



Kasuari: Physics Education Journal (KPEJ) Universitas Papua

Web: <http://jurnal.unipa.ac.id/index.php/kpej>



Theory and Practice of Conceptual Understanding in Physics Education: A Literature Review and Bibliometric Analysis of the Recent Decades

Wandi Wandī*, Fani Mardianti, Irma Rahma Suwarma, & Winny Liliawati

Department of physics education, Faculty of Mathematics and Science Education, Universitas Pendidikan Indonesia

*Corresponding author: wandi@upi.edu

Abstract: This paper aims to map the existing conceptual understanding literature to explore and classify current theory and practice in physics education. This paper systematically reviews research on conceptual understanding in the field of physics education from 2012 to 2023. The PRISMA framework for systematic literature was used, 278 research articles specific to physics education were identified through a structured keyword search in the SCOPUS database. The analysis revealed two important objectives in the conceptual understanding commonly used in physics education research. First, it relates to the distribution of conceptual understanding articles in terms of number per year, country, research discipline, and journal in which they are published. Second, revealing research collaboration between countries which is dominated by developed countries such as the United States, Germany, Chile, Croatia and Mexico. As for the future agenda, it is important to collaborate on research in developing countries.

Keywords: Conceptual understanding, Physics education, Theory and practices

Teori dan Praktek Pemahaman Konseptual dalam Pendidikan Fisika: Tinjauan Pustaka dan Analisis Bibliometrik Satu Dekade Terakhir

Abstrak: Makalah ini bertujuan untuk memetakan literatur pemahaman konseptual yang ada untuk mengeksplorasi dan mengklasifikasikan teori dan praktik terkini dalam pendidikan fisika. Makalah ini secara sistematis mengulas penelitian tentang pemahaman konseptual dalam bidang pendidikan fisika dari tahun 2012 hingga 2023. Kerangka kerja PRISMA untuk literatur sistematis digunakan, 278 artikel penelitian khusus untuk pendidikan fisika diidentifikasi melalui pencarian kata kunci terstruktur di database SCOPUS. Analisis tersebut mengungkapkan dua tujuan penting pada pemahaman konseptual yang lazim digunakan dalam penelitian pendidikan fisika. Pertama, berkaitan dengan distribusi artikel pemahaman konseptual dari segi jumlah per tahun, negara, disiplin penelitian, dan jurnal yang mempublikasikan. Kedua, mengungkap kolaborasi penelitian antar negara yang didominasi oleh negara-negara maju seperti Amerika Serikat, Jerman, Chile, Kroasia, dan Meksiko. Adapun agenda ke depan, penting untuk berkolaborasi dalam penelitian di negara-negara berkembang.

Kata kunci: Pemahaman konseptual, Pendidikan fisika, Teori dan praktik

INTRODUCTION

The world of physics education is a vibrant tapestry woven with ongoing exploration and research, driven by the dedication of educators and scholars aiming to enhance the effectiveness of their teaching methods and achieve the best possible learning outcomes (Fidan & Tuncel, 2019). At the heart of this dynamic endeavor lies the crucial concept of conceptual understanding; the profound grasp and practical application of the foundational principles governing the realm of physics (Serway & Jewett 2018; 2021; Maknun 2020).

Numerous scholarly pursuits have diligently tackled the intricate challenge of nurturing conceptual understanding within the domain of physics education (Djudin 2023; Gunawan et al. 2018). This effort emphasizes the need to move beyond mere memorization and mechanical problem-solving, recognizing the importance of a more profound approach. The existing body of literature highlights that the evolution of conceptual understanding is a nuanced dance, involving intricate interactions among cognitive mechanisms, emotional dimensions, and contextual intricacies (Izard 2007; Kiviniemi et al. 2018; Mangaroska et al. 2022).

The cognitive aspect entails the intricate mental frameworks learners construct, including the formation of mental models and schemata that allow them to comprehend the intricate web of physical phenomena. Addressing misconceptions, as illuminated by notable researchers like Speirs et al. (2021) stands as a pivotal pillar in cultivating accurate conceptual frameworks. Consequently, the literature underscores the urgency of identifying instructional methods capable of effectively rectifying these misconceptions, thereby enabling genuine shifts in conceptual understanding.

Simultaneously, affective factors emerge as essential constituents in the journey of conceptual understanding. Studies by Ince (2023) and Wu et al. (2023) emphasize the significance of motivation, self-efficacy, and metacognition in shaping learners' engagement with the intricate concepts intrinsic to physics. These emotional and motivational undercurrents wield substantial influence over learners' readiness to explore intricate ideas with depth, significantly contributing to the maturation of their conceptual mastery.

In parallel, the context in which learning takes place – encompassing curriculum design, pedagogical strategies, and assessment methods – emerges as another focal point of the scholarly discourse (Rapanta et al. 2020). Research spearheaded by figures like Lakhtakia (2022) spotlights the potency of active learning strategies, peer collaboration, and formative assessment in fostering conceptual understanding. Additionally, the integration of real-world applications and interactive simulations further strengthens the bridge between abstract theoretical concepts and tangible, practical scenarios (Deliktas, 2011)

However, as strides are taken within the landscape of conceptual understanding in physics education, it becomes apparent that inherent limitations within the current discourse need close consideration. The prevailing body of research often directs its attention toward isolated aspects of the learning journey, unintentionally sidelining the intricate interactions between cognitive, emotional, and contextual dimensions. This fragmented approach inadvertently hampers a comprehensive comprehension of the multi-dimensional nature of conceptual understanding.

Furthermore, a significant portion of existing literature is focused on examining the experiences of novice learners (Yuliati et al. 2018; Xie et al. 2021; Wang et al. 2022). While this provides valuable insights, it creates a noticeable gap in our understanding of how conceptual understanding develops across diverse educational stages. This narrow focus neglects the nuanced challenges and opportunities that emerge when nurturing deeper comprehension among advanced students navigating more intricate subject matter.

The cultural and contextual dimensions, which play a vital role in the nuanced development of conceptual understanding, remain relatively unexplored within the existing discourse. Most research originates from Western educational contexts, potentially limiting our understanding of how diverse cultural backgrounds and varying learning environments influence the evolution of conceptual understanding. This lack of

inclusivity on a cultural level restricts the applicability of findings to global educational contexts.

Moreover, the integration of technology and its potential impact on physics conceptual comprehension often take a back seat in current research discussions. While technology has the potential to revolutionize the way students engage with and internalize physics concepts, its systematic integration and its implications for conceptual understanding remain understudied. This gap impedes the realization of a comprehensive toolkit equipped to elevate conceptual learning.

The existing literature also tends to present a static view of conceptual understanding, occasionally overlooking its dynamic and evolving nature. This static perspective limits our understanding of how learners progress from novice to expert levels, potentially reducing the effectiveness of pedagogical strategies tailored to different stages of learning. Lastly, the majority of research operates within localized contexts, with limited exploration of collaborative efforts spanning across countries and cultures. This localized focus hinders the development of a global framework for fostering conceptual understanding, potentially hampering the identification of shared best practices and strategies across diverse educational systems.

Aligned with the backdrop of existing knowledge and the recognition of its limitations, this comprehensive literature review is guided by two intertwined objectives. First, it relates to the distribution of conceptual understanding articles in terms of number per year, country, research discipline, and journal in which they are published. The second objective delves into the evaluation of collaborative research endeavors pursued by countries to attain a common objective fostering conceptual understanding in physics education. Through a comprehensive analysis of international partnerships and collaborative initiatives, this review aims to uncover shared strategies and innovative approaches that collectively enhance pedagogical practices on a global scale.

METHODS

This study used the PRISMA framework to review the existing literature (Tricco et al. 2018). Following the PRISMA guidelines, the scoping process was employed to find the most relevant articles about conceptual understanding in physics education. This approach helped to identify the key aspects of critical lessons and categorize potential search terms. Several keyword combination queries were undertaken to acquire relevant published papers from a known and trustworthy research database, namely Scopus, in order to discover the relevant scientific journals and publications. To discover relevant material, the terms "conceptual understanding" and "physics education" were used in a database search. Predefined exclusion and inclusion criteria, as well as quality requirements, were used to refine the data search. Each filter ensures the quality level, and the next section discusses exclusion and inclusion measures.

The duration of the literature search was set to cover the last decade (2012-2023) to ensure that current conceptual understanding was highlighted. Initially, 550 documents were displayed; however, this contained all types of publications, such as research articles, reviews, editorials, book chapters, and others. At this step, 299 documents were chosen from a search of the literature that was confined to research articles and review papers, as shown in Figure 1. Then, this study was limited to simply using English. This resulted in a total of 287 publications being evaluated for additional assessment and the application of exclusion and inclusion criteria. The data was then exported to an Excel file so that the systematic review could begin.

This evaluation involves a thorough examination of both published original research papers and review articles to identify the most significant findings and offer a comprehensive summary of previous knowledge. To ensure the organization of the data, the outcomes, abstracts, and conclusions were categorized separately. Moreover, we considered the references mentioned in the reviewed publications. To prevent redundancy, we meticulously cross-checked the records and excluded irrelevant research to enhance the desired results.

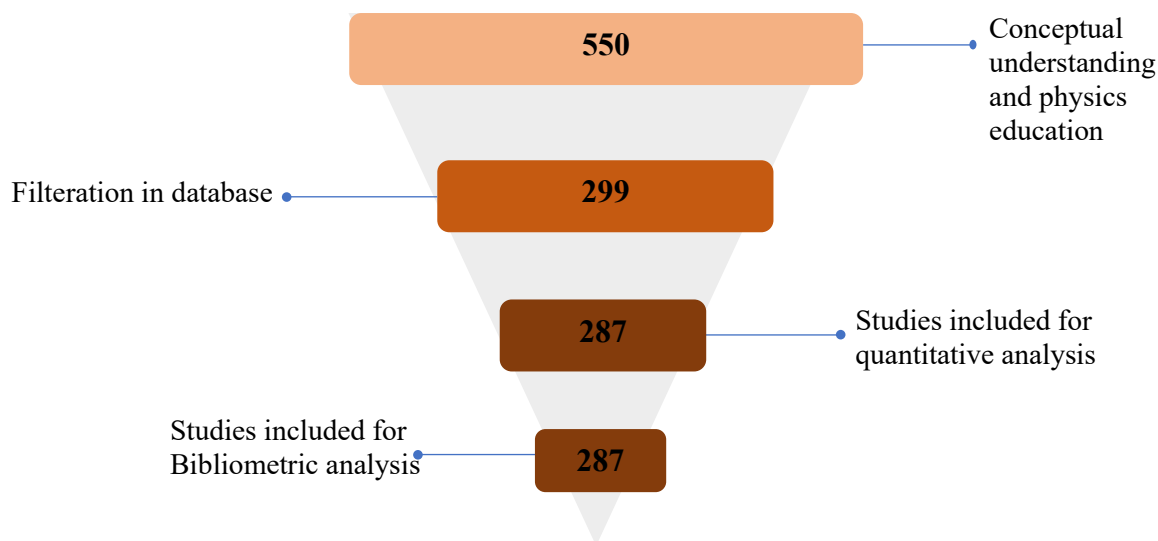


Figure 1. PRISMA Framework

After the documents were chosen, a two-phase approach was employed to validate the quality of the analysis conducted on the selected papers. Firstly, the consistent metadata was imported into Microsoft Excel for a descriptive exploration of the literature's conceptual understanding. Subsequently, a comprehensive content analysis was carried out to delineate and scrutinize the primary research themes, highlighting recent investigations in diverse areas while emphasizing potential research challenges and opportunities for the future. Content analysis is a research technique used for examining documents and texts to categorize and quantify the explicit communication content within predefined categories. It employs a systematic process that enables the production of reproducible and valid inferences from texts.

RESULT AND DISCUSSION

Figure 2 depicts the evolution of the number of articles on conceptual understanding annually from all nations during the last decade. The idea was to find theory and practice from the published literature. While there are noticeable swings in the volume of papers published, overall, the volume rises year after year. By the end of the year, the number of publications is expected to rise and surpass that of prior years, according to a projection made when this article was written in September 2023.

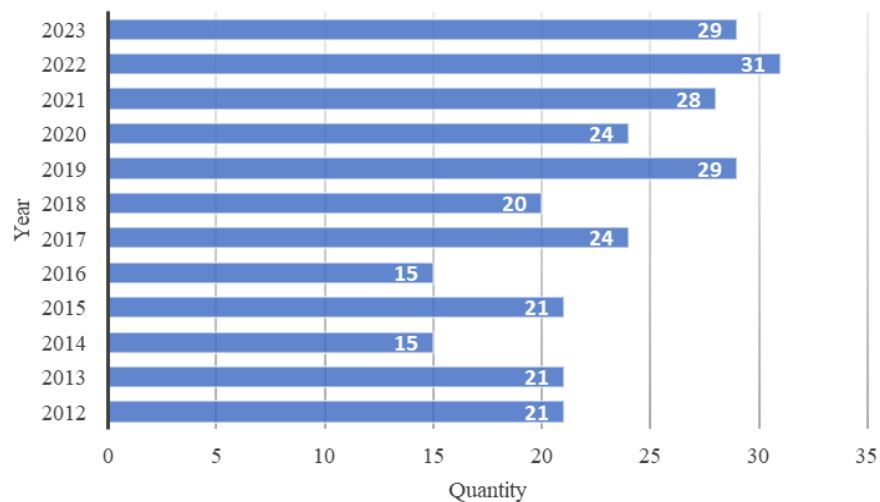


Figure 2. Distribution of Published Documents From 2012 to 2023

When compared with other keywords in physics education, the conceptual understanding keyword is relatively low, while this keyword is very important in understanding various physics concepts. Further research related to this conceptual understanding keyword needs to be explored further. This is in line with research conducted by Santoso et al. (2022), that the weight of conceptual understanding topics is still low compared to other topics: 21-st century skills, assessment, interdisciplinary aspects of physics education, research based instruction, problem solving, and educational technology. Despite the fact that 21st century skills are one of the curricular demands in learning, conceptual understanding in physics learning is still highlighted (Bao & Koenig 2019).

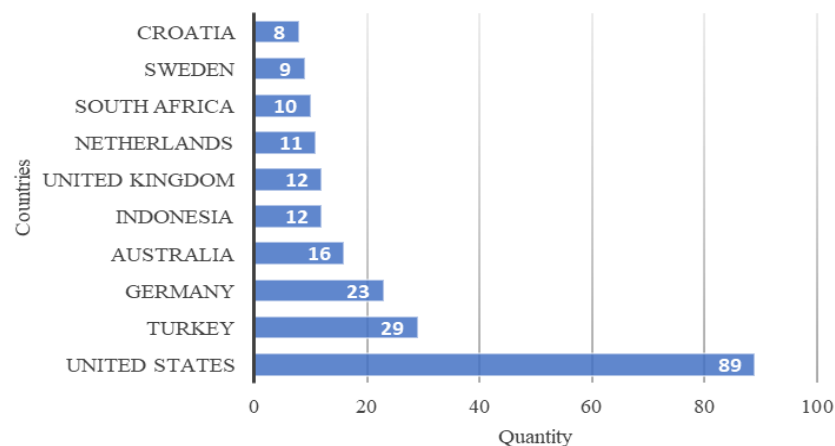


Figure 3. Distribution of Published Documents Among Top 10 Countries (2012–2023)

Figure 3 shows the top 10 country-based literature publication list. The United States produced the highest number of studies on conceptual understanding, with 89 published records. Turkey and Germany did the second and third most work, with 29 and 23 studies from each country on conceptual understanding. The large number of publications in the United States can be due to various reasons and causes; Firstly, conceptual understanding in physics is highly emphasized in the country. Secondly, understanding physics

concepts in learning is still experiencing obstacles so that competency is still an obstacle. Research trends that still require alternative solutions from researchers.

Documents by subject area

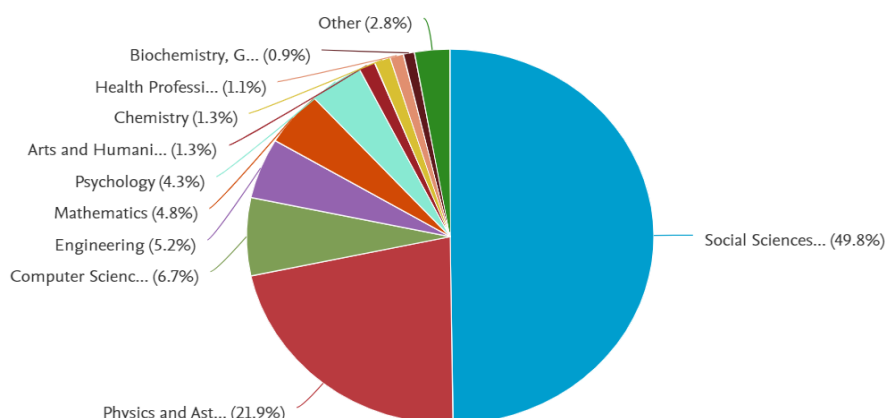


Figure 4. Distribution of Published Records According to Research Discipline (2012–2023)

The subject categories were identified from the Scopus database analysis, and the results are indicated in Figure 4. Most of the literature was about Social Sciences with a percentage of 49.8% articles. Other significant published articles are about physics and astronomy, computer sciences, engineering, mathematics, and psychology comprising 21.9%, 6.7%, 5.2%, 4.8% and 4.3% of the total documents included in the review, respectively.

The journals that published the most articles on conceptual understanding are reported in figure 5. Physical Review Physics Education Research and European Journal of Physics are at the top of the list with 27 and 21 publications, respectively. Research in Science Education is the third largest on the list with 13 studies and the rest of the list is also shown in Figure 5.

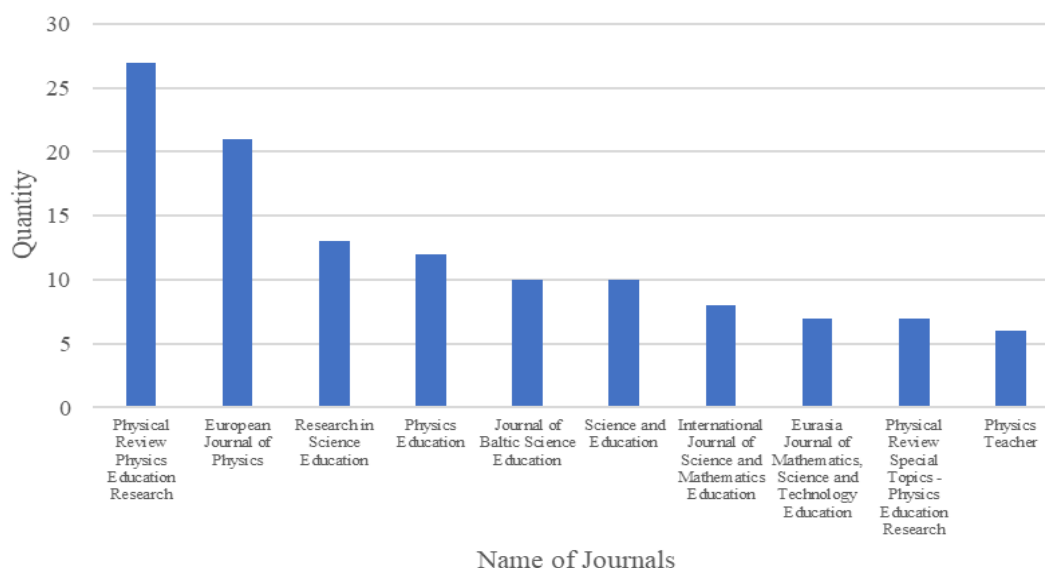


Figure 5. Journal Distribution of Published Records (2012–2023)

Physical review physics education is the journal with the most publications in the field of understanding physics concepts. Most of the articles published in this journal discuss physics concepts. Meanwhile, Physics Teacher is the journal that is least in the top 10 in publishing articles on understanding physics concepts. Classifications of Literature on Conceptual Understanding Practices.

To explore the research categories, the papers were further examined using content analysis. The VOS-Viewer software was utilized to evaluate the content within the published articles. Data networks, based on the text, were established to group related concepts. Recent research indicates that both author keywords and keywords added during the publication indexing process are equally valuable for bibliometric analysis aimed at investigating the structures of research domains. Consequently, we employed both types of terms in our study of conceptual understanding for co-occurrence analysis. In total, the research encompassed 278 entries, with 1,110 keywords extracted from the data. We carefully refined and selected only the top 241 keywords that appeared in at least four documents. The results of the content analysis are presented in Figure 6.

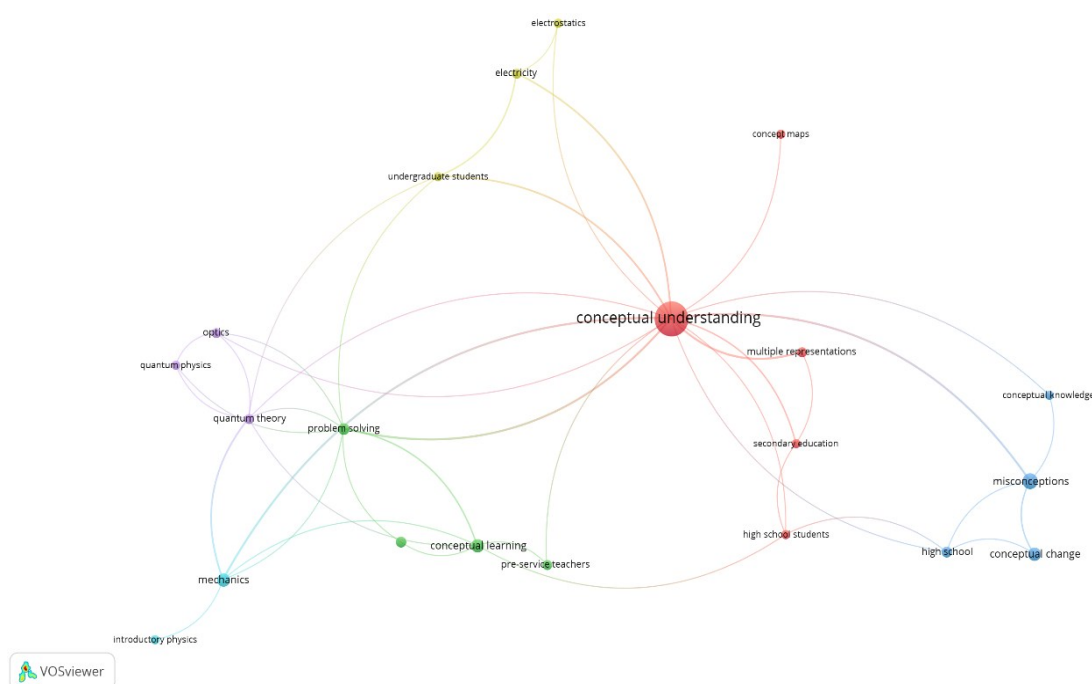


Figure 6. Result of the Content Analyze in Physics Education

Researcher focused on two objective research. Firstly, there are three domains based on analysis from vos-viewer. The major topics in physics education are Mechanics, Quantum Theory, Electricity, Optics, Quantum Physics, Electrostatics and Introductory Physics. These topics are often considered difficult by students (e.g Zuza et al. 2020; Müller & Mishina 2021; di Uccio et al. 2020). Secondly, on the level of education, there are secondary education, high school, undergraduate students, higher education and pre-service teachers. Thirdly, skill measured, there are problem solving, misconception, conceptual learning, multiple representation, conceptual change, conceptual knowledge and concepts maps.

Secondly, to answer the second objective R-studio is used for analyzing teamwork based on country as shown in figure 7 below. R-studio visualization is becoming a new trend as a decision aid tool.

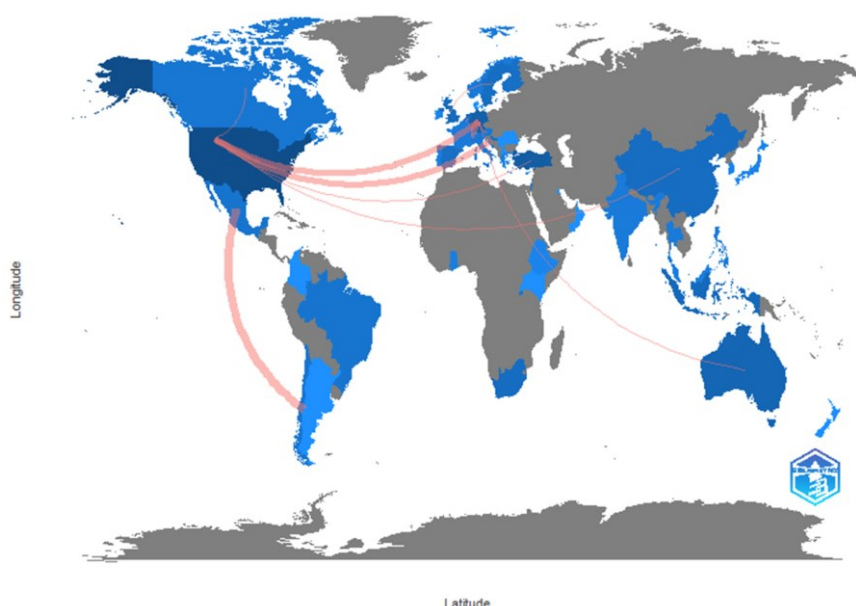


Figure 7. Result of Analyze Collaboration World Map in Physics Education

Based on figure7 above, there are four major collaborations between countries. First, USA with Croatia and second USA with Germany, thirdly Mexico with Chile and finally, Germany with Switzerland. Collaboration between countries is very necessary to support the quality of research, both between developing countries, developed countries and developed-developing countries. Research collaboration between countries allows the spread of science and technology so that it does not rely on just one country. In Figure 7 above, the dark blue on the map represents countries that frequently collaborate in this field of research, the evidence lies in the frequency of publication.

SUMMARY AND SUGGESTION

Conceptual understanding is important research, especially in theory and practices in physics education. Based on a literature review and bibliometric analysis, there are two types of research objectives. First, it relates to the distribution of conceptual understanding articles in terms of number per year, country, research discipline, and journal in which they are published. The number of conceptual understanding articles in physics education on average increases every year. The country that produces the most articles on conceptual understanding is the United States with a total of 89. Social science at 49.8% is the research discipline with the most recorded conceptual understanding. The journal Physical Review Physics Education Research is recorded as having published the most articles on conceptual understanding in physics education. Second, related to teamwork between countries, there are four major collaborations. Regarding the collaboration of countries, the majority is being done by developed countries such as the USA, Germany, Chile, Croatia, and Mexico. In the future, it will be crucial for developing countries to collaborate on research on the conceptual understanding of physics education.

ACKNOWLEDGEMENT

Thanks for the Lembaga Pengelola Dana Pendidikan (LPDP) Indonesia for funding this research.

REFERENCES

- Bao, L & Koenig, K 2019, 'Physics education research for 21st century learning', *Disciplinary and Interdisciplinary Science Education Research*, vol. 1, pp. 1-12.
- Deliktas, B 2011, 'Computer technology for enhancing teaching and learning modules of engineering mechanics', *Computer Applications in Engineering Education*, vol. 19, no. 3, pp. 421-432.
- Di Uccio, U. S, Colantonio, A, Galano, S, Marzoli, I, Trani, F, & Testa, I 2020, 'Development of a construct map to describe students' reasoning about introductory quantum mechanics', *Physical Review Physics Education Research*, vol. 16, no. 1, pp. 010144.
- Docktor, J. L, & Mestre, J. P 2014, 'Synthesis of discipline-based education research in physics', *Physical Review Special Topics-Physics Education Research*, vol. 10, no. 2, pp. 020119.
- Djudin, T 2023, 'Transferring of mathematics knowledge into the physics learning to promote students' problem-solving skills', *International Journal of Instruction*, vol. 16, no. 4, pp. 231-246.
- Dzikovska, M, Steinhäuser, N, Farrow, E, Moore, J, & Campbell, G 2014, 'BEETLE II: Deep natural language understanding and automatic feedback generation for intelligent tutoring in basic electricity and electronics', *International Journal of Artificial Intelligence in Education*, vol. 24, pp. 284-332.
- Enyedy, N, Danish, J. A, Delacruz, G, & Kumar, M 2012, 'Learning physics through play in an augmented reality environment', *International journal of computer-supported collaborative learning*, vol. 7, pp. 347-378.
- Fidan, M, & Tuncel, M 2019, 'Integrating augmented reality into problem based learning: The effects on learning achievement and attitude in physics education', *Computers & Education*, vol. 142, pp. 103635.
- Gunawan, G, Nisrina, N, Suranti, N. M. Y, Herayanti, L, & Rahmatiah, R 2018, November, 'Virtual laboratory to improve students' conceptual understanding in physics learning', *In Journal of Physics: Conference Series* (Vol. 1108, No. 1, p. 012049). IOP Publishing.
- Hamilton, D, McKechnie, J, Edgerton, E, & Wilson, C 2021, 'Immersive virtual reality as a pedagogical tool in education: a systematic literature review of quantitative learning outcomes and experimental design', *Journal of Computers in Education*, vol. 8, no. 1, pp. 1-32.
- Husnaini, S. J & Chen, S 2019, 'Effects of guided inquiry virtual and physical laboratories on conceptual understanding, inquiry performance, scientific inquiry self-efficacy, and enjoyment', *Physical Review Physics Education Research*, vol. 15, no. 1, p. 010119.
- İnce, M 2023, 'Examining the Role of Motivation, Attitude, and Self-Efficacy Beliefs in Shaping Secondary School Students' Academic Achievement in Science Course', *Sustainability*, vol. 15 no. 15, p. 11612.
- Izard, C. E 2007, 'Basic emotions, natural kinds, emotion schemas, and a new paradigm', *Perspectives on psychological science*, vol. 2, no. 3, pp. 260-280.
- Kiviniemi, M. T, Ellis, E. M, Hall, M. G, Moss, J. L, Lillie, S. E, Brewer, N. T & Klein, W. M 2018, 'Mediation, moderation, and context: Understanding complex relations among cognition, affect, and health behaviour', *Psychology & health*, vol. 33, no. 1, pp. 98-116.

- Krijtenburg-Lewerissa, K, Pol, H. J, Brinkman, A & Van Joolingen, W. R 2017, 'Insights into teaching quantum mechanics in secondary and lower undergraduate education', *Physical review physics education research*, vol. 13, no. 1, p. 010109.
- Lakhtakia, R, Otaki, F, Alsuwaidi, L & Zary, N 2022, 'Assessment as learning in medical education: feasibility and perceived impact of student-generated formative assessments', *JMIR Medical Education*, vol. 8, no. 3, p. e35820.
- Lindgren, R, Tscholl, M, Wang, S, & Johnson, E 2016, 'Enhancing learning and engagement through embodied interaction within a mixed reality simulation', *Computers & Education*, vol. 95, pp. 174-187.
- Madsen, A, McKagan, S. B, & Sayre, E. C 2015, 'How physics instruction impacts students' beliefs about learning physics: A meta-analysis of 24 studies', *Physical Review Special Topics-Physics Education Research*, vol. 11, no. 1, p. 010115.
- Maknun, J 2020, 'Implementation of Guided Inquiry Learning Model to Improve Understanding Physics Concepts and Critical Thinking Skill of Vocational High School Students', *International Education Studies*, vol. 13, no. 6, pp. 117-130.
- Mangaroska, K, Sharma, K, Gašević, D, & Giannakos, M 2022, 'Exploring students' cognitive and affective states during problem solving through multimodal data: Lessons learned from a programming activity', *Journal of Computer Assisted Learning*, vol. 38, no. 1, pp. 40-59.
- Müller, R & Mishina, O 2021, 'Milq—Quantum physics in secondary school', *Teaching-Learning Contemporary Physics: From Research to Practice*, pp. 33-45.
- Rapanta, C, Botturi, L, Goodyear, P, Guàrdia, L, & Koole, M 2020, 'Online university teaching during and after the Covid-19 crisis: Refocusing teacher presence and learning activity', *Postdigital science and education*, vol. 2, pp. 923-945.
- Santoso, P. H, Istiyono, E, Haryanto, & Hidayatulloh, W 2022, 'Thematic Analysis of Indonesian Physics Education Research Literature Using Machine Learning', *Data*, vol. 7, no. 11, pp. 147.
- Serway, R. A & Jewett, J. W 2018, 'Physics for scientists and engineers', *Cengage learning*.
- Serway, R. A, & Jewett, J. W 2021, 'Physics for Scientists and Engineers', *Cengage Learning*, vol. 2
- Speirs, J. C, Stetzer, M. R, Lindsey, B. A & Kryjevskaiia, M 2021, 'Exploring and supporting student reasoning in physics by leveraging dual-process theories of reasoning and decision making', *Physical Review Physics Education Research*, vol. 17, no. 2, p. 020137.
- Tricco, A. C, Lillie, E, Zarin, W, O'Brien, K. K, Colquhoun, H, Levac, D, ... & Straus, S. E 2018, 'PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation', *Annals of internal medicine*, vol. 169, no. 7, pp. 467-473.
- Uhden, O, Karam, R, Pietrocola, M & Pospiech, G 2012, 'Modelling mathematical reasoning in physics education', *Science & Education*, vol. 21, pp. 485-506.
- Wang, J, Stebbins, A & Ferdig, R. E 2022, 'Examining the effects of students' self-efficacy and prior knowledge on learning and visual behavior in a physics game', *Computers & Education*, vol. 178, p. 104405.
- Wu, T. T, Lee, H. Y, Li, P. H, Huang, C. N & Huang, Y. M 2023, 'Promoting Self-Regulation Progress and Knowledge Construction in Blended Learning via ChatGPT-Based Learning Aid', *Journal of Educational Computing Research*, p. 07356331231191125.

- Xie, L, Liu, Q, Lu, H, Wang, Q, Han, J, Feng, X & Bao, L 2021, 'Student knowledge integration in learning mechanical wave propagation', *Physical Review Physics Education Research*, vol. 17, no. 2, p. 020122.
- Yuliati, L, Riantoni, C, & Mufti, N 2018, 'Problem Solving Skills on Direct Current Electricity through Inquiry-Based Learning with PhET Simulations', *International Journal of Instruction*, vol. 11, no. 4, pp. 123-138.
- Zuza, K, Sarriugarte, P, Ametller, J, Heron, P. R, & Guisasola, J 2020, 'Towards a research program in designing and evaluating teaching materials: An example from dc resistive circuits in introductory physics', *Physical Review Physics Education Research*, vol. 16, no. 2, p. 020149.
- Zwickl, B. M, Hu, D, Finkelstein, N, & Lewandowski, H. J 2015, 'Model-based reasoning in the physics laboratory: Framework and initial results', *Physical Review Special Topics-Physics Education Research*, vol. 11, no. 2, p. 020113.