thinking skills. Therefore, this research wants to know the research trend on development of a sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills.

Method

Research Design

This study employed a Hybrid Review methodology, integrating a Systematic Literature Review (SLR) and a Bibliometric Review, to examine research trends and empirical evidence related to the development of sensor-based linear motion kits integrated with Problem-Based Learning (PBL) to enhance students' problem-solving skills and critical thinking. The hybrid approach allows both in-depth qualitative synthesis and quantitative mapping of scientific knowledge, strengthening the robustness and transparency of the review (Snyder, 2019; Donthu et al., 2021).

The SLR component focused on pedagogical effectiveness, learning outcomes, and design characteristics of sensor-based physics kits and PBL implementation, while the bibliometric component explored publication trends, thematic evolution, and research gaps in physics education and educational technology (Tranfield et al., 2003; Aria & Cuccurullo, 2017).

Data Sources and Research Strategy

The literature search was conducted using two primary databases: Scopus and SINTA (Science and Technology Index). Google Scholar was utilized to ensure broader coverage of Indonesian journals that may not be fully indexed in Scopus but are recognized in SINTA. Others, especially research in the field of education (Hallinger et al., 2019, 2020; Zawacki-Richter et al., 2019).

Scopus was selected to represent internationally recognized, high-impact journals, while SINTA was used to capture nationally accredited Indonesian journals relevant to physics education (Pratama et al., 2025; Roslina et al., 2023). The search process covered publications from 2020 to 2025, aligning with the global shift toward digital transformation and 21st-century learning paradigms. A comprehensive search string using Boolean operators was applied as follows:
("linear motion kit" OR "sensor-based physics kit") AND ("problem-based learning" OR "PBL") AND ("problem-solving skills" OR "critical thinking") AND "physics education"

Only peer-reviewed journal articles written in English or Indonesian were considered. This strategy is consistent with best practices in systematic review research to ensure coverage, relevance, and replicability (Kitchenham & Charters, 2007; Page et al., 2021). To see research trends in recent years, app.dimensions.ai is also used To filter data that has been collected via Publish or Perish, researchers used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Data identification was facilitated using Publish or Perish software, while Dimensions.ai was employed for supplementary trend cross-referencing.

Inclusion and Exclusion Criteria

To ensure the quality and relevance of the reviewed studies, explicit inclusion and exclusion criteria were applied. Inclusion criteria were articles published between 2020–2025, indexed in Scopus or SINTA, focusing on sensor-based learning media or experimental physics kits, applying Problem-Based Learning or inquiry-based models, and reporting outcomes related to problem-solving or critical thinking skills.

Exclusion criteria included non-empirical studies, duplicated records, and articles lacking methodological clarity (Page et al., 2021). The use of explicit inclusion and exclusion criteria enhances transparency and minimizes selection bias in systematic reviews (Moher et al., 2009).

Systematic Literature Review Procedure

The SLR process followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, which consist of four stages: identification, screening, eligibility, and inclusion (Page et al., 2021).

During the identification stage, all records retrieved from Scopus and SINTA were compiled, and duplicate articles were removed. In the screening stage, titles and abstracts were reviewed to assess relevance to the research focus. Articles that met the inclusion criteria proceeded to the eligibility stage, where full-text assessments were conducted.

The final set of included articles was analyzed using qualitative content analysis, focusing on learning models and instructional designs, sensor-based learning media or experimental physics kits Application of deep learning pedagogy, research methods and educational contexts, and reported impacts on students' critical thinking and problem solving skills

Narrative synthesis was employed to identify recurring patterns, theoretical frameworks, and research gaps relevant to the development of the proposed hybrid learning model (Snyder, 2019).

Bibliometric Review Procedure

Following the SLR phase, a bibliometric review was conducted to quantitatively analyze publication patterns and intellectual structures within the selected literature corpus. Bibliographic metadata—including authors, publication years, journals, affiliations, citations, and keywords—were exported in compatible formats from the databases. The bibliometric analysis focused on, annual publication trends to identify research growth patterns, most productive and influential authors and journals, keyword co-occurrence analysis to detect dominant and emerging themes, co-citation and bibliographic coupling analysis to map intellectual relationships.

Visualization and network analyses were conducted using bibliometric tools such as VOSviewer, which is widely used for mapping scientific knowledge domains (van Eck & Waltman, 2010; Aria & Cuccurullo, 2017).

Result and Discussion

This research aims to describe research trends on sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills. Figure 1 is presented below regarding research trends on the sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills in the las ten years (obtained from app.dimensions.ai).

Figure 1 shows that the trend in research on the sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills experiencing increases. Below are also table 1 presented research of sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills based on the type of publication. 1,524 is data for macro-trend mapping (bibliometrics), while 148 is specific data filtered for micro-synthesis (SLR).

Based on Table 1, it is known that research trend by app.dimensions.ai contained in 6 types of publications. In the form of articles there were 1,524 documents, chapters as many as 250 documents, proceedings as many as 69 documents, edited books as many as 428 documents, 83 documents of monograph and 20 publications for preprint. Research trends in article form is the type of publication that contains the most research sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills compared to other types of publications. Meanwhile, the type of publication contains the least amount of research results sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills is preprint. Research conducted by Oltarzhevskyi (2019) states that an article is a complete factual essay of a certain length created for publication in online or print media (via newspapers, magazines or bulletins) and aims to convey ideas and facts that can convince and educate. These articles are usually published in scientific journals both in print and online (Suseno et al., 2020).

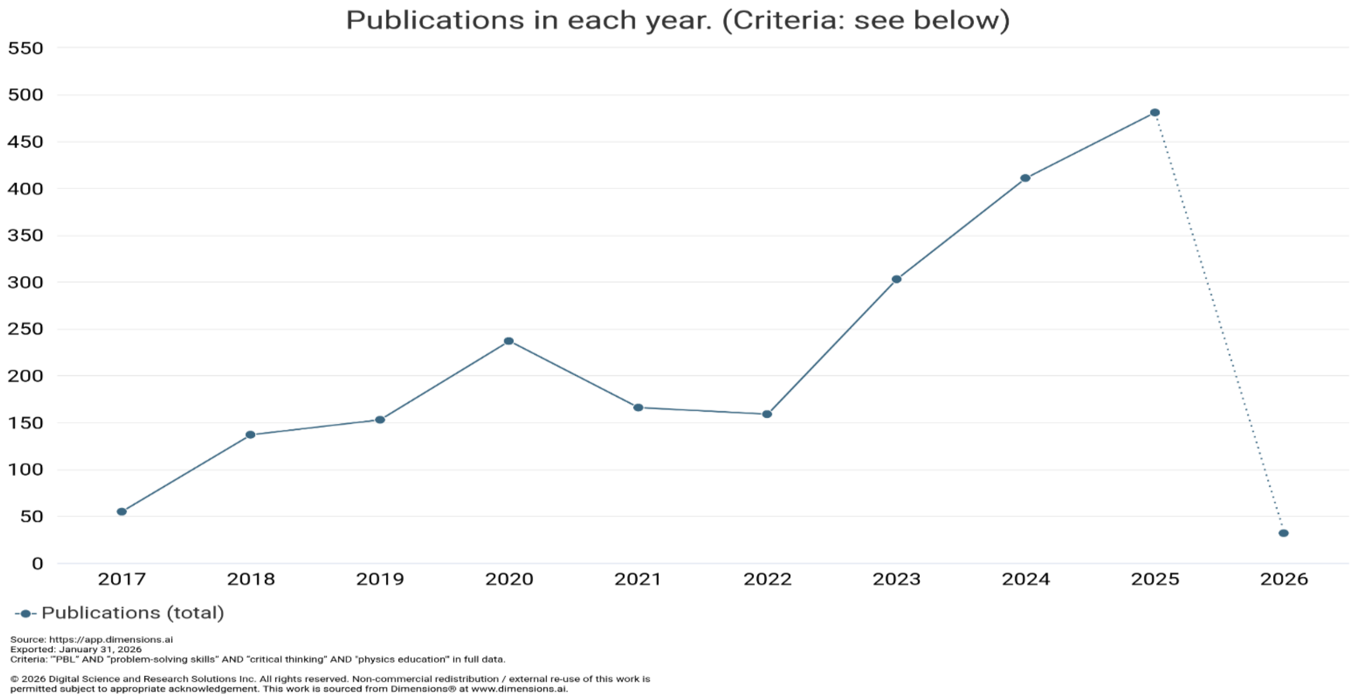

Figure 1. Research trends in sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills (app.dimensions.ai)

Table 1. Trends Research Based on Publication Types (app.dimensions.ai)

Publication Type	Publications
Article	1,524
Edited Book	428
Chapter	250
Monograph	83
Proceeding	69
Preprint	20

Below are also figure 2 presented the fields research trends in sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills. Figure 2 shows the most fields of research for research trend of sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills, namely in the criteria of education, with 1,552 publications. The most publishers are Advances in Social Science, Education and Humanities Research with 82 publications with 193 citations. The proceedings series Advances in Social Science, Education and Humanities Research aims to publish proceedings from conferences on the theories and methods in fields of social sciences, education and humanities. All proceedings in this series are open access, i.e. the articles published in them are immediately and permanently free to read, download, copy & distribute. The online publication of each proceedings is sponsored by the conference organizers and hence no additional publication fees are required.

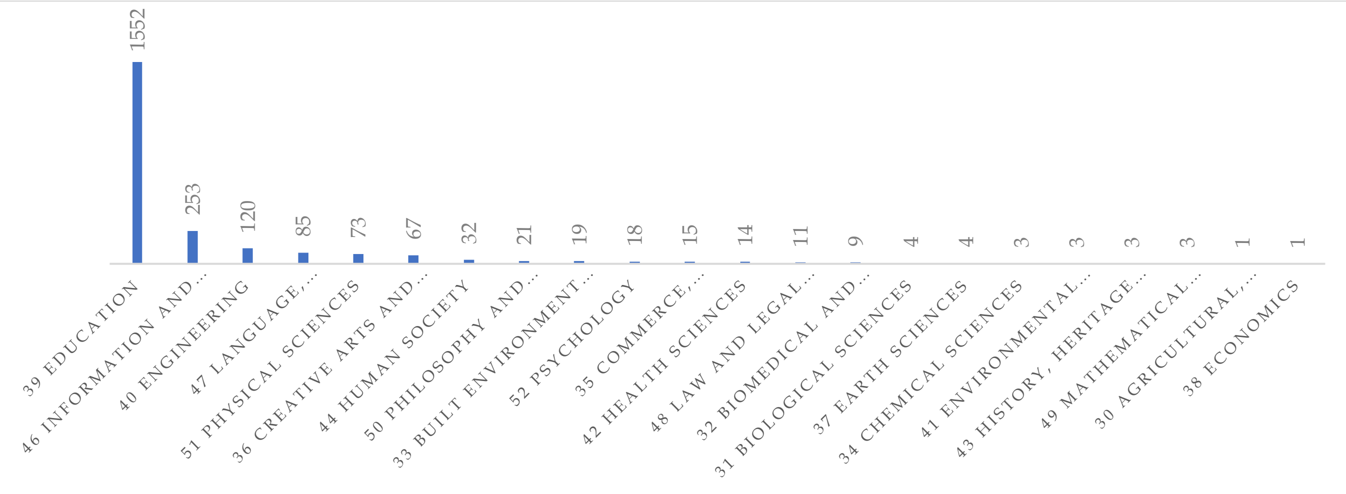

Figure 2. Research fields of Trend sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills Research

Results of Systematic Literature Review (SLR)

The review process followed the PRISMA guidelines and consisted of four systematic stages: identification, screening, eligibility, and inclusion, to ensure transparency and methodological rigor. In the identification stage, a total of 148 records were identified from two databases, including Scopus (n = 85) and SINTA (n = 63), using predefined search terms related to sensor-based linear motion kits, Problem-Based Learning (PBL), problem-solving skills, and critical thinking. All retrieved records were compiled into a reference management system.

During the screening stage, 41 duplicate records were removed, resulting in 107 unique records. These records were screened based on their titles and abstracts. As a result, 67 records were excluded because they were not relevant to physics education, did not involve sensor-based instructional media, did not apply PBL, or did not report problem-solving or critical thinking outcomes.

In the eligibility stage, 40 full-text articles were assessed in detail against the inclusion and exclusion criteria. Following full-text evaluation, 10 articles were excluded due to insufficient methodological rigor, lack of empirical data, or misalignment with linear motion or experimental physics learning contexts.

Finally, in the inclusion stage, 30 articles met all eligibility criteria and were included in the final review. These studies constituted the dataset for the Systematic Literature Review and the Bibliometric Analysis, forming the empirical foundation for identifying research trends, thematic structures, and pedagogical implications related to the development of sensor-based linear motion kits integrated with Problem-Based Learning.

Bibliometric Results: Research Trends and Knowledge Structure

The bibliometric analysis revealed a significant increase in publications related to sensor-based physics learning tools and Problem-Based Learning (PBL) over the last decade, with a notable acceleration after 2020. This trend reflects the growing demand for technology-enhanced experimental learning environments that support higher-order thinking skills in physics education (Teodorescu et al., 2020).

Keyword co-occurrence mapping showed strong linkages among the terms linear motion, sensor-based learning, Problem-Based Learning, problem-solving skills, and critical thinking. These findings indicate a convergence between experimental physics tools and constructivist learning models, positioning sensor-based kits as effective mediators for inquiry-driven learning (Srisawasdi et al., 2021).

From a theoretical perspective, PBL emphasizes ill-structured problems, collaborative inquiry, and reflective reasoning, which align well with the use of real-time sensor data in physics experiments (Hmelo-Silver, 2004). Empirical studies consistently report that students exposed to PBL-supported experimental tools demonstrate improved conceptual understanding and analytical reasoning (Fitriani et al., 2022; Gunawan et al., 2023).

SLR Findings on Learning Outcomes

The SLR results indicate that sensor-based linear motion kits significantly improve students' conceptual understanding and analytical skills when integrated with PBL scenarios (Nugraha et al., 2022; Gunawan et al., 2023). Sensors enable real-time data acquisition, supporting evidence-based reasoning and hypothesis testing.

Across quasi-experimental studies, students taught using sensor-based kits and PBL showed higher gains in problem-solving and critical thinking compared to traditional laboratory instruction (Fitriani et al., 2021).

The use of authentic problems and data-driven experimentation was identified as a key factor in these improvements.

Impact on Problem-Solving Skills

The SLR results indicate that sensor-based linear motion kits integrated with PBL significantly enhance students' problem-solving skills, particularly in identifying variables, formulating hypotheses, interpreting data, and evaluating solutions. Studies from both Scopus and SINTA-indexed journals reported medium to high effect sizes in problem-solving performance compared to traditional laboratory approaches (Rahmawati et al., 2021; Wieman & Holmes, 2020).

Sensor integration enables learners to visualize motion parameters such as displacement, velocity, and acceleration in real time, thereby reducing cognitive load associated with abstract representations (Maries & Singh, 2020). When combined with PBL scenarios, students are encouraged to iteratively test solutions and revise their reasoning based on empirical evidence, fostering adaptive problem-solving strategies (Suhendi et al., 2022).

These findings support the constructivist learning theory, which posits that knowledge is actively constructed through interaction with the environment. The empirical data confirm that sensor-based kits serve as cognitive tools that scaffold students' reasoning processes during complex problem-solving tasks (Jonassen, 2021).

In the articles researched and written by these researchers, there are many terms/keywords related to sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills. Below are presented five (5) popular keywords related to the trend.

Table 2 shows that the keywords that often appear related to research on the sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills are physics learning 13 times with a level of 0.59. Table 2 also shows that STEM is also a keyword that appears frequently in research trends, namely 5 times with a relevance of 4.58.

Table 2. Keywords on Trend research

Terms	Occurrences	Relevance
STEM	5	4.58
Project	13	1.17
Physics learning	13	0.59
Effectiveness	12	1.40
PBL	7	1.36

Below are the visualization is accomplished by generating a landscape map, which offers a visual representation of subjects related to scientific studies. The outcomes of bibliometric mapping for the co-word network in articles related to the topic sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills are illustrated in Figure 3.

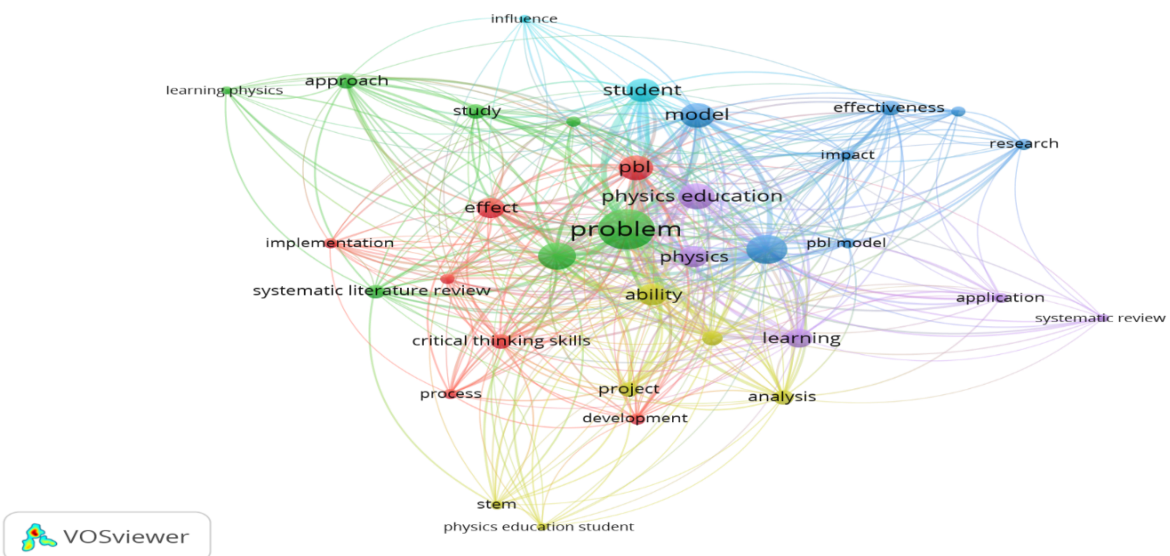

Figure 3. Network visualization on trend sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills research

Figure 3 shows the results of bibliometric keyword mapping on research trends on the topic sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills. In Figure 3 there are 34 keyword items that are often used in research on the sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills. Figure 3 also contains 6 clusters, Cluster 1 (red) shows the relationship between kit development and its effect on learning, while Cluster 2 (green) focuses on the SLR methodology in physics education. The third cluster in blue consists of 7 keyword items, namely effectiveness, meta analysis, etc. The fourth yellow cluster consists of 6 keyword items, namely project, STEM, etc. The fifth cluster consists 5 items and the sixth cluster only consists 2 items.

Figure 3 above also shows that network visualization shows the network between the terms being visualized. Keywords classified into four clusters are arranged in a color chart showing the divisions/clusters that are connected to each other. The results of this analysis can be used to determine keyword research trends in the last year. This analysis shows several keywords that are often used in research on the sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills. The more keywords that appear, the wider the visualization displayed. Below are also presented keywords regarding the sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills based on overlay visualization.

Figure 4 shows the trend of keywords related to research on sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills in Google Scholar indexed journals. Trends in the themes of writing articles related to sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills from the oldest to the newest year are marked with purple, blue themes, turquoise, dark green, light green and yellow.

Enhancement of Critical Thinking Skills

Critical thinking emerged as a dominant outcome variable in the reviewed studies. Students engaged in PBL-supported sensor experiments demonstrated significant improvements in analysis, inference, evaluation, and argumentation skills (Susilawati et al., 2023). Bibliometric clustering revealed that critical thinking is frequently associated with inquiry learning, data literacy, and experimental design competencies.

Theoretically, critical thinking development is closely linked to opportunities for evidence-based reasoning and reflective judgment. Sensor-based experiments provide authentic datasets that challenge students to question assumptions and justify conclusions (Facione, 2020). PBL further amplifies this effect by situating learning within real-world problem contexts that require decision-making and justification (Kokotsaki et al., 2021).

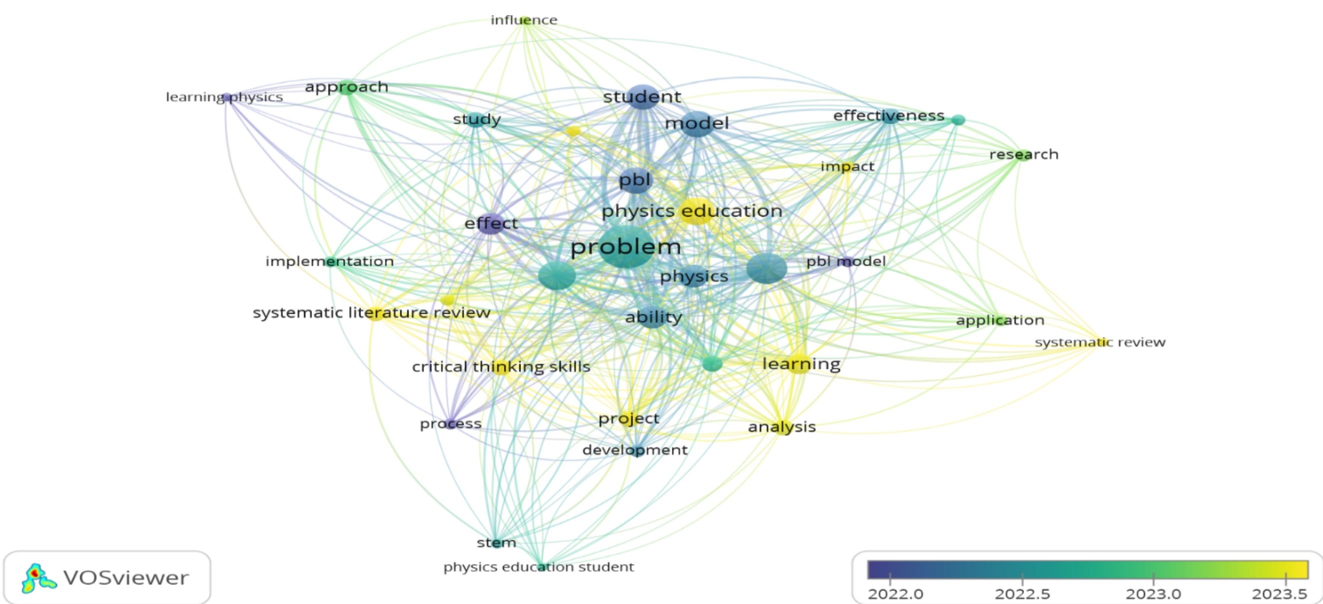

Figure 4. Overlay visualization on trend sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills research

From an instructional standpoint, these findings imply that the integration of sensor-based kits with PBL not only improves learning outcomes but also aligns with 21st-century skills frameworks emphasizing critical and analytical thinking (OECD, 2021).

Research on sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills is one area of research that has developed rapidly in recent years. The following also presents keywords for sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills research based on density visualization.

Figure 5 shows density visualization. The density of research themes is shown in bright yellow. The brighter the colors of a theme, the more research is done. The fainter the color means the theme is rarely researched (Kaur et al., 2022; Liao et al., 2018). Faintly colored themes shows that these keywords can be used as a reference for further research. While yellow indicates keywords that are currently and frequently used in research (Doyan et al., 2024, 2025).

Pedagogical and Practical Implications

The synthesis of SLR and bibliometric findings suggests that the development of sensor-based linear motion kits grounded in PBL principles represents a pedagogically sound and scalable innovation for physics education. Such kits support active experimentation, promote data-driven reasoning, and facilitate collaborative problem-solving.

For educators, this model provides a practical framework for designing physics instruction that bridges theory and practice. For researchers, the identified gaps—particularly the limited longitudinal studies and small sample sizes—highlight directions for future research. Policymakers and curriculum developers may leverage these insights to support technology-enhanced STEM learning initiatives.

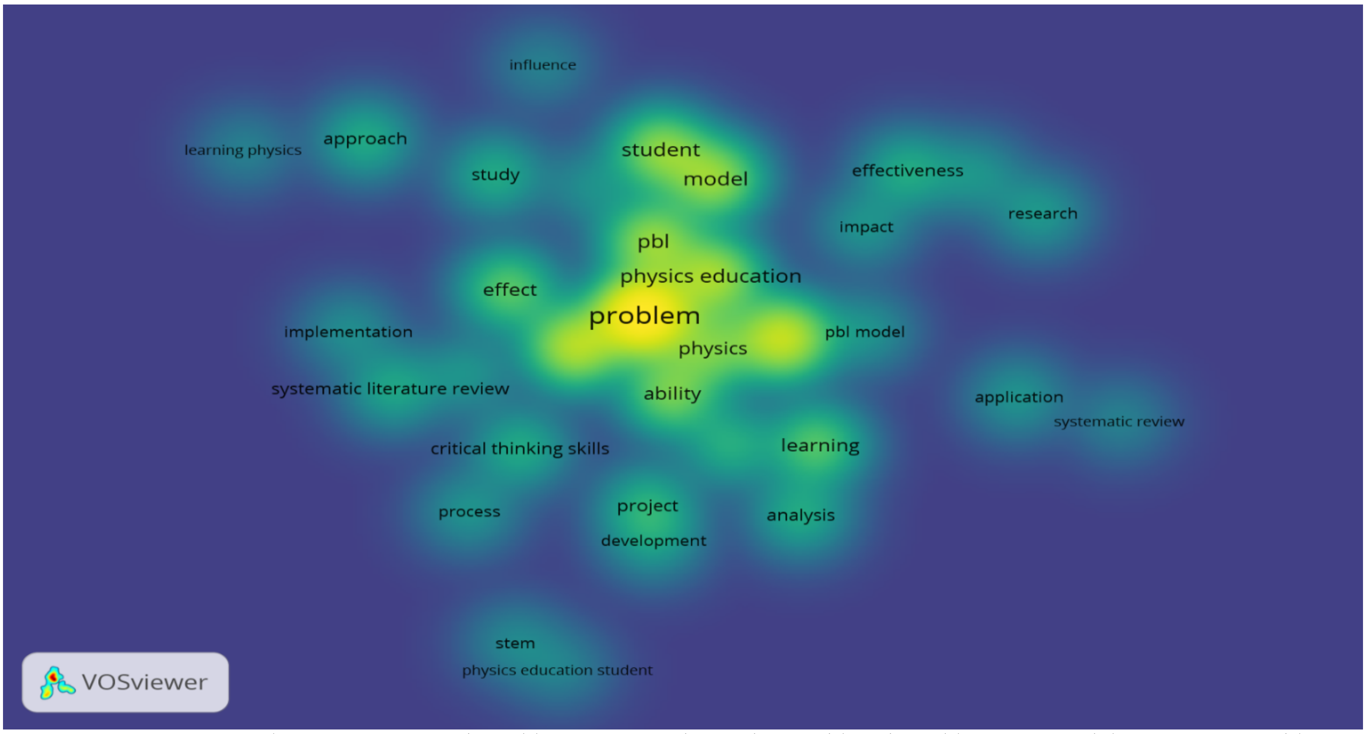

Figure 5. Density visualization on sensor-based linear motion kit with a problem-based learning model to improve problem-solving and critical thinking skills research

Despite extensive research on Problem-Based Learning (PBL) and technology-enhanced physics instruction, existing studies largely treat instructional models and experimental tools as separate interventions, with limited integration of sensor-based kits within structured PBL frameworks. Moreover, most prior research emphasizes conceptual understanding rather than explicitly targeting higher-order cognitive skills such as problem-solving and critical thinking, while the use of scalable, low-cost, and curriculum-aligned sensor kits remains underexplored. Methodologically, previous reviews tend to rely on either systematic synthesis or bibliometric mapping alone, resulting in fragmented insights into research trends and pedagogical effectiveness. Addressing these gaps, this study contributes by proposing an integrated framework for developing sensor-based linear motion kits embedded in a PBL model, focusing explicitly on problem-solving and critical thinking outcomes, and employing a Hybrid Systematic Literature Review and Bibliometric Review to provide a comprehensive, evidence-based synthesis that informs future research and instructional design in physics education.

Conclusion

The synthesis of existing literaturedemonstrates that integrating sensor-based linear motion kits within a Problem-Based Learning framework constitutes a pedagogically effective approach for enhancing students' problem-solving and critical thinking skills in physics education. The Hybrid SLR and bibliometric analysis reveal consistent evidence that real-time sensor data, when aligned with structured problem-solving activities, supports deeper conceptual understanding and higher-order cognitive engagement. The bibliometric mapping identifies a significant upward trend in publications since 2020, with 'STEM integration' and 'Real-time data' emerging as the most dominant research clusters. Despite increasing research interest, gaps remain in the development of scalable, low-cost, and curriculum-aligned kits, as well as in longitudinal empirical validation. Therefore, future studies should focus on design-based and long-term implementations to strengthen the evidence base and expand the applicability of sensor-supported PBL in diverse educational contexts.

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Author Contributions
Conceptualization, S and P. S; methodology, S., J. and S.A.; formal analysis, S and S.A; investigation, J; resources, S and P. S.; writing—preparation of original draft, S and J.; writing—reviewing and editing, S., J. and S.A.; visualization, J; supervision, S; project administration, S. All authors have read and approved the published version of the manuscript.

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