

STUDENTS' KNOWLEDGE OF THE CONCEPT OF ENERGY IN CHEMICAL REACTIONS: A STUDY WITH 12TH GRADE SCIENCE AND TECHNOLOGY STUDENTS

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ABSTRAK

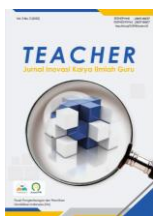
Artikel ini menyajikan analisis pengetahuan siswa kelas 12 dari mata kuliah Sains dan Teknologi di Sekolah Menengah Katolik Santa Maria Ainara tentang konsep energi dalam reaksi kimia, dengan perhatian khusus pada isi angka oksidasi, keadaan oksidasi, agen oksidasi, dan agen pereduksi. Studi ini dikembangkan dari kuesioner yang terdiri dari sepuluh pertanyaan, diterapkan kepada 39 siswa dari kelas A dan B. Jawaban diorganisasikan ke dalam kategori analisis - jawaban yang sah secara ilmiah, jawaban yang tidak lengkap, konsep alternatif, tidak adanya jawaban dan jawaban lainnya, lalu diperlakukan berdasarkan frekuensi dan persentase. Hasil keseluruhan menunjukkan 74% jawaban yang sah secara ilmiah, 6% jawaban tidak lengkap, 2% jawaban dengan desain alternatif, dan 18% jawaban lainnya. Terdapat kinerja yang sangat tinggi dalam menentukan jumlah oksidasi oksigen dan hidrogen, keduanya dengan 100% jawaban yang valid. Pemahaman yang baik tentang konsep agen pengoksidasi dan agen pereduksi juga diamati, dengan 79,49% jawaban yang valid. Di sisi lain, kesulitan yang lebih besar muncul dalam tugas-tugas yang memerlukan perhitungan dan penerapan aturan untuk menentukan angka oksidasi, terutama pada senyawa Fe_2O_3 , serta dalam identifikasi agen pengoksidasi dan pereduksi dalam reaksi reduksi oksidasi. Diskusi hasil diartikulasikan dengan tujuan dan masalah yang dirumuskan dalam studi serta dengan dasar teoretis yang disajikan, memungkinkan kita menyimpulkan bahwa mahasiswa memiliki dasar konseptual yang relevan, tetapi membutuhkan konsolidasi lebih lanjut dalam keterampilan interpretasi, perhitungan, dan aplikasi.

Kata kunci: energi kimia; reaksi oksidasi-reduksi; angka oksidasi; agen pengoksidasi; agen pereduksi; pembelajaran kimia.

ABSTRACT

This article presents an analysis of the knowledge of the students of the 12th grade of the Science and Technology course of the Santa Maria Ainara Catholic General Secondary School about the concept of energy in chemical reactions, with particular attention to the contents of oxidation number, oxidation state, oxidizing agent and reducing agent. The study was developed from a questionnaire consisting of ten questions, applied to 39 students from classes A and B. The answers were organized into categories of analysis - scientifically valid answers, incomplete answers, alternative conceptions, absence of answer and other answers and then treated by frequency and percentage. The overall results indicated 74% of scientifically valid answers, 6% of incomplete answers, 2% of answers with alternative designs and 18% of other answers. There was a particularly high performance in determining the oxidation number of oxygen and hydrogen, both with 100% of valid answers. A good understanding of the concepts of oxidizing agent and reducing agent was also observed, with 79.49% of valid answers. On the





other hand, greater difficulties arose in tasks that required calculation and application of the rules for determining the oxidation number, especially in the Fe_2O_3 compound, as well as in the identification of oxidizing and reducing agents in an oxidation-reduction reaction. The discussion of the results is articulated with the objectives and the problem formulated in the study and with the theoretical foundations presented, allowing us to conclude that students have a relevant conceptual basis, but need further consolidation of interpretation, calculation and application skills.

Keywords: chemical energy; oxidation-reduction reactions; oxidation number; oxidizing agent; reducing agent; learning chemistry.

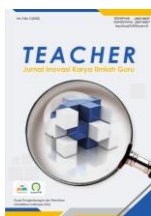
INTRODUCTION

Scientific education is an important dimension of student training, especially in a context in which scientific and technological knowledge plays a growing role in social life and national development (Adorni & Silva, 2021; Scramim & Graff, 2024). In the context of Timor-Leste, education is recognized as a responsibility of the State and as a means of ensuring training opportunities and developing the skills of citizens (Beck, 2022; Correia, da Costa Araujo, de Jesus, & da Silva, 2025). The study under analysis is part of this context and focuses on the teaching of Chemistry in General Secondary Education, specifically in the 12th year of the Science and Technology course (Putica, 2024; Suparwati, Suja, & Tika, 2023).

In the curriculum presented in the original work, Chemistry is part of the Physical-Natural Sciences component and is taught in Secondary Education with a workload of three times per week (Al Idrus, Mutiah, Rahmawati, Junaedi, & Anwar, 2021; Taneo, Narca, & Sanchez, 2025). The teaching of the discipline seeks to articulate scientific knowledge and practical activities. However, the literature mobilized in the study points out that many Chemistry contents are perceived by students as abstract and difficult, especially when they involve scientific language, relationships between concepts and calculations (Moreira, Cardoso, & Neto, 2024; Salahudin, Savalas, & Hidayanti, 2025). This situation justifies the need to know the students' level of understanding and identify the contents in which difficulties persist (Deleña & Marasigan, 2023).

Among the most relevant contents are the oxidation-reduction reactions. These reactions are present in phenomena and processes such as combustion, corrosion, metabolism, photosynthesis, metal extraction and production of electricity (Dood & Watts, 2022; Poelloth, Diekemper, & Schwarzer, 2023). The understanding of these processes requires the mastery of interconnected concepts, among which oxidation, reduction, oxidation number, oxidizing agent and reducing agent stand out (Sinaga, 2022; Supriadi, Wildan, Hakim, Savalas, & Haris, 2021). The theoretical study presented in the work highlights that difficulties in a basic concept can compromise the learning of later concepts, which is why the assessment of students' understanding is important to guide teaching.

The research problem can be summarized in the following question: what is the knowledge of the students of the 12th grade of Science and Technology of the Santa Maria Ainaro Catholic General Secondary School about the concept of energy in chemical reactions, particularly with regard to the oxidation number, oxidation state, oxidizing agent and reducing agent? The formulation of this question arises from the need to understand not only if the students can answer correctly, but also which contents they demonstrate greater mastery of and what difficulties arise when they need to interpret or apply the concepts.



The general objective is to analyze the knowledge of the students of the 12th grade of Science and Technology of the Santa Maria Ainaro Catholic General Secondary School about the concept of energy in chemical reactions. In specific terms, the study seeks to identify the main difficulties of the students in relation to the selected contents and contribute to the improvement of the learning of these concepts.

The study of the energy associated with chemical reactions is relevant to the understanding of natural and technological processes. In the original work, the relevance of the theme is related to applications such as batteries, energy sources, the chemical and pharmaceutical industry and environmental sustainability. In the school environment, understanding the concepts involved in chemical reactions allows students to interpret everyday phenomena and develop scientific skills necessary for the continuity of studies and for informed participation in society.

Research is also important because it allows the identification of differences between declarative knowledge and application skills. The results show, for example, that students can master simple oxidation number rules, but have greater difficulty when they need to use these rules in specific compounds or reactions. Thus, the analysis of the responses offers useful information for the teacher to plan review strategies, graded exercises and more contextualized learning activities.

METHODS

Approach and context of the study

This is a study developed at the Santa Maria Ainaro Catholic General Secondary School, located in the municipality of Ainaro, Timor-Leste. According to the original work, data collection took place on September 12 and 13, 2025. The study adopted a qualitative approach to analyze the students' responses, complemented by descriptive treatment in frequencies and percentages. This combination allowed us to observe both the content of the responses and the distribution of the response categories.

Population and sample

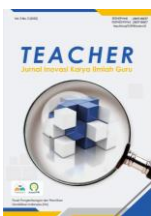
The study population consisted of students in the 12th grade of Science and Technology at the Santa Maria Ainaro Catholic General Secondary School. The total population was 39 students, distributed in two classes: 20 students in class A and 19 in class B. As the total number was less than 100, the study adopted the total population as a sample. Thus, 39 students participated.

Data collection technique and tool

Data collection was carried out by means of a questionnaire. The instrument contained ten questions related to the definition of oxidation, oxidizing agent and reducing agent, determination and calculation of the number of oxidation and identification of what occurs when an element undergoes oxidation. The questionnaire was previously validated by the advising professor, with the objective of verifying the adequacy of the questions to the objectives and contents of Chemistry addressed.

Data processing and analysis

The answers were organized question by question and classified into five categories: (1) scientifically valid answers; (2) incomplete answers; (3) answers with alternative conceptions;



(4) non-answer; and (5) other answers. The categories allowed us to identify the degree of mastery of the contents and the difficulties present in the answers. Subsequently, the frequencies were converted into percentages.

To interpret the level of comprehension, the study used the following scale: 0–20% very poor; 21–40% poor; 41–60% sufficient; 61–80% good; and 81–100% very good. In the revised version, this classification is maintained as a descriptive instrument of the study itself, without using it as a global assessment of the students or the school.

RESULTS AND DISCUSSION

Results

Characterization of the Participants

A total of 39 students participated in the study. Of these, 25 students (64.10%) were female and 14 students (35.89%) were male. Regarding age, five students (12.82%) were 16 years old, 17 students (43.59%) were 17 years old, 14 students (35.90%) were 18 years old, and three students (7.69%) were 19 years old. Students aged 17 years represented the largest proportion of the participants.

Overall Questionnaire Results

The questionnaire consisted of ten questions. Across all responses, 288 scientifically valid answers were recorded (74%), followed by 25 incomplete answers (6%), eight answers classified as alternative conceptions (2%), no non-responses (0%), and 69 other answers (18%).

Table 1. Distribution of Students' Responses to the Oxidation-Reduction Questionnaire

Category	Frequency	Percentage
Scientifically valid answers	288	74%
Incomplete answers	25	6%
Alternative conceptions	8	2%
Non-responses	0	0%
Other answers	69	18%

Knowledge of the Oxidation Number

For the question concerning the definition of oxidation number, 19 students (48.72%) provided scientifically valid answers, two (5.13%) provided incomplete answers, one (2.56%) presented an alternative conception, and 17 (43.59%) provided other answers.

Oxidizing and Reducing Agents

For the definition of oxidizing and reducing agents, 31 students (79.49%) provided scientifically valid answers, four (10.26%) provided incomplete answers, three (7.69%) presented alternative conceptions, and one (2.56%) provided another answer.

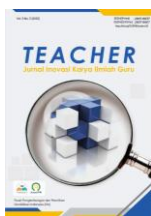
Oxidation Numbers of Oxygen and Hydrogen

All 39 students (100%) provided scientifically valid answers to both questions concerning the oxidation number rules for oxygen and hydrogen.

Oxidation Number of Oxygen in O₂

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For the O_2 molecule, 26 students (66.67%) provided scientifically valid answers, five (12.82%) provided incomplete answers, two (5.13%) presented alternative answers, and six (15.38%) provided other answers.

Oxidation Number of Sulfur in SO_4^{2-}

For the calculation of the oxidation number of sulfur in SO_4^{2-} , 27 students (69.23%) provided scientifically valid answers, while 12 students (30.77%) provided other answers. The scientifically valid answer corresponds to an oxidation number of +6 for sulfur.

Oxidation Number of Iron in Fe_2O_3

For the calculation of the oxidation number of iron in Fe_2O_3 , 23 students (58.97%) provided scientifically valid answers, while 16 students (41.02%) provided other answers. The scientifically valid result for iron is +3.

Identification of Oxidizing and Reducing Agents

In the reaction $Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$, 27 students (69.23%) correctly identified Cu^{2+} as the oxidizing agent, seven (17.95%) provided incomplete responses, and five (12.82%) provided other responses.

For the identification of the reducing agent, 25 students (64.10%) provided scientifically valid answers, six (15.38%) provided incomplete answers, and eight (20.51%) provided other answers. The reducing agent in the reaction is Zn.

Oxidation Process

In the final question, concerning what happens when an element undergoes oxidation, 32 students (82.05%) provided scientifically valid answers, six (15.38%) provided other answers, and one student (2.56%) presented an alternative conception. The scientifically valid response indicates an increase in the oxidation number.

Discussion

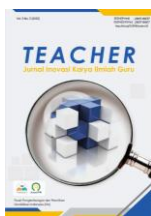
Overall Pattern of Students' Understanding

The results indicate that students demonstrated different levels of understanding across the ten questions. The highest performance occurred in the direct identification of oxidation numbers for oxygen and hydrogen, where all participants provided scientifically valid answers. In contrast, lower performance was observed in the definition of oxidation number and in the calculation of the oxidation number of iron in Fe_2O_3 . This pattern indicates a distinction between recalling or applying a single rule and solving tasks that require several related steps.

The overall distribution of responses also shows that scientifically valid answers constituted the largest category, accounting for 74% of all responses. Nevertheless, the presence of incomplete and other answers indicates that not all students had fully consolidated the assessed concepts. The categorization of responses was therefore useful for identifying not only correct knowledge but also areas in which students' understanding remained incomplete or differed from the scientific formulation used in the study.

Understanding of the Oxidation Number Concept

The relatively low proportion of scientifically valid responses for the definition of oxidation number (48.72%) suggests that the conceptual foundation of oxidation number was



less consolidated than students' knowledge of specific rules. The high proportion of other answers (43.59%) further indicates variation in how students understood or expressed the concept. This finding is consistent with previous research showing that students often experience conceptual difficulties with the nature and definition of oxidation number. Sari et al. (2023), for example, reported that most of 34 first-year chemistry students were confused about the nature of oxidation number and demonstrated misconceptions when applying oxidation-number rules. Similarly, Fanfiana & Hadisaputra (2024) found that only 10% of 31 pre-service chemistry teachers correctly defined oxidation number, while 81% demonstrated misconceptions.

The present finding also corresponds with research on redox misconceptions in which students had difficulty distinguishing oxidation number from ionic charge. Astuti & Meilinda (2024) reported that university students showed deficiencies in understanding oxidation numbers and frequently confused oxidation number with charge. Research involving Indonesian secondary students has likewise identified misconceptions related to determining oxidation numbers, indicating that such difficulties can persist across different educational levels.

This finding is relevant because oxidation number is a foundational concept for subsequent redox analysis. Confusion between oxidation number, ionic charge, and the process of oxidation may make it more difficult for students to interpret changes in oxidation states and identify oxidized and reduced species. The result therefore suggests that conceptual clarification should accompany procedural exercises rather than relying solely on memorization of rules. This interpretation is also supported by Hadinugrahaningsih (2022) and Waworuntu et al. (2024) who found that students could determine oxidation numbers in relatively straightforward cases but experienced substantial difficulty when required to explain the underlying relationships among oxidation number, electronegativity, and formal charge.

Understanding of Oxidizing and Reducing Agents

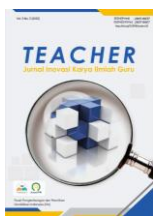
The result for oxidizing and reducing agents was relatively high, with 79.49% scientifically valid responses. This indicates that most students could recognize the relationship between electron transfer and the roles of the two agents. However, the presence of incomplete and alternative responses shows that this understanding was not uniform across the sample.

The results from the reaction-identification questions provide additional evidence. Although 69.23% correctly identified Cu^{2+} as the oxidizing agent and 64.10% correctly identified Zn as the reducing agent, performance was lower than in the general definition question. This difference suggests that students may understand the terminology at a conceptual or verbal level but experience greater difficulty when applying it to a specific chemical reaction.

Application of Oxidation Number Rules

The 100% valid responses for the oxidation numbers of oxygen and hydrogen demonstrate strong mastery of these direct rules. However, this mastery did not result in equally high performance in more complex calculations. For SO_4^{2-} , 69.23% of students provided scientifically valid answers, while only 58.97% did so for Fe_2O_3 .

The difference is particularly relevant because both calculations require students to combine the known oxidation number of oxygen with the total charge or neutrality of the chemical species. In Fe_2O_3 , students must additionally account for the coefficient of iron and solve the resulting equation. The findings therefore indicate that knowledge of individual rules



does not necessarily guarantee successful application when multiple operations must be integrated.

Understanding Oxidation in Chemical Reactions

The result for the O_2 molecule, with 66.67% scientifically valid answers, indicates that most students recognized the oxidation number of an element in its elemental form. However, 33.33% of responses were incomplete, alternative, or classified as other answers. This shows that even a fundamental rule may not be consistently applied by all students.

Similarly, 82.05% of students correctly recognized that oxidation involves an increase in oxidation number. This was one of the highest results among the conceptual questions. However, the lower performance in identifying oxidizing and reducing agents in a reaction suggests that recognizing the definition of oxidation is easier than integrating oxidation-number changes with electron transfer and the roles of chemical species.

Overall Interpretation

Taken together, the findings reveal a pattern in which students performed better on direct recall and application of individual rules and experienced greater difficulty when several concepts or calculation steps had to be integrated. The 100% valid responses for the oxidation-number rules of oxygen and hydrogen contrast with the 58.97% result for Fe_2O_3 and the 48.72% result for the definition of oxidation number.

The results therefore indicate that instruction on redox chemistry needs to address both declarative and procedural understanding. Students may benefit from learning activities that explicitly connect oxidation number, electron transfer, oxidation and reduction processes, and the identification of oxidizing and reducing agents. The response categories also provide useful information for identifying misconceptions and incomplete understanding that would not be visible from a simple percentage of correct answers alone.

CONCLUSION

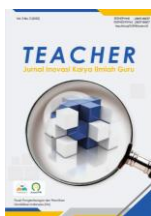
The study found that the 12th-grade Science and Technology students of Santa Maria Ainaro Catholic General Secondary School had a generally satisfactory understanding of oxidation-reduction concepts, with 74% of the responses classified as scientifically valid. The students demonstrated stronger understanding of basic concepts, particularly the oxidation numbers of oxygen and hydrogen and the definitions of oxidizing and reducing agents.

Difficulties remained in applying the concepts to calculations and interpretation. The lowest level of understanding was found in defining oxidation number and calculating the oxidation number of iron in Fe_2O_3 . Difficulties were also observed in identifying and explaining oxidizing and reducing agents. These findings indicate that although students have acquired fundamental knowledge, the application of oxidation-reduction concepts is not yet consistently consolidated.

Therefore, instruction should place greater emphasis on progressive practice, calculation, interpretation, and justification of answers. Strengthening these skills may help students move beyond memorizing rules toward applying oxidation-reduction concepts in different chemical situations.

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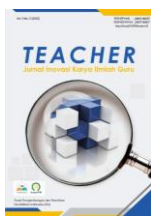
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