JPPIPA 10(4) (2024)

Jurnal Penelitian Pendidikan IPA

Journal of Research in Science Education

http://jppipa.unram.ac.id/index.php/jppipa/index

Chemistry-Focused Conceptual Understanding Research Trends: A Systematic Review

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Received: December 12, 2023
Revised: February 29, 2024
Accepted: April 25, 2024
Published: April 30, 2024

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DOI: 10.29303/jppipa.v10i4.6534

Abstract: Research related to conceptual understanding is often carried out, such as the influence of a model on conceptual understanding, or knowing students' level of understanding of chemistry concepts. However, there has been no systematic reflection on chemistry research focused on conceptual understanding. Based on this, this research aims to systematically synthesize articles related to chemistry focused on research trends in conceptual understanding with the year range of articles used 2014-2023. After conducting a national and international data search using keyword patterns (e.g., Pattern 1: conceptual and chemical understanding), 48 research papers emerged for systematic review. Then, primary and secondary codes were created by the authors for the research paper. The systematic review showed a variety of research scopes (e.g., relevance of chemistry education models) and dominant research focus for different themes (e.g., competencies and variables related to objectives, variables, samples, chemistry concepts, and conclusions). Furthermore, it was revealed that research on understanding chemical concepts includes various research fields.

Keywords: Chemistry; Conceptual understanding; Systematic review

Introduction

Chemistry is a subfield of natural science that examines concepts and theories related to substances as well as their properties, structures, and changes. It also looks at the laws and principles that govern these phenomena and explain changes in our understanding (Effendy, 2016). Chemistry is more than just numbers, formulas, and abstract theories. This is a logical discipline full of interesting ideas and applications because it is everywhere and allows students to understand many things that happen around them (Chang, 2008; Tarigan & Wiji, 2023). Chemistry is one of the subjects studied in secondary school. The learning process is called chemistry learning. Chemistry learning is viewed as acquiring knowledge, resolving issues, and developing one's understanding to provide meaningful experiences for students to have a way to build knowledge, skills, abilities, or other competencies (Koballa et al., 2000; Manurung & Manurung, 2023). Chemistry subjects in high school have many subject areas that are arranged sequentially and are interrelated between the competencies studied. To have no difficulty in studying chemistry, students must understand chemical concepts completely (Widarti et al., 2018).

Learning is carried out oriented towards learning outcomes. Good learning outcomes are one of the main factors that show that learning is carried out well (Ismayawati et al., 2016; Nasution, 2017). There is a need for meaningful learning that can lead students to understand concepts (Khairunnisak, 2018; Makhrus et al., 2020). In science, the main key to science education is having a strong conceptual understanding. Conceptual understanding is an important aspect of the learning process (Nur'aini et al., 2023; Pratiwi et al., 2023). Conceptual understanding is the ability possessed by a person to accept and interpret a mental picture of generalized knowledge of various similar phenomena

How to Cite:
Defista, C., & Aznam, N. (2024). Chemistry-Focused Conceptual Understanding Research Trends: A Systematic Review. *Jurnal Penelitian Pendidikan IPA*, *10*(4), 180–187. https://doi.org/10.29303/jppipa.v10i4.6534

(Dewi & Suhandi, 2016). Conceptual understanding is one of the cognitive processes in the cognitive process dimension according to Anderson and Krathwol Taxonomy and involves a lot of conceptual knowledge in learning (Auliyani et al., 2023). Conceptual understanding is not just a simple understanding, but can also be described as the ability to understand, apply, classify, generalize, synthesize, and conclude objects (Siregar et al., 2023). One of the problems found in science learning is low conceptual understanding, this will affect students' conceptions which ultimately gives rise to cognitive conflicts in terms of conceptions or a called misconceptions (Dewi & Ibrahim, 2019; Mursadam et al., 2017).

Various studies related to conceptual understanding of chemistry concepts are often carried out. For example, in research by Norjana et al. (2016) regarding identifying the level of understanding of the basic laws of chemistry in class X students, the results show that the average student score on the basic laws of chemistry is 48.15, meaning that the student's level of conceptual understanding is still lacking. In addition, research by Widarti et al. (2018) regarding the identification of the level of conceptual understanding of chemical bonds in class X students show that students' conceptual understanding of chemical bonds is quite sufficient, namely amounting to 59.71%. Research by Indriani et al. (2017) about identifying the pupils who struggle to understand the concept of chemical equilibrium. The study's findings demonstrate that students still have a poor grasp of the concept of chemical equilibrium, as evidenced by the high number of students who struggle to comprehend the concept.

There are various problems related to conceptual understanding in the implementation of chemistry learning. Most students stated that the concepts contained in chemistry learning were quite complicated because they presented concepts using abstract symbols and terms that had to be memorized (Handayani et al., 2021; Abdullah et al., 2021). Based on various research related to students' understanding of chemistry concepts, various problems can be identified, such as the causes of students' difficulties in chemistry material which contains many complex and abstract concepts, because understanding abstract concepts requires strong reasoning power for solving problems that cannot be observed directly (Ineng et al., 2016). Students' challenges in learning chemistry are extremely likely because students do not understand the basic concepts correctly, such that students encounter trouble in understanding the next concepts. Another cause could be that they cannot connect macroscopic, microscopic, and symbolic aspects (Nurhayati & Natasukma, 2019).

The solution that can be provided is not only in the form of modifying the learning model but also in developing various learning tools that can make it easier for students to understand chemical concepts (Kharolinasari et al., 2023). Some research related to efforts to increase conceptual understanding can take the form of the influence of a model on conceptual understanding, for example using POGIL, discovery learning, and sway-based interactive chemistry learning (Utari et al., 2023; Khairani & Prodjosantoso, 2023; Hikmah et al., 2023). Apart from the influence of models, research on the influence of teaching materials or learning media is also commonly carried out, for example, worksheet through the Edmodo and ethnoscience-integrated STEM e-books (Khairini et al., 2021; Azalia et al., 2020). Development research is also very often found, for example, interactive e-modules and interactive e-books (Rusmansyah et al., 2023; Tania & Fadiawati, 2015).

This systematic review presents the results of studies related to chemistry research trends focused on conceptual understanding. Articles covered span publication years 2014-2023. This research aims to systematically synthesize articles related to chemistry focused on research trends in conceptual understanding. Research related to conceptual understanding is generally found, but there have been no studies related to research trends related to conceptual understanding. This systematic review can be a guide for researchers who want to study conceptual understanding and chemistry education teachers and researchers to gain insight and information about high school student's understanding of chemical concepts, problems in students' conceptual understanding, and solutions to improve students' conceptual understanding.

Method

This research critically and systematically synthesizes research papers on conceptual understanding that focus on chemistry lessons by creating themes and templates (Bağ & Çalik, 2017; Çalik & Sözbilir, 2014). Therefore, this report aims to show general trends in high school students' understanding of chemistry concepts. In carrying out a systematic review there are four stages as in Table 1.

The databases used by the author in writing this article are Scholar, Pubmed, ScienceDirect, ERIC, SpringerLink, Taylor & Francis, and SAGE Journals through relevant keywords, namely pattern 1: "conceptual understanding" and "chemistry"; pattern 2: “conceptual understanding” and “chemistry” and “senior high school”; and pattern 3: “conceptual understanding” and “chemistry courses”. The articles used were for the last 10 years, namely from 2014 to 2023, and the last search for the data used was on

September 24, 2023. Then, the author determined a specific identity (i.e., short title and author's name) for each study so that there was no any duplication in the database. Then, considering the current research focus, 1,159 research papers are by the research theme. Next, title and abstract screening was carried out to determine their suitability to the inclusion and exclusion criteria. Therefore, 48 suitable articles were obtained which were then read thoroughly to check their suitability.

The author determined four inclusion criteria for the chemistry-focused conceptual understanding theme: conceptual understanding of chemical concepts in classroom learning; high school level; the period 2014-2023; and Scopus indexed. For example, research by Yaman et al. (2015) regarding the influence of CB-POE on students' understanding of the acid-base concept. This article aims to measure high school students' conceptual understanding of chemistry, was published in 2015, and has been indexed by Scopus Q1, so this article was included in the research because it met the four inclusion criteria. An example of an article that does not meet the inclusion criteria is research by Visser et al. (2018) regarding the writing exercises facilitate better conceptual understanding expression in chemistry exercises. This research does not directly review conceptual understanding but instead reviews students' writing abilities. The subjects of the study were high school students, the article was published in 2018 and was indexed by Scopus Q2. Therefore, this article was not included in the study. Thus, 27 articles met all inclusion criteria.

Table 1. Systematic Review Procedure

Steps	Description
Research focus	Defining research concept; developing research questions; deciding analytical/theoretical lens to synthesize the papers.
Selection, inclusion, and classification	Deciding well-known databases; determining keyword patterns and date range; clarifying inclusion and exclusion criteria; classifying 48 papers into chemistry-focused conceptual understanding.
Analysis, coding, and reliability	Labeling papers under three groups (intervention and descriptive); creating primary codes; examining each other's codes to confirm compatibility and applicability; generating secondary codes.
Presentation and Synthesis	Presenting the findings in regard to each theme and inferential components of the relevance model; discussing and synthesizing the findings through the relevant literature.

The articles that had been analyzed resulted in 27 articles that suited the inclusion criteria and were then grouped into three groups referring to the type of research. These three types of grouping refer to research by Çalık et al. (2021): hypothetical/theoretical research, which illustrates conceptual understanding that focuses on chemistry without any implementation or discussing examples of theoretical frameworks through existing literature; intervention research, which includes experimental design and/or treatment; and descriptive research, which explores participants' views, values, argumentation skills, understanding, and perceptions. To present a systematic review, the author adopts the matrix proposed by Çalýk et al. (2005), namely aims, variables, sample, chemistry concepts, and conclusions. Then, create primary codes for each study concerning the matrix and check individual codes to ensure compatibility and applicability. Next, use an inductive review of the primary codes to identify secondary codes for each theme. As a result, it is possible to see the overall patterns, parallels, divergences, and distinctive characteristics of the research papers.

The validity and reliability of this study were aided by two chemistry educators independently classifying 27 research papers according to pre-established inclusion criteria to minimize missing data. To ensure coding credibility, a group of experts (the author and two chemistry educators) independently coded four research papers that were chosen at random from a total of 27 research papers. Subsequently, every author carried out the coding process independently, producing primary codes for every study. Subsequently, they reviewed primary codes inductively to generate secondary codes. The authors also cross-check each other's code to make sure it is applicable and compatible.

Result and Discussion

Theme 'Aims'

Based on Table 1 (see Supplementary Materials), the objectives of the research articles analyzed consist of four codes, with a percentage range of 3.7 to 59.3. The first code and also the code with the highest percentage, namely 59.3%, shows that various models and approaches in learning are often used to improve students' conceptual understanding, for example, context-based learning model, 5E inquiry, REACT, and EMBE-R (Avargil & Piorko, 2022; Supasorn & Promarak, 2015; Karsli & Yigit, 2017; Jusniar et al., 2020). The second code is to differentiate students' conceptual understanding of different materials, for example, students' conceptual understanding of chemical reactions, energy, and matter (Höft & Bernholt, 2019). This article provides data regarding various interventions and efforts to improve students' conceptual understanding.

The third code is to determine students' conceptual understanding of a material, for example, students' perceptions of chemical equilibrium, material structure, chemical matter, amino acids, and chemical kinetics (Rahmawati et al., 2022; Samon & Levy, 2020; Geyer, 2017; Putica, 2023; Sweeder et al., 2019). The fourth code shows the results of the evaluation of students' understanding of concepts, for example in stoichiometry material (Ellis, 2013). These codes support identifying students' understanding of concepts in various materials so as not to cause alternative concepts (misconceptions) (Lu et al., 2018). This can be researched further to identify and overcome misconceptions so that students gain a proper understanding of the concept. Apart from that, instruments can also be developed to measure students' conceptual understanding.

Theme 'Variables'

As can be seen in Table 2 (see Supplementary Materials), the independent variables include various interventions in learning (e.g., modeling instruction, culture modeling, computer-based learning, visualizations, i-SMART, context-based approach, 5E inquiry, EDI, REACT, EMBE-R, concept maps, screencasts and simulations, context-based learning). Likewise, the dependent variable has several variations, although the main focus is on conceptual understanding (f = 16) but in several articles, there are multivariate examples, for example, attitudes (f = 1), motivations (f = 1), metacognitive skills (f = 1), misconceptions (f = 2), and crucial skills (f = 1). In addition, eleven articles are classified as "not applicable" because they do not have independent and dependent variables.

Based on Table 2, there are 16 articles that apply various interventions in learning as independent variables to improve students' understanding of concepts. Through providing interventions, students will learn to build their knowledge through various stages in the various interventions and increase their understanding of concepts. This means that the independent variable refers to constructivist learning theory (e.g., inquiry-based learning and context-based learning). The article focuses on students' conceptual understanding, therefore most of the independent variables are conceptual understanding. In addition, several references indicate measurements of other cognitive and affective domains (e.g., attitudes, motivation, metacognitive abilities, misconceptions, and crucial skills).

Theme 'Samples'

As can be seen in Table 3 (see Supplementary Materials), the sample focused on high school students. Several articles provide information about the grade level used, but 35.4% do not explain the grade level specifically so they are classified generally as "high school students". The majority of research was conducted in the 11th grade considering that chemistry material is difficult to teach at this level. Then, 22.6% of the samples used were 10th students and 9.7% were from 12th grade.

The fact that the majority of research was conducted in grade 11 is probably because most theories are difficult to teach at this level, for example, acids and bases (Yaman & Ayas, 2015), rate of reaction (Olakanmi, 2015), chemical equilibrium (Syahmani et al., 2020), thermochemistry (Stammes et al., 2023) and so on. In grade 10th, students are still starting to adapt to chemistry lessons, so students experience difficulties with terms and conceptual understanding (Yakina et al., 2017). Meanwhile, for grade 12th there are only 3 articles because it is likely that class 12 students already know a lot of terms and have learned chemistry concepts so their understanding of the concepts is also better.

Theme 'Chemistry concepts'

As can be seen in Table 4 (see Supplementary Materials), chemical concepts used in research regarding conceptual understanding include matter, acid-base, reaction rate, chemical equilibrium, electrochemistry, stoichiometry, redox, alkenes, macromolecules, thermochemistry, and modeling in chemistry. Most of them discuss matter, starting from the behavior of gases, energy, the structure of matter, composition, and characteristics of matter. The percentage is 25%. Acid-base, chemical equilibrium, and modeling in chemistry have the same percentage, namely 10.7%, reaction rate 14.3%, electrochemistry and macromolecules 7.1%. Then the topics of stoichiometry, redox, alkenes, and thermochemistry with a percentage of 3.6% each.

The scope of discussion regarding material in scientific articles was found to be quite varied, namely gas behavior, energy, structure, composition, and characteristics. Therefore, discussions regarding conceptual understanding in this material are studied quite often. Meanwhile, acids and bases, chemical equilibrium, and modeling in chemistry (e.g., graphs, multiple representations, and scientific models) are often studied because they are difficult subjects and they are abstract (Ningrum et al., 2022).

Problems with students' understanding of concepts generally involve chemical concepts related to calculations (e.g., acids and bases, reaction rates, chemical equilibrium, electrochemistry, stoichiometry, redox, and thermochemistry). Mathematics and chemistry lessons go hand in hand. Students must be proficient in mathematical operations and formulations (Habiddin & Nagol, 2023). This is due to students' poor understanding of mathematics fundamentals and their inability to retain mathematical formulas that are frequently utilized in chemical calculations. As a result, students struggle to perform basic mathematical operations (Hidayanti et al., 2020).

Theme 'Conclusions'

As can be seen in Table 5 (see Supplementary Materials), there are 3 codes in the conclusion. Most of the research results were concluded to provide positive developments or changes to students' conceptual understanding, namely 59.3%. Even though it has a relatively large positive impact, several research results show small developments or changes in students' conceptual understanding, namely 11.1%. Several descriptive studies show that students have a good conceptual understanding of various chemistry concepts with a percentage of 29.6%.

Based on Table 5, more than half of the research results concluded that providing an intervention (e.g., modeling instruction, culture modeling, computer-based learning, visualizations, i-SMART, context-based approach, 5E inquiry, EDI, REACT, EMBE-R, concept maps, screencasts and simulations, context-based learning) can improve students' conceptual understanding of chemistry. Therefore, the application of a learning model has a positive influence on increasing students' understanding of chemistry concepts (Dukerich, 2015; Edwards & Head, 2016; Yaman & Ayas, 2015). However, three studies show that there is some material that students have not mastered, for example, students who study chemical equilibrium with PhET show that students still experience misconceptions, meaning that students' conceptual understanding is still low. So PhET needs to improve its features in order to increase students' conceptual understanding (Rahmawati et al., 2022).

Conclusion

From the systematic review that has been carried out, it can be concluded that in research on conceptual understanding, various interventions in learning are generally used (e.g., modeling instruction, culture modeling, computer-based learning, visualizations, i-SMART, context-based approach, 5E inquiry, EDI, REACT, EMBE-R, concept maps, screencast and simulations, context-based learning) to improve students' understanding of concepts. There is also research that carries out analysis and provides descriptions of students' understanding of concepts. Students' conceptual understanding is assessed on various chemical concepts (e.g., matter, acid-base, reaction rate, chemical equilibrium, electrochemistry, stoichiometry, redox, alkenes, macromolecules, thermochemistry, and modeling in chemistry) and is carried out in grades 10^{th}-12^{th}. So, these various references, generally show positive improvements and changes in students' conceptual understanding, but a small number show that students' conceptual understanding is still low.

Acknowledgments

The authors would like to thank Ade Kurnia Putri Tanjung and Binti Mutamimmah who have reviewed the articles used in this research.

Author Contributions

This article was prepared by two people, namely Chesa Defista and Nurfina Aznam. All research members carried out each stage cooperatively until this article was completed.

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

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