



Systematic Literature Review of Studies Investigating Conceptual Understanding Related to the Subject of Gases*

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Abstract – The subject of gases is among the important subjects in physics and chemistry teaching. Students often have misconceptions in these fields, which negatively impact learning. For this reason, studies on conceptual understanding and misconceptions are important. The aim of this study is to present the findings obtained from a systematic literature review of international studies focusing on misconceptions and conceptual understanding about gases between 1992 and 2024. In this systematic literature review, literature was searched through various databases (Web of Science, Education Resources Information Center (ERIC)), and the findings were reported in accordance with the "Preferred Reporting Items for Systematic Review and Meta-Analysis" (PRISMA) steps. A total of 171 articles were identified from Web of Science (N=114) and ERIC (N=57) databases. After applying the inclusion/exclusion criteria, 41 articles were obtained. The data were analysed using descriptive and content analysis methods. In the study, it was seen that most of the subjects of the articles focused on teaching materials and especially experimental research were at the forefront. In these studies, it was found that conceptual tests were primarily used to identify participants' misconceptions about gases, with a focus on high school and undergraduate students. Research has shown that activity-based and technology-supported teaching contributes positively to conceptual development related to gases. However, it has been emphasised that abstract topics such as the ideal gas law involve serious conceptual difficulties for students. In this direction, it is recommended to use active learning-based teaching methods, diversify teaching materials, and increase laboratory experiments.

Keywords: Chemistry education, physics education, gases, conceptual understanding, misconception, systematic literature review.

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Introduction

Physics and chemistry are two dynamic disciplines that complement each other in explaining the functioning of the universe, with common topics ranging from fundamental quantities to the molecular level. In addition to fundamental quantities such as mass, volume and length, many topics such as matter, pressure, atomic structure and theories, types of bonds, behaviour of molecules, radioactivity, states of matter, thermodynamics, spectroscopy, orbital motion, wave properties and especially gases and gas theories play a central role in teaching both physics and chemistry (Toomey & Garafalo, 2003; Tüysüz et al., 2016; Yıldırım et al., 2018). By addressing these interdisciplinary topics together, teachers aim to convey the scientific context in a holistic manner and develop students' scientific thinking skills. For this reason, the subject of gases appears as a critical teaching area at the intersection of physics and chemistry disciplines. The subject of gases stands out as one of the basic components of chemistry teaching; however, it also has a structure that requires conceptual depth in the context of physics. For this reason, it is crucial that teaching activities related to gases are designed to support students' conceptual understanding (Çermik, 2008). However, while the primary aim of science courses like physics and chemistry is to develop conceptual understanding, the literature highlights that students often struggle to fully grasp scientific concepts and frequently hold misconceptions (Gobert & Clement, 1999). In this context, the success of concept teaching depends on the use of teaching strategies that will eliminate students' existing misconceptions and prevent the formation of new misconceptions. In this direction, the literature contains a large number of studies with various teaching models for defining misconceptions, explaining their causes and eliminating them (Yıldırım et al., 2018; Yurtyapan & Çirkinoğlu-Şekercioğlu, 2024).

When the research on gases is examined, it is seen that the studies are mainly concentrated in the field of chemistry education (Lin et al., 2000; Niaz & Robinson, 1992; Pinto et al., 2023; Roehrig & Garrow, 2007; Treagust et al., 2010; Yan et al., 2024; Yoshikawa & Yoga, 2016). Studies conducted within the scope of physics education follow chemistry studies (de Berg, 1995; Calzà et al., 2010; Erceg et al., 2016; Özkan & Sezgin-Selçuk, 2016), but the studies are not enough at the secondary school science level are relatively limited (Karlı-Baydere et al., 2020; Okumuş et al., 2022).

A significant part of the research on the subject of gases focuses on determining the effective teaching methods of this subject and examining the conceptual understanding levels of students. In this context, the effects of various teaching models, methods and technology-

supported approaches on the teaching of gases have been investigated (Abdullah & Shariff, 2008; Karslı-Baydere et al., 2020; de Berg, 1995; Liu, 2006; Okumuş et al., 2022; Özkan & Sezgin-Selçuk, 2016; Thomas & McRobbie, 2002). For example, in technology integration-based studies, it was found that inquiry-based computer simulations (Abdullah & Shariff, 2008), micro-computer assisted laboratory applications (Thomas & McRobbie, 2002), combined laboratory and modelling activities (Liu, 2006), interactive simulations (Hunter et al., 2021) and multimedia tools designed for concept teaching (Martinez et al., 2021) positively affected students' conceptual understanding and academic achievement. On the other hand, activity-based pedagogical approaches have also been frequently examined in the teaching of gases. The effectiveness of inquiry-based teaching has been analysed and supported by teacher opinions (Roehrig & Garrow, 2007), the contribution of argumentation-based teaching to concept learning has been emphasised (Aydeniz et al., 2012), activities based on the 5E model have been shown to support conceptual development (Karslı-Baydere et al., 2020), and four-stage constructivist-based teaching has been reported to increase the comprehension levels of high school students (Çalık et al., 2007). In addition, studies have supported that stop-motion animation development activities, one of the innovative methods, contribute to the learning process at the high school level (Yan et al., 2024).

The literature on gases includes studies on the determination of students' misconceptions, as well as effective teaching methods. In this context, misconceptions were identified using various tools such as drawings (Benson et al., 1993), concept maps (Kibar et al., 2013), simple representations (Nallabelli et al., 2024) and standardised scales (Ağgül-Yalçın & Yalçın, 2020; Samsudin et al., 2024) and suggestions were presented to eliminate these misconceptions. In addition, studies examining the questions about gases in high school chemistry textbooks and chemistry teachers prepared for exams (Nakiboğlu & Yıldırım, 2011) and studies in which assessment-evaluation tools suitable for different student levels were developed (Mayer, 2011; Pinto et al., 2023) are among the other prominent contributions in the literature.

Since the subject of gases is an interdisciplinary subject and at the same time a comprehensive subject, it is one of the important subjects that needs to be researched a lot. Examining the research on this subject as a whole facilitates access for teachers, curriculum developers and researchers conducting comprehensive studies on the subject to research methods, findings and teaching materials. For this reason, it is important to conduct a systematic literature review on the conceptual understanding of gases. In systematic literature

reviews, comprehensive and more scientific information about the subject can be reached. However, when the literature is examined, there is no study on systematic literature review on the subject of gases, and the closest study on the subject is the content analysis study conducted by Mesin et al. (2019), which covers the studies on misconceptions about gases in Türkiye between 2007 and 2017. In this study, only studies on misconceptions about gases were examined, and were limited to those conducted in Türkiye.

Purpose of the Research

This study aims to provide a broad perspective on the field by analysing the international research on conceptual understanding, such as misconceptions and concept teaching on gases, between 1992 and 2024. For this purpose, it is planned to reveal a framework of the research in the literature in the context of purpose, method, results and recommendations and to determine the general trend. In line with this goal, the following questions were sought to be answered.

1. The following questions were examined regarding the descriptive features of the articles on the conceptual understanding of gases;
 - ✓ How is the distribution of the authors of the analysed articles across their institutions (Türkiye /international)?
 - ✓ How is the distribution across journals in which they were published?
 - ✓ How is the distribution according to the years of publication?
 - ✓ What are the most frequently used keywords in the analysed articles?
2. What is the distribution of the aims of the articles on the conceptual understanding of gases? When the methodological features of the articles related to the conceptual understanding of gases are analysed;
 - ✓ Who does the sample comprise?
 - ✓ How does the sample group size vary?
 - ✓ How is it distributed according to the research method and design?
 - ✓ Which data collection tools are used?
3. Which data analysis techniques are used?
4. What is the distribution of the conclusions and recommendations of the articles on the conceptual understanding of gases?

Method

Research Model

In this study, which aims to examine studies on conceptual understanding, such as misconceptions and concept teaching about gases, the systematic review method was used. A systematic review is a comprehensive examination of all studies conducted in a particular field to find a solution to a problem. It involves determining which studies will be included in the review by applying various inclusion criteria, and collecting and synthesising data from the selected studies (Karaçam, 2013). Systematic reviews provide more scientific information because they are objective and can be repeated and verified by researchers (Yıldız et al., 2021).

Search and Selection Process

In this study, a systematic search process was carried out to identify academic research on the conceptual understanding of gases. The search process was carried out in the ERIC and Web of Science databases, which are recognised for their high academic reputation in the fields of education and science. These databases are based on internationally recognised impact indices that include peer-reviewed scientific and academic literature published worldwide and across different scientific fields and disciplines (Salisbury, 2009).

The screening process was conducted in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure methodological transparency and reproducibility (Page et al., 2021). The flow of information through the different phases of the review is mapped in Figure 1, showing the number of records identified, included, and excluded, and the reasons for exclusions.

The systematic literature search was performed using the following keywords in the "Topic" field (including Title, Abstract, and Keywords): (("gas laws" OR "particulate nature of gases") AND ("conceptual understanding" OR "misconceptions" OR "alternative conceptions")).

Following the initial search, a multi-stage selection process was applied based on pre-defined inclusion and exclusion criteria, as outlined below and illustrated in Figure 1.

- **Criterion 1:** The study's core focus must be on students' conceptual understanding (including misconceptions, alternative conceptions) of gases or gas laws.

- **Criterion 2:** The study was published between January 1992 and 2024. This timeframe was chosen to capture both foundational and recent research trends.
- **Criterion 3:** The study is a peer-reviewed, original research article published in a scientific journal. Conference proceedings, book chapters, review articles, and editorials were excluded.
- **Criterion 4:** The full text of the study is published in English.
- **Criterion 5:** Studies whose full texts were accessible and suitable for content analysis were examined. Furthermore, only studies that focused directly on conceptual understanding—such as misconceptions and concept teaching regarding gases—were included in the study, while publications addressing different topics within the scope of chemistry education but not directly related to gases were excluded.

As a result of this systematic selection process, a total of 41 articles were found to meet all the inclusion criteria and were included in the final analysis. The detailed selection process is presented in the PRISMA flow diagram (Figure 1).

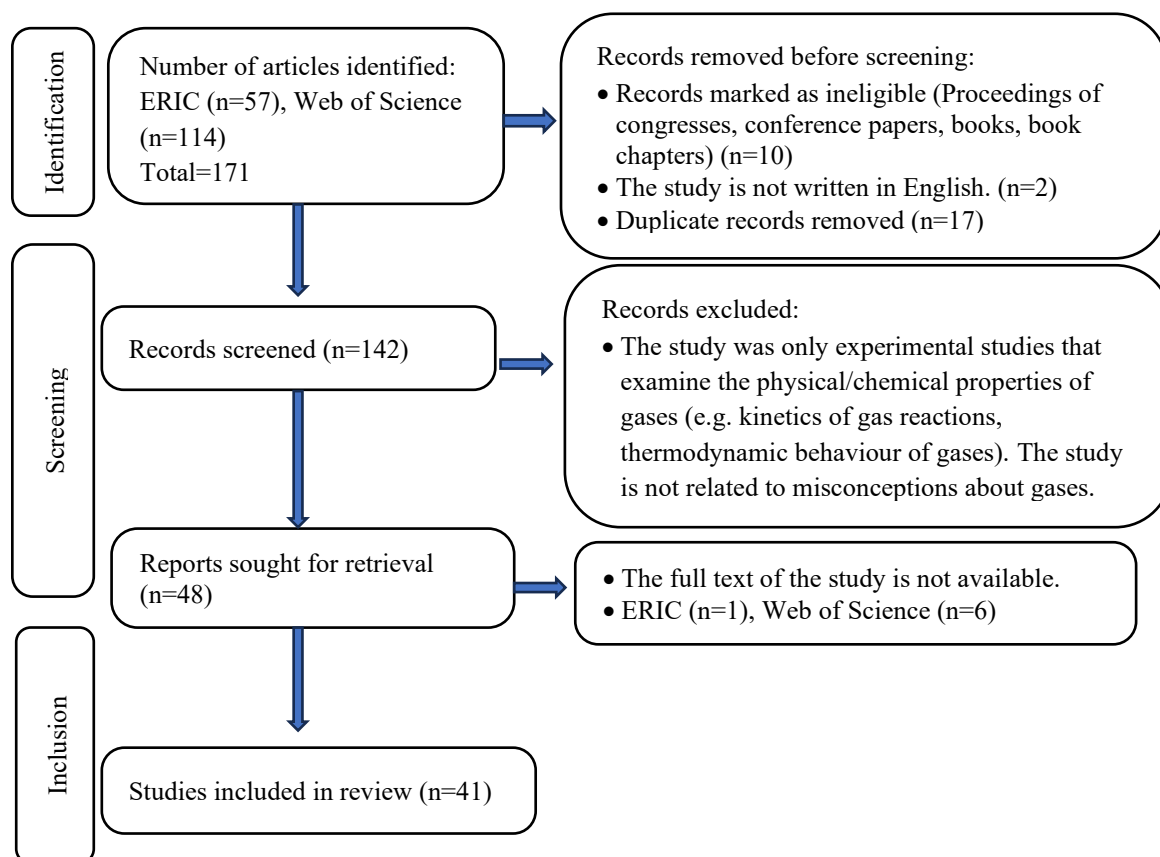


Figure 1 Flowchart of Product Process Selection

Data Collection and Analysis

In order to establish the article review criteria in the research, firstly, the articles published in the literature related to the review of the articles were examined. As a result of the review, a form was prepared to classify the articles based on the article classification form previously developed by Sözbilir et al. (2012) (Table 1). This form includes sections such as the title of the article, purpose, subject, method, sample (sample type, sample size), data collection tools, data analysis methods, conclusion and recommendation.

The data collection process was carried out in May 2025. A systematic literature search was performed in the ERIC and Web of Science databases, and the identified articles were exported to Microsoft Excel for analysis. The data obtained from the article classification form were saved in Microsoft Excel.

The data analysis was conducted in two stages. First, descriptive findings (e.g., year of publication, journal, research methods, sample characteristics) were analysed using descriptive statistics (frequencies and percentages) and presented in tables and figures (Gül & Sözbilir, 2015). Themes such as the title of the articles, research designs used, sampling characteristics, data collection tools and data analysis types were obtained through descriptive analysis and the findings were presented with graphs, percentages and frequency tables.

Second, to identify the main themes in the articles' aims, conclusions, and recommendations, a qualitative content analysis was performed. An inductive coding approach was used, where themes emerged from the data itself. The data related to the aims, conclusions and recommendations were analysed by content analysis and these findings were also presented using the same visualisation techniques (frequency tables).

Table 1 Article Classification Form

Article name:			
Authors of the article:.....			
Published in Journal:			
A. Year of publication	B. Volume:	C. Number:	D. Page range
Keywords:			
Methods			
Research design:			
Quantitative:.....	Qualitative:.....	Mixed:....	Unspecified:.....
Data collection tools:			
Sample:	Sample levels:.....Sample sizes:		
Data Analyzing Methods:	Quantitative data analysis:	Qualitative data analysis:.....	
Conclusions:			
Recommendations:			

Validity and reliability

Prior to commencing the analysis, a coding form was developed for use by the researchers. In developing this form, the characteristics specified in the article classification form presented in Table 1 were taken into account, with the aim of identifying trends that would emerge during the examination of the articles included in the study, in line with the research objective. All articles identified within the scope of the study by the third researcher were examined and analysed in terms of the characteristics listed in Table 1. The first and second researchers also carried out the coding process independently of one another in the same manner. The codes in the three separate forms created by the researchers were compared to determine the inter-coder reliability (Miles & Huberman, 1994). The Miles and Huberman (1994) reliability formula [$\text{Reliability} = \text{Agreement} / (\text{Agreement} + \text{Disagreement})$] was used to calculate the percentage of agreement between the researchers. The reliability indicating the agreement between the coders was calculated as 94%. These results show that the agreement (Miles & Huberman, 1994). Disagreements were resolved by discussion and shared consensus. Objectivity was maintained during the analysis stages to minimize validity threats.

Findings

Descriptive Findings

Regarding conceptual understanding of gases, the distribution of 41 relevant publications obtained from WoS and ERIC databases until May 2025 was evaluated according to years, journals and keywords. All 41 articles included in the analysis were published in peer-reviewed journals in the field of science education at the international level. An evaluation of the authors' nationalities revealed that 29 articles were authored solely by international researchers, 10 were authored solely by Turkish researchers, and two were co-authored by both Turkish and international researchers.

Table 2 Distribution of the Journals in which the Articles were Published

Journals	f	%
Chemistry Education Research and Practice	6	14.63
Journal of Chemical Education	6	14.63
International Journal of Science and Mathematics Education	3	7.32
Journal of Research in Science Teaching	3	7.32
Research in Science and Technological Education	2	4.88
Journal of Science Education and Technology	2	4.88
Science Educational International	2	4.88
Science & Education	2	4.88
Canadian Journal of Science, Mathematics and Technology Education	1	2.44
The Science Teacher	1	2.44
Eurasia Journal of Mathematics, Science and Technology Education	1	2.44
The Physics Teacher	1	2.44
Acta Didactica Napocensia	1	2.44
Journal of Education and Learning (EduLearn)	1	2.44
Science Education	1	2.44
European Journal of Physics	1	2.44
Journal of the Serbian Chemical Society	1	2.44
International Journal of STEM Education	1	2.44
Education Sciences	1	2.44
Advances in Physiology Education	1	2.44
International Journal of Science Education	1	2.44
Journal of Science Educational Technology	1	2.44
Physical Review Physics Education Research	1	2.44
Total	41	100

Table 2 presents the frequency (f) and percentage (%) values of the journals in which the 41 articles analysed in the study were published. According to the results of the analysis, the majority of the articles were published in “Chemistry Education Research and Practice” and “Journal of Chemical Education” (14.63% each, f=6). These were followed by “International Journal of Science and Mathematics Education” and “Journal of Research in Science Teaching” with 7.32% (f=3). Each of the other journals accounted for 4.88% or less of the total sample (2.44%), and diversity was evident throughout the distribution.

The Years in which the Articles were Published

Studies based on conceptual understanding about gases were first conducted in 1992 (Figure 2). Over the years, there has been an irregular but noticeable increase in the number of studies conducted. According to the data obtained from the reviewed studies, the majority of

research in this field has been conducted since 2010. There was a significant increase in the number of articles published in 2016 (4 articles), followed by 2020 (4 articles) and 2021 and 2024 (3 articles each). In contrast, only one study was published in each of the following years: 1992, 1993, 2002, 2004, 2006, 2008, 2012, 2018, 2022, and 2023.

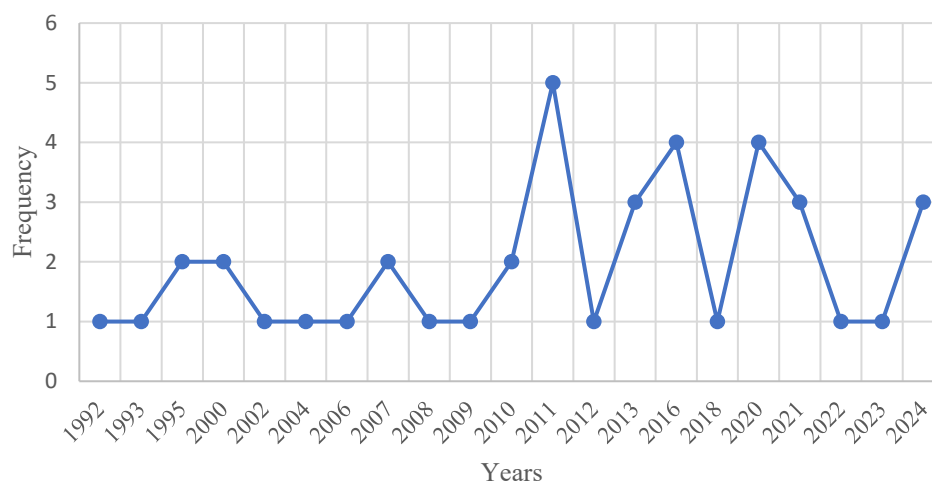


Figure 2 Frequency Distribution of Articles by Years

Keywords Used in the Analysed Articles

Based on an analysis using VosViewer (Figure 3), the following is a comprehensive overview of the terminology used in the topic “Conceptual understanding related to the subject of gases”. In general, “gases,” “chemistry education”, “gases laws”, and “misconceptions” are the dominant keywords in the analysed articles.

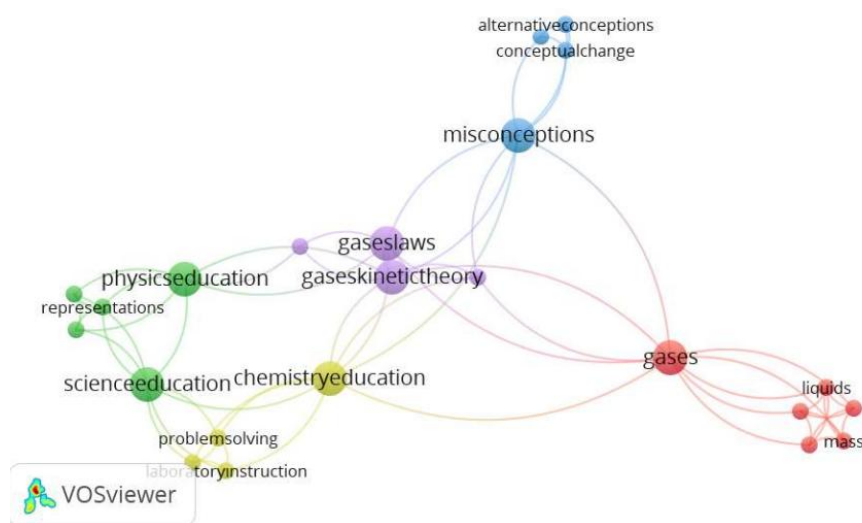


Figure 3 VosViewer Result of Keywords of the Analysed Articles

Findings on the Purposes of the Analysed Articles

The findings related to the aims of studies on conceptual understanding - such as misconceptions and concept teaching -regarding the topic of gases are presented in Table 3.

Table 3 The Purposes of the Analysed Studies

Purpose	f	%
Determination of students' current knowledge levels and misconceptions about gases.	24	45.28
Evaluation of the effect of different teaching methods (STEM, 5E, web-supported etc.) on student achievement in the subject of gases.	17	32.08
Evaluation of students' or preservice teachers' attitudes, interests, and motivations towards gases.	6	11.32
Development of achievement tests, conceptual tests or attitude scales on gases.	5	9.43
Associating the subject of gases with daily life and investigating its reflection on teaching.	1	1.89
Total	53	100

Table 3 shows that the majority of the analysed studies (f=24, 45.28%) aimed to determine students' current knowledge levels and misconceptions about gases. In second place is the evaluation of the effect of different teaching methods (STEM, 5E, web-assisted, etc.) on academic achievement in the subject of gases (f=17, 32.08%). Studies examining the attitudes, interests and motivations of students or prospective teachers towards the subject of gases (f=6, 11.32%), as well as studies aiming to develop achievement tests, concept tests or attitude scales (f=5, 9.43%), were found at lower rates. Studies investigating the association of the subject of gases with daily life and its reflections on teaching (f=1, 1.89%) are quite limited.

Methodological Findings

Research Designs

The findings related to the design/method distribution of the articles on conceptual understanding of gases are presented in Table 4 below.

Table 4 The Distribution of the Research Designs in Articles

Methods	Designs	f	%
Quantitative	Quasi-experimental study	15	36.58
	Weak experimental study	2	4.88
	Survey study	4	9.76
Qualitative	Case study	8	19.51
	Literature review	1	2.44
	Document analysis	1	2.44
Mixed		8	19.51
Other		2	4.88
Total		41	100

Quantitative studies ($f=21$, 51.22%) are the most common method in the distribution of research designs used in the studies, as shown in Table 4. In this category, quasi-experimental studies ($f=15$, 36.58%) played a dominant role, while weak experimental studies ($f=2$, 4.88%) and survey studies ($f=4$, 9.76%) were preferred in a more limited way. Qualitative research ($f=10$, 24.39%) was particularly represented by case studies ($f=8$, 19.51%), while literature reviews and document analysis ($f=1$, 2.44%) were used less frequently. Mixed methods ($f=8$, 19.51%) were adopted in approximately one fifth of the articles. The studies in the other group, which includes the studies in which activities for teaching the subject of gases are presented, have the lowest rate ($f=2$, 4.88%).

Sample Characteristics

The distribution of sample characteristics in terms of frequencies and percentages is shown in Figure 4.

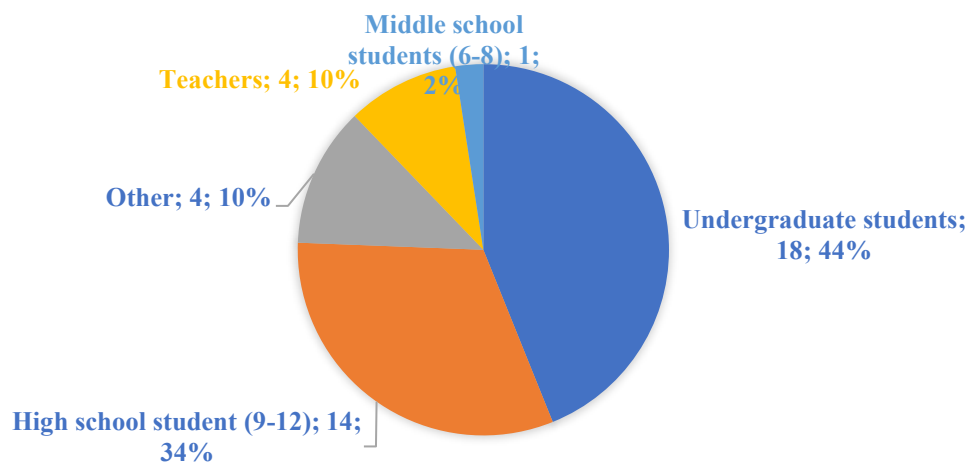


Figure 4 The Distribution of the Sample Characteristics in Articles

When Figure 4 is examined, it is seen that the highest proportion in the studies belongs to undergraduate students with 44%. This is followed by high school (9-12th grade) students with 34%, middle school (6-8th grade) students with 2% and teachers with 4%. Of the articles analysed, 4 (10%) were in the form of activity, experiment design and literature review related to gases. These studies were categorised under the "other" group as sample characteristics. It was seen that undergraduate students studying in science, physics or teaching programmes were preferred in the studies, therefore the number of studies conducted at the university level was higher.

Sample Sizes

The distribution of sample sizes in the analysed articles is shown in Figure 5.

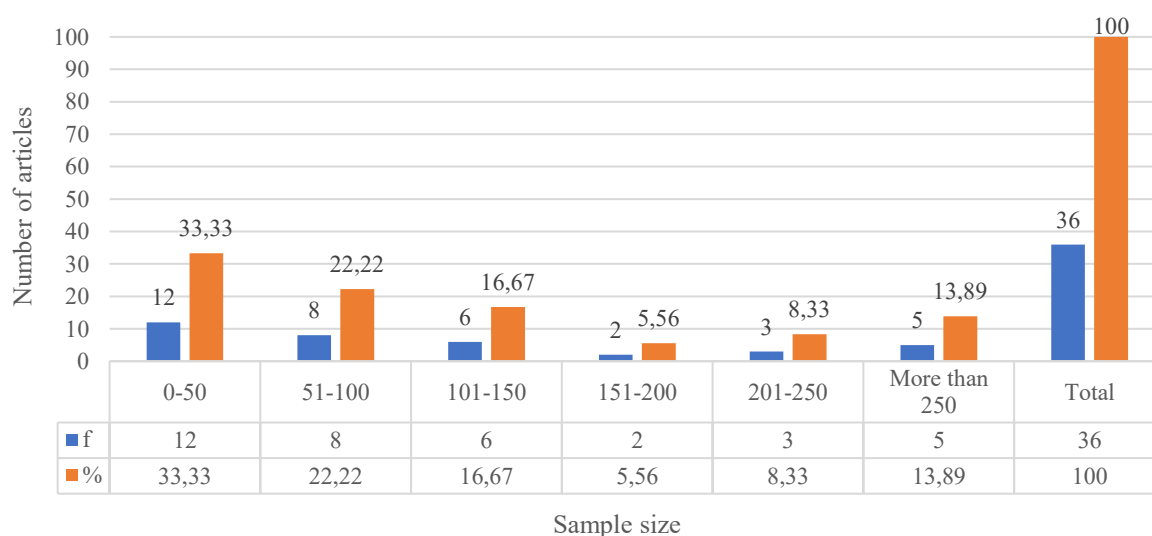


Figure 5 Distribution of the Sample Sizes in Articles

Since five of the 41 articles were related to development of a course activity, experiment design, and literature review on gases, the sample size of these articles could not be determined. Figure 2, which displays the sample sizes of the remaining 36 articles, reveals considerable variation in sample sizes across the studies. The highest rate belongs to studies with a sample size between 0-50 with 33.33%. This is followed by studies with a sample size of 51-100 with 22.22%, 101-150 with 16.67%, and more than 250 participants with 13.89%. In addition, 8.33% of the studies were with a sample size between 201 and 250, and 5.56% were with a sample size between 151 and 200. These findings show that most of the studies were conducted with medium sample sizes, while very small or very large samples are rarely preferred.

Data Collection Tools Preferred in Publications

The frequencies and percentages of data collection tools in the examined articles are presented in Table 6.

Table 6 The Distribution of the Data Collection Tools in Articles

Data Collection Tools		f	%
Tests	Conceptual tests	15	23.08
	Achievement tests	11	16.92
	Total	26	40
Surveys/Questionnaires	Open-ended	15	23.08
	Likert-type scale	10	15.35
	Total	25	38.46
Interviews		7	10.77
Observations		5	7.69
Concept maps		1	1.54
Documents		1	1.54
Total		65	100

Table 6 shows that tests were the most commonly used data collection tool in the studies, accounting for 40% of the total. They include conceptual tests (two-tier and four-tier), which account for 23.08%, and achievement tests, which account for 16.92%. This is followed by survey/questionnaires with 38.46%, interviews with 10.77%, observations with 7.69%, and documents and concept maps with 1.54%. Moreover, 23.08% of surveys/questionnaires included open-ended questions while 15.35% used Likert-type scales

(e.g. The Cooperative Learning Survey Questionnaire, Metacognitive Awareness Inventory) . These findings revealed that researchers mostly used quantitative tools to measure students' misconceptions about gases. Qualitative data collection methods such as interviews, observations and document analyses were used to a more limited extent.

Data Analysis Methods Used in Publications

Table 7 shows the findings related to data analysis methods used in publications.

Table 7 The Distribution of the Data Analysing Methods in Articles

Data Analysis Methods		f	%
Quantitative	Descriptive statistics	25	30.12
	Parametric analysis		
	t-test	8	9.64
	Analysis of Variances	5	6.02
	Multivariate Analysis of Variances	2	2.41
	Pearson correlation analysis	2	2.41
	Z-test	1	1.21
	Inferential statistics		
	Multiple regression analysis	1	1.21
	Total	18	21.69
	Nonparametric analysis		
	Chi-squared test	5	6.02
	Mann–Whitney U test	3	3.61
	Wilcoxon signed rank test	2	2.41
	Total	10	12.05
Qualitative	Total	28	33.74
	Other: Rasch analysis	1	1.21
	Total	54	65.06
	Content analysis	6	7.23
	Descriptive analysis	21	25.30
Qualitative	Constant-comparative	2	2.41
	Total	29	34.94
Total		83	100

When Table 7 is examined, it is seen that quantitative data analysis methods (65.06%) were used more than qualitative methods (34.94%) in the studies. While descriptive statistics (30.12%) and inferential analyses (33.74%) stand out among quantitative analyses, parametric tests (f=18, 21.69%) were preferred more frequently than non-parametric tests (f=10, 12.05%)

in inferential analyses. The most common parametric test was the t-test ($f=8$, 9.64%) and the most common non-parametric test was the chi-square test ($f=5$, 6.02%). On the other hand, Z-test, multiple regression analysis and Rasch model (each $f=1$, 1.21%) were the least used methods.

In qualitative analyses, descriptive analysis ($f=21$, 25.30%) was preferred more, while content analysis ($f=6$, 7.23%) and constant comparative ($f=2$, 2.41%) were preferred less. As a result, although the data reveal the dominant tendency towards quantitative methods in the studies in the field, it shows that qualitative analyses also have an important share.

Conclusions of the Analysed Articles

The findings of the analysis related to the conclusions of the reviewed articles are presented in Table 8.

Table 8 The Distribution of the Conclusions in Articles

Category	Conclusions	f	%
The effect of teaching methods	Positive effects of activity-based teaching methods (conceptual understanding, attitude, interest).	17	38.64
	The effect of technology-supported methods on success (Web 2.0, animation, simulation, etc.).	9	20.45
	Total	26	59.09
Conceptual understanding problems	Having many misconceptions about gases.	15	34.09
	Inadequacy of materials supporting conceptual understanding.	2	4.55
	Total	17	38.64
Contextualised learning	The contribution of associating with daily life to permanent learning	1	2.27
	Total	44	100

Most of the results of the articles analysed in Table 8 (59.09%) point to the determining role of activity-based teaching methods on learning outcomes. In these studies, it was found that activity-based teaching approaches had a significant positive effect on students' conceptual understanding levels, attitudes towards the course and their interest. In addition, in 20.45% of the articles analysed, technology-supported teaching tools (such as Web 2.0 applications, animations and simulations) were found to be effective in increasing academic achievement. However, 34.09% of the studies revealed that students had significant misconceptions about the basic concepts of gases and 4.55% of the studies associated this situation with the fact that the existing teaching materials were insufficient to support conceptual learning. Another relatively less emphasised result (2.27%) is that teaching the

subject of gases in connection with daily life supports permanent learning. In general, the findings show that the cognitive domain in the teaching approaches on the subject of gases, especially in the elimination of misconceptions and the application of effective teaching methods, is emphasized.

Recommendations of the Analysed Articles

The findings of the analysis related to the recommendations of the reviewed articles are presented in Table 9.

Table 9 The Distribution of the Recommendations in Articles

Category	Recommendation	f	%
Learning environment design	Use of dynamic visualisations	4	7.14
	Realisation of applied laboratory activities	13	23.21
	Use of contemporary teaching methods (STEM etc.)	14	25
	Material development in accordance with contemporary teaching methods	10	17.86
	Total	41	73.21
Teacher training	Preparation of content for misconceptions	9	16.07
Future research	Conducting comprehensive studies (different grade levels, etc.)	6	10.72
	Total	56	100

When Table 9 is analysed, it is seen that the suggestions in the researches on the subject of gases are grouped under three main categories. The learning environment design category stands out as the most dominant theme, constituting 73.21% (f=41) of all suggestions. In this category, the use of contemporary teaching methods (STEM etc.) was the most frequently emphasised suggestion with a rate of 25%. In the design of the learning environment, the students emphasised that applied laboratory activities should be carried out (23.21%) and dynamic visualisations should be used in the teaching of gases (7.14%). The category of Teacher Training in the Suggestions covers 16.07% (f=9) of the suggestions and it is seen that the focus is especially on "preparation of contents for misconceptions". The suggestions under the Future Research heading constitute 10.72% (f=6) of the total and emphasise the need for more comprehensive studies. In general, the suggestions offer concrete steps towards increasing students' conceptual learning, making the teaching process more effective and improving teacher competences. This situation points to the need for systematic improvement in terms of both teacher training and teaching materials and methods.

Discussion

In this study, it was aimed to reveal the general trends of the studies on conceptual understanding such as misconceptions and concept teaching on the subject of gases in ERIC and Web of Science (WoS) databases by systematic literature analysis. For this purpose, 41 articles that meet the criteria determined were analysed. In this section, the findings of the articles examined are discussed under specific headings.

Focus Areas of Research on Gases

This systematic review has revealed the general trends in research on conceptual understanding and misconceptions regarding gases. The vast majority of studies have been conducted in the field of chemistry education and within the context of chemistry lessons. The prominence of the term ‘chemistry education’ in the keyword analysis suggests that the studies were predominantly carried out by chemistry researchers; however, it may also indicate that the topic of gases has not been sufficiently embraced by physics educators. However, the topic of gases is a common area of study for both chemistry and physics disciplines (e.g. kinetic theory, thermodynamics). This situation points to a significant gap, suggesting that the studies examined do not fully reflect the interdisciplinary potential and may lead to conceptual learning issues regarding the topic of gases being overlooked in physics education.

The distribution of research by year shows a significant increase in the number of studies after 2010. This increase can be directly attributed to the increased awareness of conceptual learning difficulties in science education (Kurtuluş & Tatar, 2021) and the increased visibility of theoretical frameworks such as conceptual change and mental modelling in science, physics, and chemistry education research. However, despite this increase, these studies have largely remained at the descriptive level. While approximately half of the research focuses directly on identifying misconceptions, the number of studies explaining the processes for correcting these misconceptions is smaller. This situation indicates that research in the field is concentrated in the problem-defining phase, and is insufficient in the solution-developing and process-understanding phases.

Nearly half of the research on the conceptual understanding of gases focuses on determining students' current level of knowledge and common misconceptions about gases. Similarly, in studies involving systematic literature reviews on misconceptions, it has been observed that researchers mostly conduct research aimed at identifying misconceptions (Dağ

& Horzum, 2022; Türkdogan et al., 2015; Yıldız et al., 2021). These studies document conceptual difficulties, particularly those stemming from the abstract nature and unobservable properties of gases. A significant number of studies evaluate the effects of different teaching strategies (modelling, simulation, experiments, etc.) on academic achievement and conceptual understanding of gases. A much smaller portion of research focuses on analysing the attitudes, interests, and motivation levels of students and prospective teachers towards gases, and on developing novel achievement tests, concept tests, and attitude scales to identify misconceptions about gases. This research trend is consistent with the general trend in science education research where diagnosis comes first, followed by intervention and assessment. When teaching abstract and microscopic phenomena like gases, understanding students' mental models and determining their knowledge levels is crucial (Johnstone, 1991). The abstract nature of the particle-level behaviour of gases for students reveals that this topic is particularly challenging in terms of cognitive processes that require transitions between levels of representation. In this context, educators need to plan evidence-based strategies and develop appropriate teaching methods to enrich students' learning experiences (Gabel, 1999). Thus, educators can plan what needs to be done to improve students' learning experiences and create teaching strategies that take this into account. In teaching gases, the focus should not only be on correcting misconceptions; priority should also be given to comprehensive research that measures the effectiveness of approaches that also encompass affective characteristics such as attitude, motivation, and interest.

Methodological Characteristics of Research on Gases

An examination of the methodological characteristics of the studies included in the compilation reveals a noticeable uniformity in the field. The dominance of quantitative research methods (especially quasi-experimental designs) indicates that research on misconceptions tends to focus more on establishing cause-and-effect relationships. Researchers consistently prefer these methods to measure the effectiveness of different teaching strategies (Alkış Küçükaydın, 2020; Dağ & Horzum, 2022). However, this dominant methodological preference also has some limitations.

Firstly, understanding misconceptions actually requires in-depth and context-based analysis. However, the limited use of qualitative methods (e.g., phenomenology, case studies) makes it difficult to understand students' conceptual thinking processes holistically. As Özcan & Bakır (2023) also point out, qualitative data collection tools such as interviews, observation, and document analysis are very important for understanding students' mental

models. The limited use of these tools indicates that the research examined struggles to strike a balance between quantitative studies that allow for generalizations and qualitative studies that delve deeply into students' thinking.

Secondly, the fact that mixed methods are less preferred compared to other methods limits the simultaneous evaluation of both generalizable quantitative findings and in-depth qualitative insights. However, the use of mixed methods designs is important for answering both the questions of what misconceptions are (quantitative) and why and how they arise (qualitative) (Creswell & Plano Clark, 2011). Therefore, the increased use of mixed methods in future research on conceptual understanding of gases will contribute to a more comprehensive evaluation of the effectiveness of teaching practices.

Sample Characteristics of Research on Gases

When participant groups were examined, it was found that the majority of studies were conducted with university students, followed by high school students, teachers, and middle school students, respectively. Some systematic literature studies show that more studies have been conducted with university students (Mesin et al., 2019; Ferk Savec & Mlinarec, 2021). The dominance of studies with university students reveals that researchers prefer to examine misconceptions at a more advanced level and in contexts with intense mathematical abstractions (Johnstone, 1991; Taber, 2002). However, this preference makes it difficult to understand the processes related to how misconceptions are formed. Misconceptions generally take shape in early learning periods (middle and high school) and, if not adequately addressed during the teaching process, deepen and persist at the university level (Barke et al., 2009; Taber, 2018). In this context, the scarcity of studies at the middle and high school levels points to a significant research gap in terms of preventing and early intervention for misconceptions. The limited number of studies, particularly those conducted with teachers (Çalık & Ayas, 2005), represents a significant deficiency in the context of pedagogical content knowledge (PCK). Teachers' abilities to recognize, anticipate, and develop teaching strategies to address misconceptions directly impact the quality of students' conceptual learning (Shulman, 1986; Kind, 2019). Therefore, studies at both the teacher training and secondary school levels are critically important in addressing this knowledge gap.

In terms of sample size, it was observed that most studies were conducted with groups of fewer than 50 people. The most frequently used research method in the analysed articles was the quasi-experimental design. This is consistent with the nature of quasi-experimental designs in terms of sample size. Quasi-experimental studies in education are generally

conducted with small or medium-sized samples due to their applicability in real classroom settings (Fraenkel et al., 2019).

Data Collection and Data Analysis Preferences of Research on Gases

The studies reviewed showed that tests and questionnaires were the most preferred data collection tools for determining conceptual understandings related to gases. This finding indicates that researchers tend to use quantitative methods to reliably analyse students' mental models and conceptual levels on large samples. This preference is also clearly seen in similar studies in the literature (Alkış Küçükaydın, 2020; Mert et al., 2024; Treagust et al., 2010; Soeharto et al., 2019). The use of two-stage tests in these studies is a powerful approach in revealing not only the existence of misconceptions but also the ways in which students justify them (Treagust et al., 2010). This shows that research in this field has reached a certain level of methodological maturity. In questionnaires, it was observed that open-ended questions, which allow students to reflect on their conceptual thoughts in their own words, were used more frequently than Likert-type scales, which measure affective variables such as attitudes and awareness. This situation shows that research focuses not only on the level of knowledge but also on approaches and tendencies toward learning (Abdullah & Shariff, 2008). Furthermore, the limited use of qualitative data collection tools such as interviews and observations in the studies examined indicates that the opportunity to deeply examine the contextual and cognitive sources of misconceptions has not been fully utilized; whereas such methods are of great importance for understanding students' mental models in more detail. Therefore, although the current trend is towards quantitative data collection tools, it is important to integrate more of the depth provided by qualitative methods in conceptual understanding related to the topic of gases into research.

Findings regarding data analysis techniques in studies examining conceptual understanding of gases reveal that quantitative analysis methods are used in the vast majority of studies, while qualitative analyses are less preferred. Similar results have been obtained in some systematic literature studies investigating misconceptions (Alkış Küçükaydın, 2020; Dağ & Horzum, 2022). The frequent use of descriptive statistics (30.12%) and inferential analyses (33.74%) in quantitative analyses stems from the researchers' need to evaluate students' conceptual levels in terms of both general trends and intergroup differences. The more frequent preference for parametric tests (especially t-tests and ANOVA) reflects the aim of obtaining stronger statistical results when sample sizes are sufficient and the data meet the assumption of normal distribution (Liu, 2006; Mayer, 2011). These tests are frequently used

to measure the effect of instructional interventions, compare levels of conceptual change, and evaluate the effectiveness of instructional strategies. On the other hand, it is observed that qualitative analyses are also used to a considerable extent (34.94%). This situation shows that understanding misconceptions is considered important not only at the quantitative level but also in the context of students' thinking styles, justification processes, and mental models. The most preferred method in qualitative analyses was descriptive analysis (25.30%). This is because descriptive analysis is an effective tool in revealing conceptual patterns by classifying students' open-ended responses thematically (Yıldırım & Şimşek, 2018). Although more in-depth analysis techniques such as content analysis and continuous comparative methods were used less frequently, they make significant contributions to understanding the structure and continuity of students' alternative conceptions (Treagust et al., 2010). In conclusion, while the frequent use of these methods stems from the need to objectively evaluate the impact of quasi-experimental teaching methods on teaching, the considerable preference for qualitative analyses reveals that understanding misconceptions together with students' thinking processes and justifications is considered important.

Evaluation of the Results and Recommendations of Research on Gases

According to the results of studies examining conceptual understanding of gases, 59.09% of the studies focused on the 'effect of teaching methods' category, and these studies specifically revealed that activity-based and technology-supported teaching methods significantly improved students' conceptual understanding, attitudes, and interest. In line with this, the fact that activity-based applications support students' conceptual understanding, increase learning participation, and are effective in reducing misconceptions is consistent with previous studies (Geçit et al., 2024; Yavuz & Çelik, 2013). Furthermore, findings frequently emphasize in the literature that technology-supported applications such as Web 2.0 tools, simulations, and animations enable students to achieve more lasting learning by visualizing abstract concepts at a microscopic level (Correia et al., 2019; Velázquez-Marcano et al., 2004). Thirty-eight-fourths of the studies focused directly on problems of conceptual understanding. Findings in this area indicated that students hold common and persistent misconceptions about gases. A significant reason for these misconceptions was attributed to the inadequacy of teaching materials in concretizing abstract concepts and the difficulty students have in internalizing scientific explanations that contradict their daily experiences (Mayer, 2011). Indeed, some studies concluded that there were no materials supporting conceptual understanding (4.55%). Designing teaching materials that present students'

potential misconceptions alongside their scientifically accurate counterparts could facilitate students' awareness and correction of these misconceptions (Mboniyirivuze et al., 2019). Although few in number, studies have found that teaching gases by relating them to everyday life contributes to lasting learning. Students' ability to relate newly learned concepts to real-life situations supports the transfer of information to long-term memory and conceptual learning (Gilbert, 2006; Güldal & Doğru, 2018). The fact that most research on conceptual understanding of gases focuses on the effectiveness of teaching methods indicates that misconceptions are strongly influenced not only by a lack of information but also by the teaching methods that structure students' learning processes. While findings suggesting that activity-based and technology-supported applications in teaching methods increase conceptual understanding are noteworthy, studies showing that students still hold persistent misconceptions suggest that current methods and the materials used in these teaching methods are insufficient in concretizing the abstract nature of gases. This situation highlights the importance of not only teaching methods but also the quality of materials used in applying these methods and the integration of content with everyday life contexts to support conceptual understanding. In conclusion, this systematic review reveals that misconceptions about gases can be influenced by both teaching methods and the materials and contexts used.

A striking picture emerges when examining the recommendations section of the research. The fact that 73.21% of the recommendations are grouped under general headings such as "learning environment design" shows that researchers have difficulty transforming their findings into concrete and subject-specific recommendations. The observation of a similar trend in other systematic review studies, such as Alkış Küçükaydın (2020), suggests that this situation is not unique to the topic of gases, but is a general characteristic of concept teaching studies in science education.

The relatively low number of recommendations for teacher training (16.07%) indicates a significant deficiency in preventing misconceptions. Shulman (1986) and Kind (2019) emphasized that teachers' pedagogical content knowledge (PCK) plays a crucial role in anticipating students' conceptual difficulties and designing appropriate interventions. In this context, the scarcity of recommendations for teacher training shows that research focuses more on addressing misconceptions rather than preventing them. However, effective interventions in the early stages (middle and high school) can prevent persistent misconceptions encountered at the university level (Barke et al., 2009). Similarly, the limited number of recommendations (10.72%) for large-scale studies encompassing different grade

levels and contexts indicates that longitudinal research in the field is insufficient. However, understanding how misconceptions change over time will allow for both the development of curricula and a realistic assessment of the effectiveness of teaching strategies. In conclusion, the results of the research on conceptual understanding of gases reveal that activity-based and technology-supported applications positively influence conceptual understanding; however, the general statements in the recommendations section indicate limitations in translating these findings into concrete application recommendations.

Conclusions and Suggestions

This systematic review shows that conceptual understanding research on gases has accumulated significantly over the past two decades, but this accumulation has certain methodological and conceptual limitations. Research in the field has provided a strong foundation for identifying misconceptions and testing the effectiveness of different teaching methods. However, this research has not sufficiently focused on understanding the processes by which misconceptions form, evaluating their interdisciplinary dimension, and tracing their developmental processes. More importantly, the repetition of general statements in the recommendations section of the research indicates limitations in translating the findings into concrete application recommendations.

This study reveals three key gaps in conceptual understanding research on gases:

The concentration of the studies examined within the context of chemistry education leads to the neglect of common areas of study with physics education (e.g., kinetic theory, thermodynamics). However, the interdisciplinary nature of the topic of gases necessitates a comprehensive examination of how misconceptions arise in different contexts and how they can be addressed.

The limited number of studies conducted at the middle and high school levels in the research examined indicates a lack of sufficient knowledge regarding the early detection and prevention of misconceptions. However, a research approach that does not delve into the root causes of misconceptions is more like trying to cope with the problems that arise rather than understanding where the problem originates.

When the research examined is reviewed, the question of "which method is more successful?" is predominantly addressed, while there are fewer studies that explore "how does the conceptual change process work?". This highlights the importance of interventions aimed at correcting misconceptions.

Future studies on gases should focus on the following topics, as research into conceptual understanding will lead to more effective teaching and outcomes in the field of gases:

- Mixed-methods studies that strengthen the connections between macro-micro-symbolic representations through technology integration (simulations, augmented reality),
- Intervention studies focusing on improving teachers' pedagogical content knowledge at the middle and high school levels,
- Longitudinal studies that track the change of misconceptions over time,
- Interdisciplinary research that brings together the disciplines of physics and chemistry education.

Limitations

While this review provides a comprehensive synthesis of research on conceptual understanding such as misconceptions and concept teaching in the topic of gases, it also recognises some limitations inherent in the review process. This study is limited to articles in the WoS and ERIC indexes. However, the selection of only these two databases means that some relevant publications may have been missed due to biases arising from the choice of database or the search terms used. It is also noted that there is a language bias as only English language articles were included in this review. Therefore, further studies covering different indexes could be conducted.

Compliance with Ethical Standards

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Research involving Human Participants and/or Animals

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Gazlar Konusuyla İlgili Kavramsal Anlamayı Araştıran Çalışmaların Sistematik Literatür Taraması

Özet: Gazlar konusu fizik ve kimya öğretiminde önemli konular arasında yer almaktadır. Öğrencilerin bu alanlarda sıklıkla kavram yanlışlarına sahip olması öğrenmeyi olumsuz etkilemektedir. Bu nedenle kavram yanlışları ve kavram öğretimi üzerine yapılan çalışmalar önemlidir. Bu çalışmanın amacı, 1992-2024 yılları arasında gazlarla ilgili kavram yanlışları ve kavramsal anlamaya odaklanan uluslararası çalışmaların sistematik bir literatür taramasından elde edilen bulguları sunmaktır. Bu sistematik literatür taramasında çeşitli veri tabanları (Web of Science, Education Resources Information Center (ERIC)) aracılığıyla literatür taraması yapılmış ve bulgular "Preferred Reporting Items for Systematic Review and Meta-Analysis" (PRISMA) adımlarına uygun olarak raporlanmıştır. Web of Science (N=114) ve ERIC (N=57) veri tabanlarından toplam 171 makale tespit edilmiştir. Dahil etme/dışlama kriterleri uygulandıktan sonra 41 makale elde edilmiştir. Veriler betimsel ve içerik analizi yöntemleri kullanılarak analiz edilmiştir. Çalışmada, makalelerin konularının çoğunun öğretim materyalleri üzerine yoğunlaştığı ve özellikle deneysel araştırmaların ön planda olduğu görülmüştür. Bu çalışmalarda katılımcıların gazlarla ilgili kavram yanlışlarını tespit etmek için çoğunlukla kavramsal testlerin kullanıldığı ve daha çok lise ve lisans öğrencilerine odaklanıldığı tespit edilmiştir. Araştırmalar, etkinlik temelli ve teknoloji destekli öğretimin gazlarla ilgili kavramsal gelişime olumlu katkı sağladığını göstermiştir. Ancak ideal gaz kanunu gibi soyut konuların öğrenciler için ciddi kavramsal zorluklar içerdiği vurgulanmıştır. Bu doğrultuda aktif öğrenme temelli öğretim yöntemlerinin kullanılması, öğretim materyallerinin çeşitlendirilmesi ve laboratuvar deneylerinin artırılması önerilmektedir.

Anahtar kelimeler: Kimya eğitimi, fizik eğitimi, gazlar, kavramsal anlama, kavram yanlışlığı, sistematik literatür analizi.

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