

DOI: 10.5281/zenodo.1250001

## Knowledge Integration Approach for Building Profound Conceptual Understanding in Physics Learning: A Systematic Literature Review

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Received: 10/03/2026

Accepted: 14/04/2026

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### ABSTRACT

Conceptual understanding is a fundamental aspect of physics learning. However, many studies show students still struggle to develop integrated knowledge structures. Resource theory offers an alternative by emphasizing the importance of activating and integrating students' prior knowledge. One approach rooted in this theory is knowledge integration, which aims to help students build coherent networks of ideas by reinforcing central ideas. This study is a systematic literature review of 22 Scopus-indexed articles discussing the application of knowledge integration in physics learning since 2002. The method used refers to the systematic procedure of Petticrew and Roberts, including the stages of search, selection, critical analysis, and synthesis of findings. The study shows that the knowledge integration approach can enhance students' conceptual understanding, strengthen the latent knowledge structure, and facilitate the transition from novice to expert student profiles. The systematic literature review results found consistency in the application of the approach in learning, namely: (1) the development of a conceptual framework, (2) the development of knowledge integration-based assessment, and (3) learning interventions. More in depth, the results of this study also offer a simple, strategic pattern that can serve as a guide for further research.

**KEYWORDS:** Knowledge Integration, Physics Learning, Resource Theory, Systematic Literature Review.

## **INTRODUCTION**

Students' difficulties in understanding physics concepts have been a major concern in science education for decades (Chiu et al., 2007; Maries & Singh, 2018). Various intervention efforts have been made to address this issue, such as the use of learning models (Ruiz-Martín & Bybee, 2022; Setemen et al., 2023), changes to textbook content (Barbieri et al., 2023; Güven & Özmen, 2022), resource-based multi-representation learning (Munfaridah et al., 2021; Waldrip & Rusdiana, 2012), using resource graphs (Wittmann, 2006), peer instruction learning (Wood et al., 2014), or the application of educational videos (Fyfield et al., 2022; Wray et al., 2021). However, several studies still indicate that certain conceptual aspects remain unresolved (Bahtaji, 2023; Tsivitanidou et al., 2021), and many students still struggle to achieve a comprehensive understanding of physics concepts (Ashley et al., 2023; Rahayu et al., 2019; Salmento et al., 2021). Therefore, some studies emphasize the importance of implementing interventions that develop students' knowledge structures, as per the resource theory perspective, to address difficulties in students' conceptual understanding (Robertson et al., 2023; Soeharto & Csapó, 2021). In response to these issues, the knowledge integration approach emerged as a pedagogical framework grounded in resource theory and has been widely adopted in both educational research and instructional interventions in recent years. Currently, the knowledge integration approach, revitalized and prominently advanced by Bao and Koenig (2019), has been widely implemented in physics education research across China and the United States. This approach emphasizes the identification, articulation, and refinement of students' intuitive ideas to support the development of a coherent and well-organized network of knowledge (Dai et al., 2019; Lu et al., 2023; Nie et al., 2019; Wang et al., 2019; Xie et al., 2021). Such networks are structured around central ideas that function as conceptual anchors in the development of students' understanding (Bao & Fritchman, 2021a; Lu et al., 2023; Xu et al., 2020; Ye et al., 2024). In this context, the Knowledge Integration approach becomes highly relevant and urgent to apply in physics education. Physics, as a discipline that emphasizes the relationships between concepts and real-world phenomena, requires a knowledge structure that is not only broad but also deeply organized and cohesive (Bao & Redish, 2006; Lu et al., 2023). Unlike the social sciences and humanities, which tend to be narrative, interpretive, and contextual, scientific fields such as physics, chemistry, and biology require strong conceptual integration to bridge theoretical and applied understanding. This is evident from the dominance of

the Knowledge Integration approach, which is currently more prevalent in science education contexts (Nie et al., 2019; Wang et al., 2019; Xu et al., 2020) compared to non-science fields. Even within the science field itself, this approach is most widely implemented in physics education due to the complexity of hierarchical, intertwined relationships among concepts such as force, motion, and energy (Ding et al., 2024; Lu et al., 2023; Ye et al., 2024). Therefore, narrowing this systematic study to the field of physics provides greater urgency and more meaningful contributions, both theoretical and practical. Several studies have demonstrated the success of the knowledge integration approach in improving students' understanding of physics concepts. The materials studied include measurement (Lu et al., 2023), force and motion (Bao & Fritchman, 2021a, 2021; Ding et al., 2024; Nie et al., 2019), Friction (Wang et al., 2019), momentum and impulse (Xu et al., 2020, 2023), work and energy (Tong et al., 2023), mechanical waves (Xie et al., 2021), light interference (Dai et al., 2019), electromagnetic induction (Xiao & Bao, 2024), dan electricity (Liu et al., 2022). This success was supported by a conceptual framework that visually mapped the structure of knowledge and the relationships between ideas (Nie et al., 2019).

The knowledge integration approach based on resource theory has shown great potential in strengthening students' knowledge structures (Bao & Fritchman, 2021b; Ding et al., 2024; Lu et al., 2023; Nie et al., 2019; Xu et al., 2020). This approach has been implemented since 2002 until the writing of this article. Therefore, it is necessary to systematically summarize and analyze developments, intervention patterns, and research trends in this field (Loh et al., 2023; Moreno et al., 2024). This systematic review is essential for mapping how this approach is implemented in learning, particularly in physics. Furthermore, this literature review will discuss the development of the instruments used, changes in the knowledge structure, and the extent to which this approach contributes to the development of a profound conceptual understanding. Through the Systematic Literature Review research process, this study will not only identify gaps that have not been revealed in the literature but also provide simple patterns and strategic directions for further meaningful research (Banha et al., 2022; Manso et al., 2024; Savastano et al., 2019). Therefore, this study attempts to answer two research questions:

- RQ 1:** How are the patterns and strategies of knowledge integration applied in physics learning to build student's profound conceptual understanding?
- RQ 2:** How successful are knowledge integration-based learning in physics learning?

## **RESEARCH METHOD**

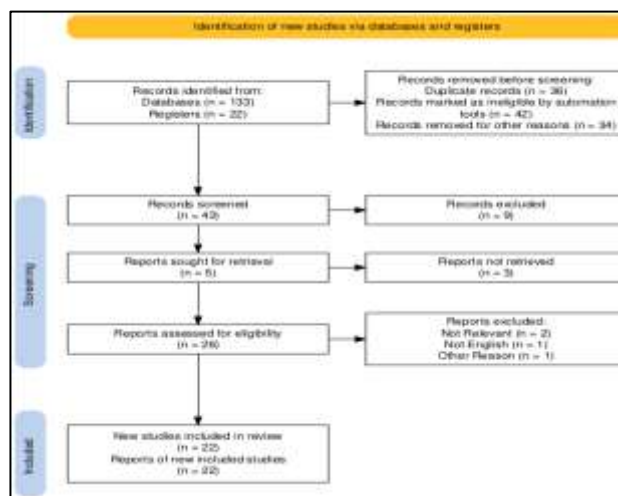
This study adopts a systematic, structured approach outlined by Peticrew and Roberts (2008). The research was conducted using a structured, comprehensive search of articles relevant to the research questions. This began with defining the research questions, establishing inclusion and exclusion criteria, searching and sorting articles, critical appraisal, and

in-depth analysis (Myung, 2023; Sargeant & O'Connor, 2020). Various efforts were made to ensure that the articles obtained could answer the research questions posed (Petticrew & Roberts, 2008). Inclusion criteria were determined based on the research title and its details. Several considerations were taken into account, including findings on knowledge integration, the use of physics as a research topic, the development of a conceptual framework for the research, and the development of related instruments. The inclusion and exclusion criteria are clearly presented in Table 1.

**Table 1: Inclusion and Exclusion Criteria.**

Inclusions Criteria	Exclusion Notes
The journal is published at intervals between 2002 and 2025.	Journals published before the specified time period.
The journal index is Scopus.	Journals not indexed by Scopus.
The learning approach used is Knowledge Integration.	Other approaches such as STEM, STEAM, student-centered learning, etc.
The research topic is science and physics education.	Articles with other research topics, such as social sciences, humanities, etc.
The research results include one of three discussions: (1) development/application of a conceptual framework, (2) development/assessment of indicators, and (3) intervention in learning.	Research results that do not include any of the three topics mentioned above.

The article search process involved collecting research results from several main databases, namely IOP Publishing, AAPT Publications, and APS Publications, as well as the popular Scopus article search application. The search was conducted using a combination of several terms related to knowledge integration (conceptual integration, idea integration, conceptual linking, cognitive integration, and knowledge organization). In addition, it was specific to several keywords (physics, science education, physics education) and was also used several times with specific physics topics, such as Newton’s laws, impulse, and momentum, among others. The total number of articles obtained by entering each keyword into the web database was 155, with details as follows: IOP Publishing 21, AAPT Publications 10, APS Publications 44, Publish or Perish 58, and 22 from other sources. Additionally, the search was conducted using the snowball strategy, starting with referenced articles that met the criteria. The flow diagram of the paper inclusion and exclusion process is shown in Figure 1.



**Figure 1: PRISMA Flow Diagram.**

## RESULTS AND DISCUSSION

### Patterns and Strategies for Knowledge Integration in Physics Learning

The knowledge integration approach is a learning process that aims to help students develop a coherent, comprehensive knowledge structure (Bao & Fritchman, 2021a, 2021b; Ding et al., 2024; Nie et al., 2019). This approach was first researched in the field of learning by Linn and Eylon (2000), who focused on integrating knowledge to understand science and promote lifelong science learning (Linn & Eylon, 2000). Recent research by Bao (2019) specializes in knowledge integration in physics learning (Bao et al., 2019). The approach aims to help students build a deeper and more integrated understanding (Bao & Fritchman, 2021a). Bao's approach can be considered an application of Linn's principles of knowledge integration in physics education, with an emphasis on conceptual analysis and targeted instruction to address students' conceptual difficulties. This approach has also been used across various physics concepts, and some studies show that knowledge integration effectively improves students' conceptual understanding (Nie et al., 2019; Xu et al., 2024; Xie et al., 2021; Y. Ding et al., 2024).

The results of the review and critical analysis of the 22 articles studied in this study reveal consistent research patterns in the application of the knowledge integration approach in science learning. These patterns reflect the main focus of researchers in developing learning strategies that are not only conceptual but also applicable in improving student understanding. In general, three major patterns were found to be the main focus of the studies, namely the implementation of a conceptual framework (Bao & Fritchman, 2021a; Lu et al., 2023; Xu et al., 2023), the design of knowledge integration-based assessments (Wang et al., 2019; Xiao & Bao, 2024; Xu et al., 2020; Ye et al., 2024), and the implementation of learning interventions to promote more effective knowledge integration (Ding et al., 2024; Linn & Eylon, 2005; Nie et al., 2019; Xie et al., 2021). This subchapter will explain the first two aspects, namely the implementation of the Conceptual Framework and the design of knowledge integration-based assessment, while the third discussion on the implementation of knowledge integration in learning will be included in the next subchapter, along with its success.

### 3.2 Implementation of Conceptual Framework

The conceptual framework serves as the main guideline for knowledge Integration-based learning. In its implementation, the conceptual framework is used to visualize students' thinking flows and patterns, compared with those of experts (Bao & Fritchman, 2021b; Lu et al., 2023; Xu et al., 2023). In general, students' thinking patterns differ from those of experts when understanding a concept. Therefore, a conceptual framework helps educators identify the connections and differences in students' thinking patterns. This understanding is expected to facilitate educators in designing appropriate learning scenarios, using students' prior knowledge structure as the main foundation, in line with the principles of resource theory in learning.

The first step in developing a conceptual framework is to identify the central idea of a topic (Bao & Fritchman, 2021a; Lu et al., 2023; Xu et al., 2023). The central idea here is a main concept that serves as an anchor for resolving various contexts within the topic (Dai et al., 2019; Lu et al., 2023; Nie et al., 2019). Table 2 below presents central ideas explicitly identified by researchers in their studies.

**Table 2: Central Idea of Each Topic in Physics.**

Topics	Central Idea	Article
Measurement Uncertainty	Systematic uncertainty + random uncertainty	Lu et al., 2023
Force and Motion	$\Sigma F = ma$	Nie et al., 2019
Newton's Third Law	Force as interaction and symmetrical pairs	Bao & Fritchman, 2021a, 2021b
Impulse and Momentum	$\Delta p = F_{net}\Delta t$	Xu et al., 2020
Friction	Passivity of Friction Force	Wang et al., 2019
Mechanical Waves	Expert: wave interpretation Novice: particle interpretation	Xie et al., 2021

Topics	Central Idea	Article
Work and Energy	$W_{net} = W_{nc} - \Delta U = \Delta K$	Tong et al., 2023
Light Interference	Phase difference + wave superposition	Dai et al., 2023
Simple Electricity	Integrate three concepts, namely the principle of electric current, mathematical equations, and the conservation of charge and current.	Liu et al., 2022

These central ideas serve as a crucial starting point for building a cohesive conceptual framework and play an important role in designing learning strategies and analyses oriented toward a deep understanding of the topics being studied.

### 3.3 Design of Knowledge Integration-based Assessment

In an effort to identify students' level of knowledge integration, Linn et al. (2003) conducted research on Knowledge Integration assessment using essay questions. In this study, they used a tiered scoring rubric (from non-normative to complex link) to evaluate how students relate and integrate various scientific ideas. The content focus was on general science learning (not specific to physics), and the study aimed to develop a framework and rubric for Knowledge Integration assessment and inquiry-based curriculum design. Furthermore, this assessment does not merely evaluate answers as correct or incorrect but assesses how well students can connect and integrate various ideas in their responses to a problem (Schmidt et al., 2021; Sreenivasa et al., 2022). Thus, the Knowledge Integration assessment developed by Linn provides a relevant evaluative tool for detecting the extent to which students have constructed increasingly scientific conceptual representations (Mahadini et al., 2021; Ozfidan & Mitchell, 2022).

On the other hand, the latest knowledge integration approach, pioneered by Bao et al. (2019), uses multiple-choice questions to assess students' understanding. Bao et al. (2019) also use conceptual framework visualizations to help teachers map and visualize students' thought processes. Bao et al. (2019) uses resource theory to map students' thinking patterns as a dynamic system composed of various knowledge resources (resources) that can be activated and reorganized in a learning context. Furthermore, the knowledge integration approach by Bao et al. (2019) also classifies students into three categories of knowledge integration levels, namely novice, transition, and expert. To support this classification, a special assessment form was developed that utilizes two types of questions, namely typical and atypical (Wang et al., 2019; Xiao & Bao, 2024; Xu et al., 2020; Ye et al., 2024). Typical questions refer to standard questions commonly found in textbooks, with contexts and variables that are general and familiar to students (Ye et al., 2024). In contrast, atypical questions are designed to challenge students' ability to integrate concepts by presenting unusual problems that require the combination of various physics concepts into a single central idea in the problem-solving process (Maries et al., 2017). Other research conducted by Xie et al. (2021) and Liu et al. (2022) further enriched the knowledge integration assessment features by examining students' abilities to solve questions at three levels of complexity: single-link typical, multilink typical, and integrated-link atypical. These three types of questions represent a gradation of interrelationships between concepts required in the solution process, ranging from simple interrelationships to complex and unusual conceptual relationships. Thus, students' ability to tackle each type of question reflects the level of knowledge integration they have developed. To support this analysis, Table 3 was compiled to illustrate the characteristic design of each question type and the typical abilities demonstrated by students at various skill levels, ranging from novice to expert.

**Table 3: Question Design to Assess Knowledge Integration.**

Knowledge Integration	Single-Link Typical	Multilink Typical	Integrated-Link Atypical
Novice level	Sometimes successful	Rarely successful	Guessing/using a novice model
Transition Level	Mostly successful	Often successful	Sometimes successful
Expert level	Always successful	Always successful	Mostly successful

Thus, the classification of student abilities by question type and skill level, as shown in Table 3, provides a systematic, measurable framework for evaluating the level of knowledge integration. Through this mapping, educators and researchers can better understand how students' thinking patterns develop as their ability to connect various concepts improves. In addition, the information obtained from this assessment can be used to design more targeted learning interventions that encourage deeper, more meaningful knowledge integration.

### **Success of Intervention in Learning and Its Outcomes**

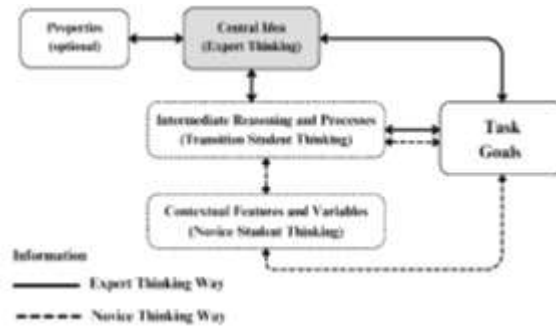
Knowledge integration-based research has been extensively conducted using a two-group experimental design, consisting of a control group receiving conventional instruction and an experimental group receiving knowledge integration-based instruction (Dai et al., 2019; Nie et al., 2019; Tong et al., 2023). In the intervention group, students were introduced to central ideas earlier and more explicitly. Each learning session systematically connects these central ideas with various relevant principles and new contexts, thereby encouraging students to build a more integrated understanding. Additionally, this approach consistently emphasizes the development of causal reasoning rather than merely procedural reasoning, prompting students to understand why a phenomenon occurs rather than just how to solve a problem. In contrast, the control group focused on a traditional teaching approach, which emphasized routine problem solving and mastery of laws or concepts in isolation, without explicitly linking concepts. This approach tends to result in fragmented understanding, where students know individual concepts but are not yet fully able to integrate them in understanding phenomena as a whole (González-Marcos et al., 2021; Overskott et al., 2024).

After implementing knowledge integration-based learning interventions in the experimental class, the researchers found that this approach was successful. Students in the experimental class showed increased deep understanding of concepts (Dai et al., 2019; Nie et al., 2019; Tong et al., 2023). They were also able to connect various ideas and apply them in new situations. In general, students' knowledge structure in the intervention class became more integrated and flexible. They did not just memorize formulas, but also understood the relationships between concepts. Students also demonstrated more logical reasoning based on the central ideas of a concept. In contrast, students in the control class tended to rely on memorization and procedures. They struggled when faced with problems in new or unfamiliar contexts. This suggests that the knowledge integration intervention helps construct more conceptual and transferable understanding.

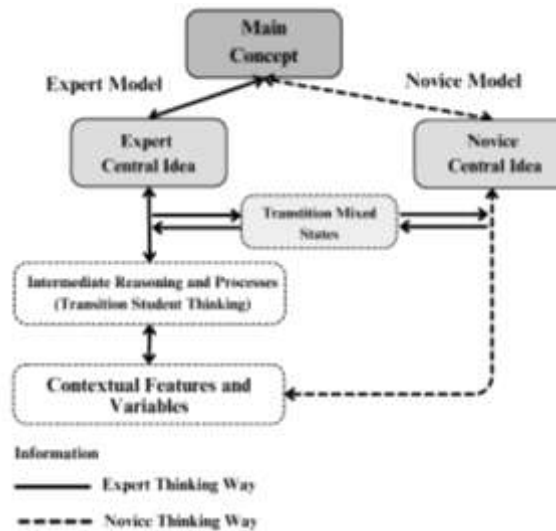
In a study by Xu et al. (2023) about momentum learning, students in the experimental class who received conceptual framework-based instruction showed significant improvements in understanding the relationship between force, time, and changes in momentum. They were not only able to solve momentum conservation problems but also explain the reasons behind the law using causal reasoning based on the impulse-momentum theorem. In contrast, students in the control class were more focused on formulas without a deep understanding of the concept of impulse, and they struggled when faced with problems in unfamiliar contexts. Similarly, in developing a framework for Newton's third law by Bao and Fritchman (2021a, 2021b), the designed intervention emphasized that force results from simultaneous interactions between two objects. Students who received this approach demonstrated the ability to avoid common misconceptions, such as the assumption that larger objects exert greater force, and to identify pairs of interacting forces in various contexts correctly. This suggests they developed a deeper, more stable understanding than traditional approaches that rely on misleading "action-reaction" language. Similar findings emerged in a study by Xu et al. (2020) on measurement uncertainty. Students in the intervention class, who learned using a conceptual framework of uncertainty, were able to identify various sources of uncertainty (random and systematic) and explain the experimental process as a complex interaction between humans, tools, and the environment. They also demonstrated reflective thinking by comparing two experimental results and by understanding the statistical meaning of the experimental data. In contrast, students who learned only through traditional approaches tended to view uncertainty as a technical or procedural error rather than an inherent characteristic of scientific measurement. On the other hand, research by Nie et al. (2019) provides empirical evidence that knowledge integration learning can change students' latent profiles, namely the hidden characteristics of their understanding patterns of style and motion concepts. Latent profile analysis is used to identify latent groups (profiles) within a population based on patterns across multiple variables (Bu et al., 2023; Shin et al., 2022; Spurk et al., 2020). Using latent profile analysis (Troia et al., 2019), students were categorized into three conceptual profiles: expert, transition, and novice. The results of the intervention show that knowledge-integration-based learning can encourage students to move from profiles 3 or 2 to profile 1 (Z. Liu et al., 2022). This transition is more significant in the knowledge integration-based teaching group than in the traditional teaching control group. This finding indicates that knowledge integration not only improves surface-level performance but also transforms students' underlying conceptual understanding. Through this process, fragmented ideas are reorganized into more coherent and scientifically consistent knowledge structures. As a result, students can apply concepts more flexibly and engage in deeper reasoning when solving problems.

### **Findings, Implications, and Future Research Directions**

By observing the conceptual framework patterns in 14 of the 22 reviewed articles, this study identifies two main design models: (1) a hierarchical structure from novice to expert with interconnected pathways (Bao & Fritchman, 2021a; Liu et al., 2024; Lu et al., 2023; Nie et al., 2019; Tong et al., 2023; Xu et al., 2023), and (2) a parallel structure contrasting novice and expert thinking with transitional pathways (Xie et al., 2021). These models suggest that conceptual understanding can develop gradually or through shifts between different ways of thinking, influenced by instructional strategies, learning environments, student engagement, prior knowledge activation, opportunities for meaningful concept integration, and continuous reflection processes that support deeper conceptual restructuring. Therefore, this study proposes a simplified pattern for developing conceptual frameworks, as illustrated in Figures 2 and 3.



**Figure 2: Sketch of Conceptual Framework Second Model.**



**Figure 3: Sketch of Conceptual Framework Second Model.**

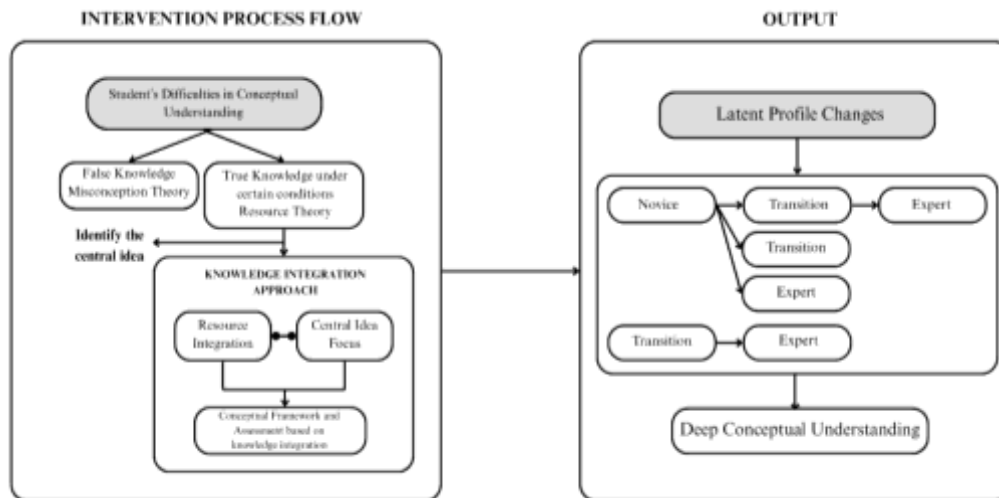
Figure 2 presents the first conceptual framework, which organizes students' levels of understanding hierarchically from bottom to top (Bao & Fritchman, 2021a; Xu et al., 2023). In this model, novice students' thinking is placed at the bottom, transitional student's thinking in the middle, and expert thinking at the top. Central ideas are the main focus points directly connected to transitional thinking, while novice thinking is linked through weaker, separate paths (Dai et al., 2019; Xie et al., 2021). The relationship to task goals or learning objectives flows from the central idea and transitional thinking, illustrating that transitional thinking plays an important role in the maturation of understanding. This model reflects a gradual development process in which students move from an initial understanding to a more scientific and integrated understanding by activating the central idea and strengthening conceptual connections.

Meanwhile, Figure 3 shows the second conceptual framework, which organizes students' thinking in parallel. In this model, there are two parallel lines of thinking: the expert model on the right and the novice model on the left. The central ideas for both novices and experts are placed side by side and connected to the transitional thinking. Transitional thinking serves as a bridge, enabling movement or shifts in understanding between the novice and expert pathways. At the bottom, novice students' thinking is still shown as the foundation that needs to be transformed. This model emphasizes the importance of a horizontal shift in thinking patterns, in which students gradually build a more sophisticated understanding through exploration and comparison of novice and expert representations, rather than through linear, hierarchical development.

The differences in the design of the two conceptual frameworks show that students' understanding of science learning (including physics) is not static, but develops dynamically through distinctive stages. To understand how this shift in understanding occurs, it is important to examine in depth the characteristics of students at each level of understanding, namely novice, transition, and expert. Each level represents different ways of thinking, cognitive tendencies, and qualities of knowledge integration. By understanding the characteristics of each level, educators can design more targeted learning interventions to encourage a shift in understanding toward more scientific conceptual representations.

Based on the findings described above, this study has successfully formulated a systematic framework that can serve as a reference for researchers and education practitioners when designing and implementing knowledge integration-based learning. This pattern includes a series of strategic stages to ensure the learning process is structured, starting with

identifying central ideas, developing a conceptual framework, preparing appropriate assessment instruments, and planning effective learning interventions. Each stage is described comprehensively and visualized more clearly in Figure 4.



**Figure 4: Intervention Patterns in Knowledge Integration Learning Approaches.**

This entire flow shows how knowledge integration learning can serve as a systematic framework to improve students' knowledge structures, integrate conceptual understanding, and develop them from novice learners to expert-like scientific understanding. The first stage is the intervention process flow. The flow begins with students' difficulties in mastering concepts, which can be caused by two things: (1) incorrect knowledge or misconceptions, which are ideas that contradict science (Bahtaji, 2023; Haryono & Aini, 2021; Laliyo et al., 2019; Yuliasari et al., 2023), (2) correct knowledge in certain conditions (resource theory), which is a correct understanding but only applicable in a limited context (Richards et al., 2020; Scheer, 2007). The study then chose the second option, resource theory, which assumes that students have a correct knowledge structure. This correct knowledge structure then becomes the starting point for knowledge integration. Then, an intervention was carried out in the form of Knowledge Integration-based learning, which began by establishing central ideas for the topics to be further intervened on. At this stage, there are two main components: (1) resource integration, which involves linking students' knowledge fragments to correct scientific concepts, and (2) focus on the central idea, which emphasizes understanding the core principles of a physics concept. Both are supported by the development of a Conceptual Framework and knowledge integration-based assessment, which help design instruction and evaluation to build a connected knowledge structure (Liu et al., 2024; Lu et al., 2023; Tong et al., 2023; Xu et al., 2023; Bao & Fritchman, 2021a; Nie et al., 2019). The second stage is output (student profile development and profound conceptual understanding). Through this learning process, students can progress from one level of development to the next: novice to transition, and finally to expert. This process

can be direct or gradual, depending on the effectiveness of integrating ideas and context. (Wood et al., 2014; Nie et al., 2019; Vančugovienė et al., 2024). This leads to the outcome: a deep understanding of the concept, marked by students' ability to relate ideas across various contexts. In addition, changes in students' latent profiles, namely the transformation of the hidden knowledge structure from fragmentation to integration, are indicators of the achievement of a deep understanding of the concept. Thus, the findings presented in this subsection are expected to enrich the references available to researchers and education practitioners in designing Knowledge Integration-based learning interventions. The visual presentation of the conceptual framework design and the systematically arranged intervention stages provide simpler, more structured, and flexible guidelines that can be easily adapted to various physics learning contexts. This design is intended not only to help students integrate knowledge in a more meaningful way but also to encourage a shift in thinking toward a more comprehensive, scientific conceptual understanding (Juliangkary et al., 2024; Widiyatmoko & Shimizu, 2018). Additionally, these findings open opportunities for future researchers to explore and integrate various learning models aligned with the principles of Knowledge Integration, such as the learning cycle (Sharma, 2018; Jaya et al., 2023), project-based learning (Loyens et al., 2023; Nicholus et al., 2023; Santhosh et al., 2023), or model-based inquiry (Sam, 2024; Strat et al., 2024; Lammert, 2020). This development effort is expected to contribute to the creation of more effective, adaptive, and high-quality physics learning, ultimately supporting the achievement of student competencies in the conceptual domain and higher-order thinking skills.

## CONCLUSION

Based on a collection of in-depth research, the findings show that the knowledge integration approach follows a specific research pattern. The researchers' analysis of the articles shows that knowledge integration research begins by identifying central ideas to create a path of thinking for experts and students within a conceptual framework sketch. The results are then used to develop a knowledge integration-based assessment. The final stage is to apply the conceptual framework and assessment in learning to determine students' level of understanding. Uniquely, this systematic literature review not only discusses the body of research on knowledge integration but also examines the collection of research on it. This study also aims to provide a simple conceptual framework for the researchers, an explanation of assessment development indicators, and a research flow that can serve as a reference for readers. Knowledge integration-based instruction explicitly emphasizes connections among concepts through central ideas, consistently improves students' understanding, reduces reliance on memorization, and shifts students' latent profiles toward a more integrated level. Thus, knowledge integration provides a strong, comprehensive framework for designing learning and evaluation that promotes the transformation of students' understanding from novice to expert levels.

## ACKNOWLEDGEMENTS

This research was supported by Lembaga Pengelola Dana Pendidikan (LPDP). Any opinions expressed in this article are those of the authors and do not necessarily reflect the views of LPDP.

## REFERENCES

1. Ashley, S., Schaap, H., & de Bruijn, E. (2023). Illustrating conceptual understanding in international business undergraduate writing. *Research Papers in Education*, 38(4), 499–519. <https://doi.org/10.1080/02671522.2022.2030394>
2. Bahtaji, M. A. A. (2023). Examining the physics conceptions, science engagement and misconceptions of undergraduate students in STEM. *Journal of Baltic Science Education*, 22(1), 10–19. <https://doi.org/10.33225/jbse/23.22.10>
3. Banha, F., Coelho, L. S., & Flores, A. (2022). Entrepreneurship education: a systematic literature review and identification of an existing gap in the field. *Education Sciences*, 12(5). <https://doi.org/10.3390/educsci12050336>
4. Bao, L., & Fritchman, J. C. (2021a). Development of a conceptual framework for knowledge integration in learning Newton's third law. *ArXiv Preprint*, 1–14. <https://doi.org/10.48550/arXiv.2104.05944>
5. Bao, L., & Fritchman, J. C. (2021b). Knowledge integration in student learning of Newton's third law: Addressing the action-reaction language and the implied causality. *Physical Review Physics Education Research*, 17(2), 20116. <https://doi.org/10.1103/PhysRevPhysEducRes.17.020116>
6. 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>
7. Bao, L., & Redish, E. F. (2006). Model analysis: Representing and assessing the dynamics of student learning. *Physical Review Special Topics - Physics Education Research*, 2(1), 1–16. <https://doi.org/10.1103/PhysRevSTPER.2.010103>
8. Barbieri, C. A., Booth, J. L., & Chawla, K. (2023). Let's be rational: Worked examples supplemented textbooks improve conceptual and fraction knowledge. *Educational Psychology*, 43(1), 1–21. <https://doi.org/10.1080/01443410.2022.2144142>
9. Bu, X., Zhang, J., Li, J., & Zhang, N. (2023). A latent profile analysis linking individual intellectual capital to radical and incremental creativity. *Current Psychology*, 42(11), 9391–9403. <https://doi.org/10.1007/s12144-021-02221-5>
10. Chiu, M. H., Guo, C., & Treagust, D. F. (2007). Assessing students' conceptual understanding in science: An introduction about a national project in Taiwan. *International Journal of Science Education*, 29, 379–390. <https://doi.org/10.1080/09500690601072774>
11. Dai, R., Fritchman, J. C., Liu, Q., Xiao, Y., Yu, H., & Bao, L. (2019). Assessment of student understanding on light interference. *Physical Review Physics Education Research*, 15(2), 20134. <https://doi.org/10.1103/PhysRevPhysEducRes.15.020134>
12. Ding, Y., Zhu, G., Bian, Q., & Bao, L. (2024). Analysis of students' conceptual change in learning Newton's third law with an integrated framework of model analysis and knowledge integration. *Physical Review Physics Education Research*, 20(2), 20141. <https://doi.org/10.1103/PhysRevPhysEducRes.20.020141>
13. Fyfield, M., Henderson, M., & Phillips, M. (2022). Improving instructional video design: A systematic review. *Australasian Journal of Educational Technology*, 38(3), 155–183. <https://doi.org/10.14742/ajet.7296>
14. Güven, B., & Özmen, Z. M. (2022). Enhancing pre-service mathematics teachers' understanding of sampling distributions with

- conceptual change texts. *Journal of Pedagogical Research*, 6(1), 110–130. <https://doi.org/10.33902/jpr.2022175561>
15. Haryono, H. E., & Aini, K. N. (2021). Diagnosis misconceptions of junior high school in Lamongan on the heat concept using the three-tier test. *Journal of Physics: Conference Series*, 1806(1). <https://doi.org/10.1088/1742-6596/1806/1/012002>
  16. González-Marcos, A., Navaridas-Nalda, F., Jiménez-Trens, M. A., Alba-Elías, F., & Ordieres-Meré, J. (2021). Academic effects of a mixed teaching methodology versus a teacher-centered methodology and approaches to learning. In *Revista de Educación* (Vol. 2021, Issue 392). <https://doi.org/10.4438/1988-592X-RE-2021-392-481>
  17. Jaya, D. P., Sulistiawati, & Arifin, S. (2023). The impact of the 7E learning cycle model on students' capacity for understanding mathematics. *AIP Conference Proceedings*, 2886(1). <https://doi.org/10.1063/5.0154654>
  18. Juliangkary, E., Yuntawati, Y., Nissa, I. C., Pujilestari, P., Masjudin, M., Nitiasih, P. K., Riastini, P. N., & Sudartha, I. G. W. (2024). Strengthening conceptual understanding through critical pedagogical approaches in mathematics education in Indonesia. *ICoMSE*, 57–67. [https://doi.org/10.2991/978-2-38476-275-0\\_5](https://doi.org/10.2991/978-2-38476-275-0_5)
  19. Laliyo, L. A. R., Botutihe, D. N., & Panigoro, C. (2019). The development of two-tier instruments based on distractors to assess conceptual understanding level and student misconceptions in explaining redox reactions. *International Journal of Learning, Teaching and Educational Research*, 18(9), 216–237. <https://doi.org/10.26803/ijlter.18.9.12>
  20. Lammert, C. (2020). Becoming inquirers: a review of research on inquiry methods in literacy preservice teacher preparation. *Literacy Research and Instruction*, 59(3), 191–217. <https://doi.org/10.1080/19388071.2020.1730529>
  21. Linn, M. C. (2005). The knowledge integration perspective on learning and instruction. In R. K. Sawyer (Ed.), *The Cambridge handbook of: The learning sciences* (pp. 243–264). Cambridge University Press.
  22. Linn, M. C., & Eylon, B. S. (2000). Knowledge integration and displaced volume. *Journal of Science Education and Technology*, 9(4), 287–310. <https://doi.org/10.1023/A:1009451808539>
  23. Linn, M. C., Clark, D., & Slotta, J. D. (2003). WISE design for knowledge integration. *Science Education*, 87(4), 517–538. <https://doi.org/10.1002/sc.10086>
  24. Liu, Z., Pan, S., & Bao, L. (2024). Effectiveness of conceptual-framework-based instruction on promoting knowledge integration in learning simple electric circuits. *Physical Review Physics Education Research*, 20(2), 1–13. <https://doi.org/10.1103/PhysRevPhysEducRes.20.020113>
  25. Liu, Z., Pan, S., Zhang, X., & Bao, L. (2022). Assessment of knowledge integration in student learning of simple electric circuits. *Physical Review Physics Education Research*, 18(2), 20102. <https://doi.org/10.1103/PhysRevPhysEducRes.18.020102>
  26. Loh, S. M. R., Kraaykamp, G., & van Hek, M. (2023). Do students' ICT skills pay off in math performance? Examining the moderating role of countries' ICT promotive environment. *European Educational Research Journal*. <https://doi.org/10.1177/14749041231201197>
  27. Loyens, S. M. M., van Meerten, J. E., Schaap, L., & Wijnia, L. (2023). Situating higher-order, critical, and critical-analytic thinking in problem- and project-based learning environments: A systematic review. *Educational Psychology Review*, 35(1), 39. <https://doi.org/10.1007/s10648-023-09757-x>
  28. Lu, C., Liu, Y., Xu, S., Zhou, S., Mei, H., Zhang, X., Yang, L., & Bao, L. (2023). Conceptual framework assessment of knowledge integration in student learning of measurement uncertainty. *Physical Review Physics Education Research*, 19(2), 20145. <https://doi.org/10.1103/PhysRevPhysEducRes.19.020145>
  29. Mahadini, M. K., Setyaningsih, E., & Sarosa, T. (2021). Using conventional rubric and co-matrix to assess EFL students' essays. *International Journal of Language Education*, 5(4), 260–270. <https://doi.org/10.26858/ijole.v5i4.19105>
  30. Malgieri, M., Onorato, P., & De Ambrosis, A. (2017). Test on the effectiveness of the sum over paths approach in favoring the construction of an integrated knowledge of quantum physics in high school. *Physical Review Physics Education Research*, 13(1), 1–25. <https://doi.org/10.1103/PhysRevPhysEducRes.13.010101>
  31. Manso, D. F., Parnell, G. S., Pohl, E., & Belderrain, M. C. N. (2024). Gaps in strategic problem-solving methods: A systematic literature review. *Journal of Multi-Criteria Decision Analysis*, 31(1–2). <https://doi.org/10.1002/mcda.1828>

32. Maries, A., Lin, S. Y., & Singh, C. (2017). Challenges in designing appropriate scaffolding to improve students' representational consistency: The case of a Gauss's law problem. *Physical Review Physics Education Research*, 13(2), 1–17. <https://doi.org/10.1103/PhysRevPhysEducRes.13.020103>
33. Maries, A., & Singh, C. (2018). Case of two electrostatics problems: Can providing a diagram adversely impact introductory physics students' problem solving performance? *Physical Review Physics Education Research*, 14(1), 10114. <https://doi.org/10.1103/PhysRevPhysEducRes.14.010114>
34. Moreno, S. A. L., Forero, J. A. M., Revilla, R. G., & Moure, O. M. (2024). Research trends in communication and tourism: A systematic review and a bibliometric analysis. *Administrative Sciences*, 14(9), 208. <https://doi.org/10.3390/admsci14090208>
35. Munfaridah, N., Avraamidou, L., & Goedhart, M. (2021). The use of multiple representations in undergraduate physics education: What do we know and where do we go from here? *Eurasia Journal of Mathematics, Science and Technology Education*, 17(1), 1–19. <https://doi.org/10.29333/ejmste/9577>
36. Myung, S. K. (2023). How to review and assess a systematic review and meta-analysis article. *Science Editing*, 10(2), 119–126. <https://doi.org/10.6087/kcse.306>
37. Nicholus, G., Muwonge, C. M., & Joseph, N. (2023). The role of problem-based learning approach in teaching and learning physics: A systematic literature review. *F1000Research*, 12(1), 1–24. <https://doi.org/10.12688/f1000research.13633.9.2>
38. Nie, Y., Xiao, Y., Fritchman, J. C., Liu, Q., Han, J., Xiong, J., & Bao, L. (2019). Teaching towards knowledge integration in learning force and motion. *International Journal of Science Education*, 41(16), 2271–2295. <https://doi.org/10.1080/09500693.2019.1672905>
39. Overskott, H. L., Markholm, C. E., Sehic, A., & Khan, Q. (2024). Different methods of teaching and learning dental morphology. *Dentistry Journal*, 12(4), 114. <https://doi.org/10.3390/dj12040114>
40. Ozfidan, B., & Mitchell, C. (2022). Assessment of students' argumentative writing: A rubric development. *Journal of Ethnic and Cultural Studies*, 9(2), 121–133. <https://doi.org/10.29333/ejecs/1064>
41. Petticrew, M., & Roberts, H. (2008). *Systematic reviews in the social sciences: A practical guide*. Blackwell Publishing.
42. Rahayu, S., Treagus, D., & Chandrasegaran, A. (2019). High school and preservice chemistry teacher education students' understanding of voltaic and electrolytic cell concepts: Evidence of consistent learning difficulties across years. *International Journal of Science and Mathematics Education*, 20(1), 1859–1882. <https://doi.org/10.1007/s10763-021-10226-6>
43. Richards, A. J., Jones, D. C., & Etkina, E. (2020). How students combine resources to make conceptual breakthroughs. *Research in Science Education*, 50(3), 1119–1141. <https://doi.org/10.1007/s11165-018-9725-8>
44. Robertson, A. D., Goodhew, L. M., Bauman, L. C., Hansen, B., & Alesandrini, A. T. (2023). Identifying student conceptual resources for understanding physics: A practical guide for researchers. *Physical Review Physics Education Research*, 19(2), 20138. <https://doi.org/10.1103/PhysRevPhysEducRes.19.020138>
45. Ruiz-Martín, H., & Bybee, R. W. (2022). The cognitive principles of learning underlying the 5E Model of Instruction. *International Journal of STEM Education*, 9(1). <https://doi.org/10.1186/s40594-022-00337-z>
46. Salmento, H., Murtonen, M., & Kiley, M. (2021). Understanding teacher education students' research competence through their conceptions of theory. *Frontiers in Education*, 6(1), 1–9. <https://doi.org/10.3389/feduc.2021.763803>
47. Sam, R. (2024). Systematic review of inquiry-based learning: Assessing impact and best practices in education. *F1000Research*, 1–12. <https://doi.org/10.12688/f1000research.15536.7.1>
48. Santhosh, M., Farooqi, H., Ammar, M., Siby, N., Bhadra, J., Al-Thani, N. J., Sellami, A., Fatima, N., & Ahmad, Z. (2023). A meta-analysis to gauge the effectiveness of STEM informal project-based learning: Investigating the potential moderator variables. *Journal of Science Education and Technology*, 32(5), 671–685. <https://doi.org/10.1007/s10956-023-10063-y>
49. Sargeant, J. M., & O'Connor, A. M. (2020). scoping reviews, systematic reviews, and meta-analysis: applications in veterinary medicine. *Frontiers in Veterinary Science*, 7(1), 1–14. <https://doi.org/10.3389/fvets.2020.00011>
50. Savastano, M., Amendola, C., Bellini, F., & D'Ascenzo, F. (2019). Contextual impacts on industrial processes brought by the digital transformation of manufacturing: A systematic review. *Sustainability (Switzerland)*, 11(3), 891. <https://doi.org/10.3390/su11030891>

51. Scheer, R. R. (2007). Modeling student thinking: An example from special relativity. *American Journal of Physics*, 75(1), 272–280.
52. Schmidt, D., Raupach, T., Wiegand, A., Herrmann, M., & Kanzow, P. (2021). Relation between examinees' true knowledge and examination scores: systematic review and exemplary calculations on Multiple-True-False items. *Educational Research Review*, 34(1), 100409. <https://doi.org/10.1016/j.edurev.2021.100409>
53. Setemen, K., Sudirtha, I. G., & Widiana, I. W. (2023). E-Learning model based on project-based learning on the conceptual understanding and agility of students. *Journal of Technology and Science Education*, 13(3), 583–596. <https://doi.org/10.3926/jotse.1624>
54. Sharma, S. (2018). 7E learning cycle model : A paradigm shift in instructional approach. *Shanlax International Journal of Education*, 6(2), 13–22.
55. Shin, J. Y., Kim, E., & Ahn, J. (2022). A latent profile analysis of living a calling, burnout, exploitation, and work–life imbalance. *Journal of Career Development*, 49(4), 816–830. <https://doi.org/10.1177/0894845321994168>
56. Spurk, D., Hirschi, A., Wang, M., Valero, D., & Kauffeld, S. (2020). Latent profile analysis: A review and “how to” guide of its application within vocational behavior research. *Journal of Vocational Behavior*, 120(1), 103445. <https://doi.org/10.1016/j.jvb.2020.103445>
57. Soeharto, S., & Csapó, B. (2021). Evaluating item difficulty patterns for assessing student misconceptions in science across physics, chemistry, and biology concepts. *Heliyon*, 7(11), e08352. <https://doi.org/10.1016/j.heliyon.2021.e08352>
58. Sreenivasa, M., Armitage, L., & Lee, W. C. C. (2022). Assessment of biomedical engineering knowledge using true–false questions. *Physical and Engineering Sciences in Medicine*, 45(1), 273–278. <https://doi.org/10.1007/s13246-021-01088-x>
59. Strat, T. T. S., Henriksen, E. K., & Jegstad, K. M. (2024). Inquiry-based science education in science teacher education: a systematic review. *Studies in Science Education*, 60(2), 191–249. <https://doi.org/10.1080/03057267.2023.2207148>
60. Tong, D., Liu, J., Sun, Y., Liu, Q., Zhang, X., Pan, S., & Bao, L. (2023). Assessment of student knowledge integration in learning work and mechanical energy. *Physical Review Physics Education Research*, 19(1), 10127. <https://doi.org/10.1103/PhysRevPhysEducRes.19.010127>
61. Troia, G. A., Wang, H., & Lawrence, F. R. (2019). Latent profiles of writing-related skills, knowledge, and motivation for elementary students and their relations to writing performance across multiple genres. *Contemporary Educational Psychology*, 71(1), 102100. <https://doi.org/10.1016/j.cedpsych.2022.102100>
62. Tsivitanidou, O. E., Georgiou, Y., & Ioannou, A. (2021). A learning experience in inquiry-based physics with immersive virtual reality: Student perceptions and an interaction effect between conceptual gains and attitudinal profiles. *Journal of Science Education and Technology*, 30(6), 841–861. <https://doi.org/10.1007/s10956-021-09924-1>
63. Vančugovienė, V., Södervik, I., Lehtinen, E., & McMullen, J. (2024). Individual differences in secondary school students' conceptual knowledge: Latent profile analysis of biology concepts. *Learning and Individual Differences*, 111(March). <https://doi.org/10.1016/j.lindif.2024.102436>
64. Waldrip, B., & Rusdiana, D. (2012). Impact of representational approach on the improvement of students understanding of acceleration. *Jurnal Pendidikan Fisika Indonesia*, 8(2), 161–173. <https://doi.org/10.15294/jpfi.v8i2.2156>
65. Wang, B., Zhang, Y., Wang, Q., Li, D., & Tang, Z. (2019). Assessment of student knowledge integration in learning friction force. *Journal of Baltic Science Education*, 23(4), 767–785. <https://doi.org/10.33225/jbse/24.23.767>
66. Widiyatmoko, A., & Shimizu, K. (2018). An overview of conceptual understanding in science education curriculum in Indonesia. *Journal of Physics: Conference Series*, 983(1), 0–6. <https://doi.org/10.1088/1742-6596/983/1/012044>
67. Wittmann, M. C. (2006). Using resource graphs to represent conceptual change. *Physical Review Special Topics - Physics Education Research*, 2(2), 1–27. <https://doi.org/10.1103/PhysRevSTPER.2.020105>
68. Wood, A. K., Galloway, R. K., Hardy, J., & Sinclair, C. M. (2014). Analyzing learning during peer instruction dialogues: A resource activation framework. *Physical Review Special Topics - Physics Education Research*, 10(2), 1–15. <https://doi.org/10.1103/PhysRevSTPER.10.020107>
69. Wray, A., Goubert, R., Gadepally, R., Boysen-Osborn, M., Wiechmann, W., & Toohey, S. (2021). Utilization of educational videos to improve communication and discharge instructions. *Western Journal of Emergency Medicine*, 22(3), 644–647. <https://doi.org/10.5811/westjem.2021.1.48968>

70. Xiao, Y., & Bao, L. (2024). Assessing and enhancing university students' knowledge integration in learning electromagnetic induction. *International Journal of Science Education*, July, 1–23. <https://doi.org/10.1080/09500693.2024.2371165>
71. Xie, L., Liu, Q., Lu, H., Wang, Q., Han, J., Feng, X. M., & Bao, L. (2021). Student knowledge integration in learning mechanical wave propagation. *Physical Review Physics Education Research*, 17(2), 20122. <https://doi.org/10.1103/PhysRevPhysEducRes.17.020122>
72. Xu, A. H., Deng, B. T., B Xianlong Xu, & B Xiaoqing Gu. (2024). The effectiveness of educational interventions on thinking and operational skills in complex learning—A meta-analysis. *Thinking Skills and Creativity*, 53(101574). <https://doi.org/10.1016/j.tsc.2024.101574>
73. Xu, W., Jiang, Y., Yang, L., & Bao, L. (2023). Conceptual framework based instruction for promoting knowledge integration in learning momentum. *Physical Review Physics Education Research*, 19(2), 20124. <https://doi.org/10.1103/PhysRevPhysEducRes.19.020124>
74. Xu, W., Liu, Q., Koenig, K., Fritchman, J., Han, J., Pan, S., & Bao, L. (2020). Assessment of knowledge integration in student learning of momentum. *Physical Review Physics Education Research*, 16(1), 10130. <https://doi.org/10.1103/Physrevphyseducres.16.010130>
75. Ye, D., Qian, J., Xu, W., Lu, Y., Wang, S., Xiao, L., & Bao, L. (2024). Assessment of knowledge integration in student learning of galvanic cells: An interdisciplinary approach connecting physics and chemistry. *Physical Review Physics Education Research*, 20(2), 20129. <https://doi.org/10.1103/PhysRevPhysEducRes.20.020129>
76. Yuliasari, A., Hari, D. L. H., & Marianingsih, P. (2023). Identification of students' misconceptions on the photosynthetic and plant respiration concepts using a two-tier diagnostic test. *International Journal of Biology Education Towards Sustainable Development*, 3(1), 16–23. <https://doi.org/10.53889/ijbetsd.v3i1.155>