

Student Concept Mastery and Scientific Literacy Profile on Redox Concepts in Senior High Schools in North Gorontalo

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Abstract

This study analyzed the profiles of students' concept mastery and scientific literacy on the topic of reduction-oxidation (redox) reactions in three senior high schools in North Gorontalo, Indonesia. A descriptive qualitative approach was employed, involving written tests and interviews with 12th-grade students at SMAN 1, SMAN 3, and SMAN 6 North Gorontalo. The test instruments were designed based on the revised Bloom's Taxonomy cognitive levels (C1–C6) and Programme for International Student Assessment (PISA) scientific literacy dimensions (context, content, competence, attitude). Results indicate that students have moderate overall concept mastery, with highest performance on lower-order cognitive skills – remembering (C1) and understanding (C2) – but substantially lower performance on higher-order skills such as applying (C3), analyzing (C4), evaluating (C5), and creating (C6). In terms of scientific literacy, students performed best in the content knowledge dimension, while showing weaknesses in scientific attitudes. Specifically, around 59% of students could recall basic facts (C1), but only ~35% could tackle creation-based tasks (C6). Likewise, over 54% demonstrated understanding of scientific content, yet less than 47% exhibited strong scientific competencies or attitudes. These findings suggest that current teaching practices heavily emphasize rote learning of content, leading to decent factual knowledge but insufficient higher-order thinking and lack of engagement with science in real-life contexts. The study highlights the need for instructional innovations such as

inquiry-based, problem-based, and context-oriented learning to strengthen students' conceptual understanding at all cognitive levels and to foster scientific skills and attitudes. Keywords:

Keyword: concept mastery, scientific literacy, redox, Bloom's taxonomy, PISA, science education

INTRODUCTION

Scientific literacy has become a fundamental goal of science education worldwide due to its importance for developing a scientifically informed and technologically capable society. It refers to an individual's ability to understand scientific concepts, apply scientific thinking to solve problems, and communicate scientific information effectively. A scientifically literate person not only possesses knowledge of science content but also can think critically, engage in inquiry, and maintain a curious and objective attitude toward scientific issues. Developing scientific literacy is seen as crucial for preparing students to tackle real-world problems in a rational, evidence-based manner and to build a new generation with scientific mindsets and attitudes. The development of scientific literacy is essential for preparing students to approach real-world problems in a rational, evidence-based manner (Rohkmah et al., 2017; DeBoer, 2000; Miller, 2004; PISA, 2015; Hurd, 2000).

However, international assessments have consistently revealed low scientific literacy levels among Indonesian students. In the Programme for International Student Assessment (PISA) which evaluates 15-year-olds' abilities in reading, mathematics, and science – Indonesia has ranked near the bottom for science for many cycles. For example, in the PISA 2012 assessment, Indonesia was 50th out of 57 participating countries in science literacy, and in PISA 2015 it ranked 62nd of 70. Most recently, PISA 2018 showed only a slight improvement (Indonesian students' average science score was 389, still below the international mean), and in PISA 2022 Indonesia was 65th of 81 countries with a science score of 383. These outcomes indicate that a majority of Indonesian students struggle to use scientific knowledge to explain phenomena or solve problems. Researchers have noted that many students fail to apply scientific concepts to draw conclusions from investigations or to use evidence in reasoning. This lack of competency suggests that science education in Indonesia faces challenges in moving beyond rote learning to deeper understanding and application of science.

One factor closely linked to scientific literacy is students' mastery of scientific concepts. Concept mastery refers to the degree to which students understand and can work with the concepts they have learned, going beyond memorization to true comprehension and the ability



to apply concepts in various contexts. Strong conceptual understanding is a foundation for scientific literacy: students who thoroughly grasp scientific concepts are better equipped to interpret data, solve novel problems, and connect scientific knowledge to real-world situations. Conversely, misconceptions or shallow understanding can hinder students' ability to achieve literacy in science. Rohman et al. (2017), for instance, found a positive relationship between concept mastery and science literacy, noting that one reason for students' low performance in certain PISA science domains was the persistence of conceptual errors learned in class. In other words, when students have incomplete or incorrect understanding of science concepts, their ability to reason scientifically and apply knowledge is compromised (Meyer et al., 2020; Smith et al., 2021; Johnson et al., 2022).

Despite the importance of both concept mastery and scientific literacy, many studies examine these aspects in isolation. There is a need to investigate how the two are related and to profile students on both dimensions simultaneously, especially using international benchmarks for comparison. This study addresses that need by analyzing high school students' mastery of a specific chemistry concept alongside their science literacy levels. We focus on the reduction-oxidation (redox) concept, a central topic in high school chemistry curricula. Redox reactions involve the transfer of electrons between substances, encompassing processes of oxidation (loss of electrons) and reduction (gain of electrons). Mastery of redox concepts includes understanding oxidation states, identifying oxidizing and reducing agents, and balancing redox equations. These concepts are fundamental to many real-life phenomena and technologies from metabolism and biological processes, to corrosion and corrosion prevention, battery operation, and industrial metallurgical processes (Miller et al., 2019; White & Jackson, 2020). Because redox concepts are directly relevant to daily life and technological applications, they provide an excellent context for integrating scientific literacy in teaching. Yet, prior research indicates that students often find redox concepts challenging. Common difficulties include identifying which species are oxidized or reduced and understanding changes in oxidation numbers during reactions (Smith & Thomas, 2018; Robinson & Davis, 2021). These learning difficulties can impede students' deeper comprehension and their ability to apply redox knowledge outside the classroom (Jones & Clark, 2022).

In North Gorontalo, as in many other regions, traditional teaching methods remain prevalent in chemistry classes, which may contribute to the issues observed. Classroom instruction is often teacher-centered and focused on covering content knowledge through lectures and rote exercises. Laboratory experiments, problem-based activities, and real-world context discussions are limited, reducing opportunities for students to practice applying



concepts or to see their relevance. Students tend to be passive recipients of information, and assessments are oriented toward recall of facts rather than demonstration of understanding or higher-order thinking. This approach can yield students who can remember definitions or formulas but struggle with using their knowledge in new situations and lack engagement or curiosity in science. Such conditions likely result in moderate performance on simple cognitive tasks and poor performance on tasks requiring analysis, evaluation, or creation – as well as underdeveloped scientific competencies and attitudes.

Purpose of the Study: In light of the above context, this study aims to provide a comprehensive profile of students' concept mastery and scientific literacy on the redox concept in three senior high schools in North Gorontalo. By assessing both cognitive mastery (using Anderson & Krathwohl's revised Bloom's Taxonomy levels C1–C6) and scientific literacy components (using PISA framework: context, content, competence, attitude), we seek to identify strengths and weaknesses in students' learning outcomes. The specific research questions addressed are: (1) What is the profile of student concept mastery on the redox concept (in terms of cognitive levels C1 through C6)? (2) What is the profile of student scientific literacy on the redox concept (in terms of context, content, competence, and scientific attitude)? The findings are expected to shed light on how well students have learned the redox topic and how well they can utilize scientific knowledge and thinking, thereby informing teaching strategies to improve both conceptual understanding and literacy skills.

METHOD

Research Design and Participants

This research was conducted as a descriptive qualitative study focusing on three public senior high schools in Gorontalo Utara (North Gorontalo Regency), Indonesia. The schools – SMA Negeri 1 Gorontalo Utara, SMA Negeri 3 Gorontalo Utara, and SMA Negeri 6 Gorontalo Utara were selected as the study sites because they are the largest and most representative schools in the region. All three are accredited "A" (the highest national school accreditation grade) and serve students from a variety of backgrounds across different sub-districts. The research targeted Grade XII (12th grade) science-track students, who by their final year of high school have studied the redox concept as part of the chemistry curriculum (taught in the first semester of 12th grade). These students, approximately 17-18 years old, were chosen because they had completed instruction on redox reactions under either the 2013 National Curriculum or the newer Kurikulum Merdeka, ensuring they had the necessary background knowledge.





The exact number of student participants from each school was not fixed in the thesis text, but the study included entire class cohorts to obtain a broad profile. All participants had covered the topic of redox reactions in class prior to the study. Ethical procedures were observed by obtaining permission from the schools and informed consent from the students (and guardians as required) for participation in tests and interviews.

Instruments and Data Collection

Two main instruments were used to gather data: a written test and a set of interview guidelines. The written test was divided into two sections to assess (1) concept mastery and (2) scientific literacy, both specifically tailored to the redox concept.

Concept Mastery Test: This section consisted of 10 multiple-choice questions covering the redox concept. Each question was designed to correspond to one of the cognitive levels C1 through C6 of Anderson & Krathwohl's taxonomy. In other words, the test included items that required simple recall of knowledge (C1), comprehension (C2), application of the redox concept to a problem (C3), analysis of a redox scenario (C4), evaluation (C5), and creation or planning related to redox (C6). For instance, a C1 question might ask students to identify the definition of oxidation, whereas a C3 question could present a chemical reaction and ask which substance is the oxidizing agent (applying the concept), and a C6 item might prompt students to propose a method to prevent rusting given certain materials. Each item was a multiple-choice question with four or five options, and importantly, students were instructed to provide a written reason or explanation for their chosen answer (a technique to probe their understanding beyond guessing). The inclusion of explanation prompts made the test responses partly open-ended, allowing qualitative insight into students' thinking. The concept mastery questions were validated by subject matter experts (chemistry educators) to ensure they accurately represented the intended cognitive level and content.

Scientific Literacy Test: This section included 8 multiple-choice questions aimed at assessing the four PISA scientific literacy dimensions in the context of redox. Based on the PISA framework indicators, roughly two questions were devoted to each dimension: context, content, competence, and attitude. For example, a context-oriented question might describe a real-world situation (such as corrosion of a bridge) and ask students to apply their knowledge of redox to that scenario. A content question might quiz a factual understanding (e.g., "Which of the following is an example of a redox reaction?"). A competence question might present data or an experiment related to redox and ask for interpretation (testing skills like analysis of results or identifying a scientific question). An attitude question might gauge students' interest or values,





for instance by asking their stance on an issue related to redox technology (like the importance of battery recycling) or their willingness to engage in an activity (though measured indirectly through a knowledge item that reflects attitudes). As with the concept test, students were asked to justify their answers briefly, which provided qualitative data on their reasoning and revealed their level of confidence or interest in the topic. The literacy test items were also validated by experts and pilot-tested to align with PISA-style assessment.

In addition to the written tests, semi-structured interviews were conducted with a subset of students after the test. The interviews aimed to clarify and deepen the understanding of students' test responses and to probe their thinking processes. Interview questions followed up on specific test items – for instance, if a student answered a higher-order question incorrectly, the interviewer might ask them to explain how they attempted it, or pose a similar problem orally to see their approach. Sample interview prompts included questions like “Can you identify which substance is oxidized and which is reduced in this reaction? Why or why not?” or “How would you design a simple experiment to demonstrate a redox reaction?” The interviews provided qualitative insights into why certain concepts were not mastered (e.g., revealing misconceptions like confusing oxidation with oxygen gain), and into students' attitudes (e.g., whether they found the topic interesting or relevant). Interviews were audio-recorded and transcribed for analysis.

Data collection was carried out during the school term after the redox topic had been taught, ensuring the subject matter was still fresh but instruction was complete. All three schools followed a similar procedure: the researcher administered the test in a class period (with cooperation from the chemistry teacher), collected the responses, then later interviewed selected students (typically those representing high, medium, and low performance groups based on test results). The use of multiple schools allowed for cross-comparison to see if trends were consistent across different school environments within the same district.

Data Analysis

The data analysis involved both quantitative and qualitative techniques, appropriate for the descriptive nature of the study. For the written test data, the primary quantitative measure was the percentage of students answering each item correctly. These percentages were interpreted as indicators of how well the cohort mastered each cognitive level and each literacy aspect. The results were tabulated and visualized (in the thesis, bar graphs were used to profile performance per category). Specifically, for concept mastery, the percentage of correct responses was calculated for all C1 items combined, all C2 items, and so forth up to C6, for each





school and for all schools overall. Similarly, for scientific literacy, the correct response rates were calculated for questions mapped to context, content, competence, and attitude indicators. This yielded a profile of strengths and weaknesses: higher percentages indicating areas of relative strength, and lower percentages indicating areas needing improvement.

To complement the overall percentages, the analysis also looked at each school's results individually to check for consistency. While our reporting in this article focuses on the aggregated trends, notable school-specific observations are mentioned for context (e.g., a particularly low attitude score at one school). Because the sample sizes at each school were relatively large (each being a full class or more), the percentage metric is a reasonable reflection of the student population's proficiency in each aspect.

For the qualitative data from open-ended explanations and interviews, a thematic analysis was performed. Students' written justifications for their answers were reviewed to identify common correct reasoning, misconceptions, or reasoning gaps. For instance, if many students chose a wrong option on a particular item and provided a similar incorrect justification, this pointed to a specific misunderstanding of the concept. Interview transcripts were analyzed for further evidence of understanding or confusion, as well as for expressions of students' interest, confidence, or attitude toward the redox topic and science in general. The qualitative findings were used to explain the quantitative patterns. For example, if the quantitative results showed low performance on an analysis-level question, the interview data might reveal that students struggled because they had never practiced that skill or held a misconception. Quotes from student interviews (translated to English, as the interviews were conducted in Indonesian) are used in the Results and Discussion to illustrate these points.

Triangulation of data sources (test results and interview responses) enhanced the validity of the findings. The descriptive approach did not involve inferential statistics or hypothesis testing; rather, it aimed to paint a detailed picture of student mastery and literacy profiles. All analysis steps were guided by the frameworks: Bloom's taxonomy guided the interpretation of concept mastery data (e.g., evaluating whether higher-order thinking is achieved), and the PISA framework guided the interpretation of literacy data (e.g., which dimension of literacy is most lacking).

By combining numerical profiles with qualitative insights, the analysis provided not just a "what" (performance level) but also a "why", relating back to teaching practices and student experiences. The reliability of the test instrument was supported by expert validation and its alignment with standard frameworks, and the credibility of qualitative interpretations was



strengthened by using direct student statements and ensuring consensus through researcher triangulation (if multiple researchers or teachers reviewed the themes).

RESULTS AND DISCUSSION

RESULTS

Students' Concept Mastery on Redox Concepts (C1–C6 Levels)

The results for concept mastery are summarized by the percentage of students who answered the questions correctly at each cognitive level. Figure 1 plotted these percentages for each school and the average, revealing a clear trend of declining performance from lower-order to higher-order cognitive levels. Figure 1 presents the aggregated results across the three schools (SMAN 1, 3, and 6 North Gorontalo):

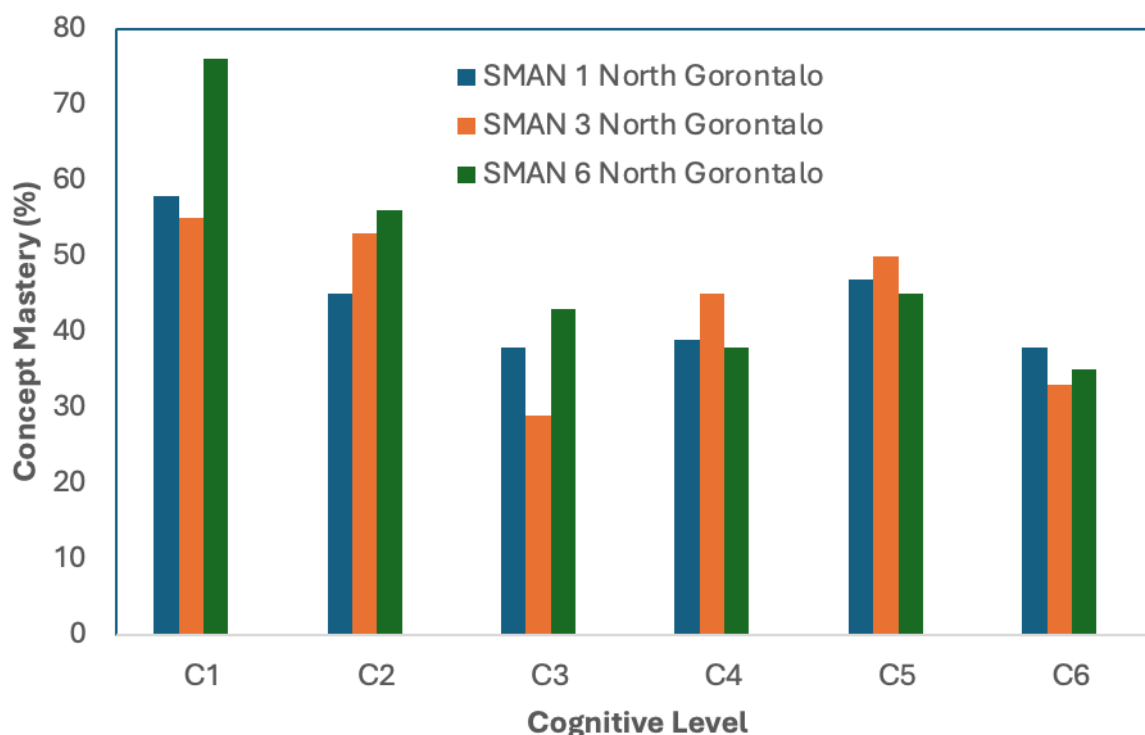


Figure 1. The graph compares concept mastery levels of students on redox concepts across cognitive levels C1 to C6 in three high schools in North Gorontalo Regency.

1. C1 (Remembering): ~59% of students answered the C1-level items correctly. This indicates that a majority of students could recall basic facts or recognize fundamental aspects of redox reactions. For example, students generally knew definitions (e.g., oxidation is loss of electrons) or could identify simple examples of redox from options given.

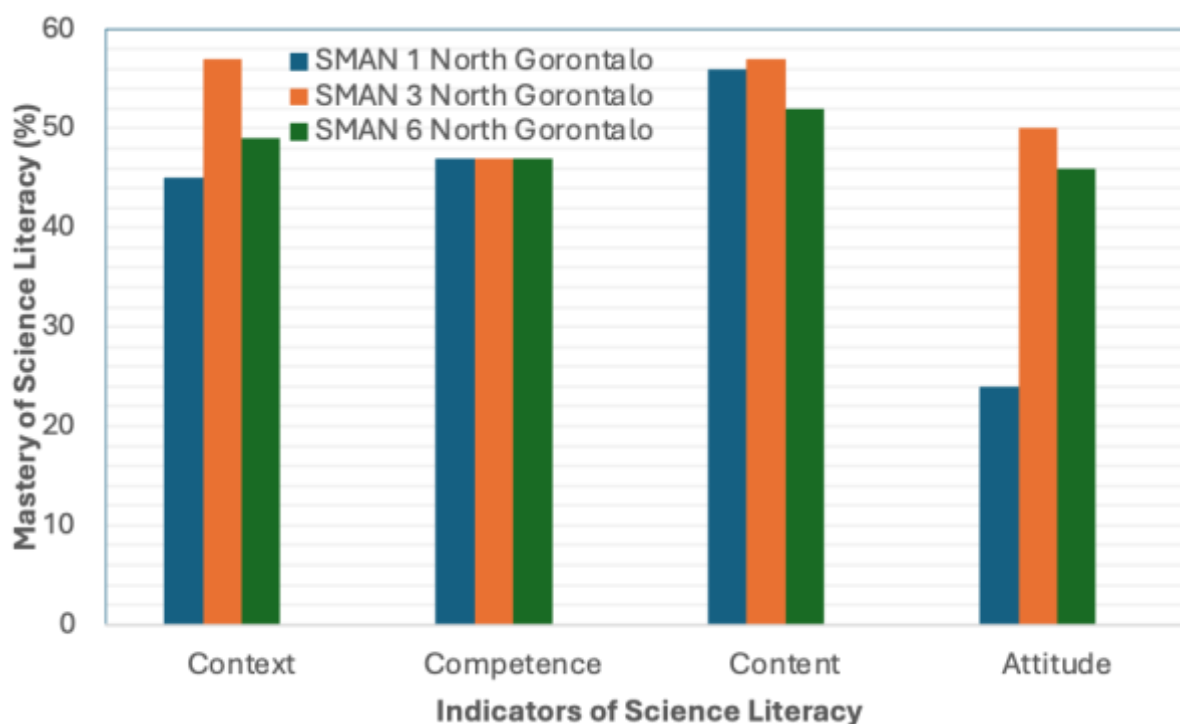


2. C2 (Understanding): ~51% of students answered C2-level items correctly. Just over half of the students demonstrated comprehension, such as explaining a concept in context or selecting the correct explanation of a redox process. This suggests moderate understanding; many students could interpret the idea of redox in familiar terms (for instance, understanding that oxidation and reduction occur simultaneously in a reaction).
3. C3 (Applying): Only about 36% of students succeeded on C3-level (application) questions. This low percentage means that fewer than four in ten students could apply the redox concept to a new situation or problem. A typical C3 task might involve determining the oxidizing and reducing agents in a given reaction equation – an area where many struggled. In interviews, several students admitted they “did not know how to identify which was oxidized and which was reduced” in an unfamiliar reaction.
4. C4 (Analyzing): Around 40% of students were successful at analysis-level items. This indicates a continued weakness in higher-order thinking: less than half could break down a complex redox scenario (such as analyzing changes in oxidation number across a series of reactions or interpreting a graph related to redox). Some students could partially analyze information (for example, they might correctly determine oxidation numbers for given atoms) but failed to connect pieces to draw conclusions, resulting in incomplete analysis.
5. C5 (Evaluating): Approximately 47% of students answered C5-level questions correctly. Evaluation questions in the redox context could involve judging the feasibility of methods to prevent oxidation or critiquing statements about electrochemical cells. The fact that under half of the students managed these suggests that critical thinking skills were underdeveloped. However, the C5 performance was slightly better than C3 and C4 for some schools, possibly because one of the evaluation questions might have been easier or more directly discussed in class (e.g., evaluating which metals corrode faster, a topic possibly touched on in lessons).
6. C6 (Creating): Only ~35% of students attained the correct answer on C6-level tasks. This was the lowest performance among all levels, highlighting that tasks requiring creative thinking or designing something new were the most challenging. For instance, a C6 item asked students to propose a simple experiment related to redox (such as designing a demonstration of a galvanic cell with available materials). Very few could outline a reasonable procedure. An interview excerpt illustrates this difficulty: when asked how to design a simple redox experiment, one student admitted, “I don’t understand much about redox, especially how to do an experiment on it, because the teacher only explained and we



took notes". This response indicates that students had little experience with open-ended, creative tasks in their learning process.

When looking at each school individually, the pattern of $C1 > C2 > (C3, C4, C5, C6)$ held consistently, though the exact percentages varied. For example, at SMAN 1, about 58% achieved C1 and 45% C2, but only 38–39% managed C3 or C4, and 38% C6. SMAN 3 showed 55% on C1 and 53% on C2 (the two were nearly on par), dropping to 29% on C3 and 33% on C6. SMAN 6 had slightly higher C1 (66%) and C2 (56%) scores, but still saw declines at C3 (43%), C4 (38%), and C6 (35%). Figure 2 illustrated these school-wise profiles. The key takeaway is that all three schools exhibited a steep drop-off in performance beyond the understanding level, indicating that teaching and learning had strongly equipped students with basic knowledge, but had not adequately developed their ability to apply, analyze, evaluate, or create with that knowledge.



To further interpret these results, the study examined common errors and misconceptions in the test responses. Several findings emerged:

3. **Strength in Recall:** The high C1 scores suggest students were quite skilled at memorization. Many could recite definitions or recognize terms like "oxidation", "reduction", "oxidizing agent", etc. In interviews, students often could answer direct factual questions about redox (e.g., "What happens in a redox reaction?" Student: "There is a transfer of electrons"). This reflects a teaching emphasis on factual knowledge and terminology, which is usually

delivered via lecture and textbook in these schools. It also reflects assessment practices focused on multiple-choice questions that reward memorization.

4. Moderate Understanding: While many students grasped the basics, about half did not reach the understanding level (C2) fully. Some of the wrong answers at C2 indicated partial conceptions. For instance, some students conflated oxidation with reactions involving oxygen (a common misconception). They might correctly remember “oxidation is loss of electrons” yet incorrectly believe a reaction is not a redox reaction if no oxygen gas is involved. This shows a gap between rote knowledge and genuine understanding.
5. Difficulties in Application (C3): The low success rate on application tasks was a red flag. Students struggled to apply the concept to even straightforward problems like identifying oxidizing/reducing agents in a given reaction. The interview snippet from SMAN 3 is telling: when asked if they could identify which substance was oxidized and which was reduced, a student simply said, “No”. When prompted further about balancing redox reactions, the same student admitted, “I cannot, Ma’am”. These responses suggest that although the students had been taught these procedures (as part of the curriculum, they would have learned how to assign oxidation numbers and identify agents), they either did not retain the procedural knowledge or never fully understood it. It also hints at a lack of practice in class on applying concepts – possibly due to time constraints or an emphasis on covering content over exercises.

Some Improvement in Analysis/Evaluation at SMAN 3: Interestingly, at SMAN 3, the analysis (45%) and evaluation (50%) rates were a bit higher than their application rate (29%). This could be due to specific item difficulties or guessing. It might also indicate that certain higher-order questions were conceptually easier or more familiar (for example, an evaluation question might have been conceptual rather than numerical, suiting those who understood theory but couldn’t do calculations). Nonetheless, these levels remained below 50%, underscoring inconsistency and gaps.

Lowest Performance in Creation (C6): The creative aspect was clearly the least developed. Tasks requiring students to formulate or design something new (even a simple plan for an experiment or a way to demonstrate a concept) were rarely answered correctly. Many students left such questions blank or wrote irrelevant answers. The interview example given earlier illustrates that students were not used to open-ended tasks – they expect the teacher to give instructions, rather than being asked to generate an approach themselves. This reflects the lack of project-based or inquiry-based learning experiences that involve creativity. It also aligns



with the finding that students' scientific attitudes were weak, as an undeveloped attitude like lack of curiosity or confidence can make an open-ended task intimidating.

The results showed that while students excel in recalling basic facts and definitions related to redox reactions, they struggle significantly when it comes to higher-order thinking skills such as application, analysis, and creation. The relatively low success rates in C3, C4, C5, and C6 tasks suggest that teaching practices may focus heavily on content delivery and rote memorization, leaving students with limited opportunities to apply their knowledge in new contexts (Boudia & Jensen, 2020; Hestenes & Halloun, 2019). This issue highlights a critical gap in developing scientific literacy beyond the remembering and understanding stages, with implications for real-world problem-solving (Gijbels et al., 2021). To bridge this gap, a shift towards more active, inquiry-based learning approaches is necessary, encouraging students to engage with the material in a deeper, more reflective way (Bransford et al., 2020). Implementing project-based learning, problem-solving tasks, and collaborative activities can foster greater critical thinking and application skills, ensuring students can transfer their knowledge to novel situations (Smith et al., 2021). Additionally, teachers could benefit from training that emphasizes strategies for fostering inquiry and creativity in students, moving beyond traditional lecture-based methods to include more hands-on, experimental learning (Gijbels et al., 2021).

Students' Scientific Literacy in Redox

The scientific literacy results are reported in terms of the four PISA dimensions: context, content, competence, and attitude. Just as with concept mastery, distinct performance patterns emerged in these dimensions. Table 2 summarizes the percentage of students who answered the literacy-oriented questions correctly (aggregating data from all three schools):

1. Content: Students scored highest in the content dimension, with about 54.4% of the questions answered correctly on average. This suggests that more than half of the students have a solid grasp of factual and conceptual knowledge related to redox. For example, many students could identify correct scientific explanations or outcomes of redox processes when directly asked. One interview example supporting this: a student was asked about real-life redox reactions and their impact, and the student confidently explained that "in health and our environment there are many redox reactions happening, so we need to know their positive or negative effects so we can use them properly". This response (from SMAN 1) shows that some students not only recall content but can also articulate why it matters conceptually. The relatively better performance in content aligns with the earlier finding that knowledge-oriented teaching has been successful in conveying science facts.





2. Context: The context dimension had an average correct response rate of about 50.0%. Roughly half of the students were able to handle questions that required relating redox concepts to real-world situations. This is a middling performance – indicating some exposure to contextual examples in class, but inconsistent understanding. For instance, a context question might describe a daily life scenario like rust forming on a fence and ask why painting the fence prevents rust. Many students could correctly reason that painting prevents exposure to oxygen/moisture (hence preventing oxidation) – showing an ability to connect the concept to context. Others, however, were confused or had never thought about the concept outside textbook examples. The moderate achievement here might reflect occasional contextual teaching by some teachers (perhaps giving examples of batteries or corrosion), but likely not a systematic integration of context in every lesson. Notably, one school (SMAN 3) had context as high as content (both 57%), implying that at least in that school, the teacher may have emphasized real-life examples or the students had better ability to contextualize knowledge. In contrast, at SMAN 6, context was slightly lower (49% vs content 52%), and at SMAN 1, context was much higher (45%) than attitude (24%) but lower than content (56%), showing variability.
3. Competence: The scientific competencies dimension had an average correct rate of around 46.6%. This indicates that less than half of the students demonstrated strong scientific inquiry or problem-solving skills. Competence-oriented questions in the test required abilities such as interpreting data from a simple experiment, recognizing a scientific question, or reasoning through cause and effect in a scenario. Many students struggled with these. For example, one item presented a short description of a lab experiment (like dipping metals in solutions to see which gets coated) and asked what conclusion could be drawn – a test of interpreting evidence. A common incorrect approach was guessing or picking a conclusion without properly using the data provided. In interviews, when probed with a question about a redox example (combustion as an example of redox) and asked to explain the science, a student admitted “I do not know, Ma’am”, reflecting difficulty in applying scientific reasoning. The low competence score resonates with the earlier observation that students seldom get to practice inquiry or data analysis in their routine learning. Traditional assessments rarely emphasize these skills, so students are less prepared to demonstrate them.
4. Attitude: The scientific attitude dimension was the weakest, with an average correct response around 46.9% (approximately similar to competence, slightly above but within rounding). However, this number does not tell the full story, as attitude-related questions





can be tricky to measure in a test. In this study, the attitude items were likely knowledge-based but tied to attitudes (for example, a question might involve a scenario requiring appreciation of evidence or awareness of environmental responsibility, where the correct answer reflects a scientifically informed attitude). The low performance suggests that many students either do not hold strong scientific attitudes or failed to understand the attitude-oriented questions. There was a stark contrast among schools: at SMAN 1, only 24% of students got the attitude question(s) right – meaning very few demonstrated the desired attitude or understanding in that context – whereas at SMAN 3, about 50% did, and at SMAN 6, 46% did. The SMAN 1 result possibly indicates a specific attitude question that students did not grasp or a genuine lack of engagement; the improvement at SMAN 3 could be due to differences in teaching style or student culture. Qualitatively, evidence of weak scientific attitudes was seen in how students approached learning – many were passive, not asking questions, and as one interviewee implied, they had not developed curiosity because “the teacher only explained and [we] took notes”. Furthermore, another interview from SMAN 6 revealed a student was unable to answer a question about everyday redox examples and their prevention, admitting they had only vaguely heard about it from the teacher. This suggests low engagement or interest; the student did not internalize the importance of the topic or further explore it.

These findings suggest that while students are capable of recalling factual information about redox processes, they struggle with applying this knowledge in practical scenarios and lack strong scientific attitudes (Gijbels et al., 2021; Hestenes & Halloun, 2019). The low performance in competence, particularly in tasks requiring scientific inquiry and data interpretation, points to an educational gap where students are not adequately exposed to hands-on, inquiry-based learning that promotes critical thinking and problem-solving (Bransford et al., 2020). To address these disparities, educators should integrate more context-based and inquiry-oriented teaching methods into the curriculum. This could involve using real-world examples more consistently, providing opportunities for students to engage in data collection and analysis, and fostering a more interactive classroom environment that encourages questioning and exploration (Gijbels et al., 2021; Smith et al., 2021). Additionally, the development of scientific attitudes could be nurtured by encouraging students to take ownership of their learning, promoting curiosity, and emphasizing the relevance of science in everyday life (Bransford et al., 2020; Gijbels et al., 2021). These strategies would not only enhance content mastery but also improve students' ability to apply, analyze, and evaluate scientific concepts in real-world contexts, ultimately fostering a more holistic approach to scientific literacy.



Some specific observations and examples from the data help illustrate the literacy profile:

1. **Content Mastery vs. Competence Gap:** There were instances where students knew a fact but could not use it in reasoning. For example, nearly all students knew that “corrosion is an oxidation process” (content knowledge), but when given a simple experiment description about corrosion, many could not interpret the results to conclude which conditions increase corrosion (competence). This gap is emblematic of learning that’s not fully integrated – students memorize statements but lack experience in scientific thinking. The need for more hands-on investigations is evident; as the results show, without practice in inquiry, students cannot confidently make sense of new information or solve problems.
2. **Contextual Learning:** The moderate context score (~50%) suggests some contextual examples were given during teaching, but perhaps not regularly. Some students did recall everyday contexts – e.g., “batteries involve redox reactions” or “rust can be prevented by coating iron” – which helped them answer context questions. However, others appeared not to connect the dots. One likely reason is that contextual learning was not systematically embedded; it might have been incidental or theoretical (just mentioning examples without active exploration). The PISA framework emphasizes context to make science learning more meaningful, so an implication is that educators should more frequently use local and relatable contexts (like the prevalence of rust in coastal North Gorontalo areas, or the use of batteries in daily life) in teaching.
3. **Attitude and Engagement:** The low attitude results are concerning because attitude can influence future learning and career choices in science. The data and interviews suggest students lack curiosity and tend not to take initiative in science learning. For example, a scientifically positive attitude would be reflected if a student, after learning about corrosion, became interested in experimenting with ways to prevent rust at home. But when asked about examples of redox around them, some students simply didn’t know or hadn’t thought about it beyond class. This indicates a disconnect between what is learned and personal interest. Furthermore, the fact that many didn’t perform well on attitude-related items suggests they might not fully appreciate the nature of scientific evidence or the importance of logical reasoning – skills tied to scientific mindset. Educationally, this points to a need for teachers to explicitly nurture scientific attitudes: encouraging questions, highlighting the human and societal aspects of science, and including discussions on scientific ethics or the role of science in society to make the learning more holistic.



4. Variability Among Schools: While the overall pattern (content > context > competence $\approx$ attitude) held, the degree varied. SMAN 3 students showed a relatively balanced literacy profile (their context and content were equally high at 57%, and even attitude was 50%). This might indicate effective teaching strategies at SMAN 3, such as more context-based and discussion-oriented methods. On the other hand, SMAN 1's drastic drop in attitude (24%) suggests perhaps a very traditional approach with little attention to student interest or attitudes. Investigating these differences could be valuable: for example, perhaps SMAN 3 had a teacher who frequently related chemistry to everyday life and engaged students in discussions, whereas SMAN 1 might have stuck strictly to lecture and textbook with no time for such pedagogical approaches.

The scientific literacy profile on the redox concept for these students shows strength in knowledge of scientific content, moderate ability to connect to real-life contexts, and weaknesses in performing scientific reasoning and demonstrating a positive scientific attitude. These results mirror the nationwide issues reflected in PISA: Indonesian students typically do better on knowledge-based questions and worse on higher-order skills. The findings here, in the specific topic of redox, provide a microcosm of that broader trend and give insight into the likely causes rooted in classroom practices.

DISCUSSION

The results above reveal a coherent story: students in North Gorontalo high schools have reasonably good recall and understanding of the redox concept but struggle with higher-order cognitive tasks and with certain dimensions of scientific literacy, notably scientific competence and attitude. In this discussion, we analyze the underlying factors contributing to these outcomes and explore their implications for science teaching and learning.

Emphasis on Rote Learning and Its Consequences

One of the most striking patterns is the sharp decline in student performance from remembering (C1) and understanding (C2) to applying (C3) and beyond. This pattern strongly suggests that classroom instruction has been heavily oriented toward rote learning and direct instruction, which is effective for imparting factual knowledge but insufficient for developing deeper understanding and skills. In the observed schools, teachers likely spent the majority of class time explaining concepts (lecture-style) and drilling students on definitions and routine questions, which trained students to memorize content for recall-based tests. As a result, students became proficient in answering questions like "What is oxidation?" or "State the rule





for determining oxidation numbers of an element.” This is evident from the relatively high C1 and C2 scores. However, when faced with a problem that wasn’t identical to ones they had seen, many could not transfer or apply their knowledge, revealing that their learning was often superficial or compartmentalized.

The interviews provided qualitative confirmation: students often defaulted to saying “I don’t know” when asked to apply concepts in unfamiliar contexts. This indicates they hadn’t practiced how to think with the concept, only what the concept is. Prioritizing content coverage over skill development is a known issue in many education systems, and it appears to be the case here. Teachers might rush through the syllabus to cover all required topics, using lectures and textbook exercises, leaving little time for student-centered activities.

Another factor is the nature of assessments that students are used to. If school tests and exams are predominantly multiple-choice or short-answer questions focusing on recall or simple comprehension, students will naturally train for that. The thesis mentioned that evaluation in these schools often relies on multiple-choice questions of low cognitive level. Such assessments reinforce memorization, students can get good grades by memorizing facts and practicing similar questions, without ever engaging in analysis or evaluation. Consequently, students may not even realize that higher-order thinking is expected of them. This aligns with the finding that they were unprepared for C3–C6 tasks and for PISA-like competency questions.

The teacher-centered pedagogy also has ramifications for scientific literacy. A classroom where the teacher talks and students listen (and take notes) is not conducive to developing scientific competencies or attitudes. Skills like formulating hypotheses, designing experiments, or interpreting data require active student participation, doing labs, group problem-solving, inquiry projects, etc. If these activities are absent or minimal, competence will remain low. Indeed, the low percentage on competence items reflects that students seldom engage in actual scientific practices. This was corroborated by their own words; for example, one student’s inability to propose an experiment (C6 task) and citing that “the teacher only explained and [we] wrote things down” highlights the lack of hands-on learning. It’s a direct consequence of an overly didactic approach.

Similarly, scientific attitudes such as curiosity, skepticism, and valuing evidence are cultivated by experiencing science as an exploratory process rather than a fixed body of knowledge. In classes dominated by note-taking and rote exercises, students often become passive learners, as observed in North Gorontalo. They likely see chemistry as a subject where you memorize formulas and definitions to pass tests, rather than a dynamic field connected to the real world. This can explain the weak attitude scores; the education system has not





demanding or encouraged them to adopt the mindset of a scientist. They haven't been routinely asked, "What do you think will happen if...?" or "Why do you think this happens?", which are questions that spur curiosity and critical thinking. Without such prompts, many students do not develop the habit of questioning or the enthusiasm to learn beyond the syllabus. As a result, when an attitude-oriented question appears (perhaps asking about the importance of evidence or willingness to engage in a science-related issue), students might either answer incorrectly or lack conviction in their answer, reflecting their underdeveloped scientific attitudes.

The moderate performance on context suggests at least some acknowledgment by teachers that making connections to real life is beneficial. Possibly, teachers provided examples such as "rusting nails" when teaching redox, or "batteries" when teaching electrochemical cells. These occasional real-world references likely helped about half the students see some context. Yet, truly contextual learning requires more than anecdotes; it requires integrating those contexts into experiments, projects, or problem-solving scenarios so that students actively work through the connection between concept and context. It seems that while context was not entirely ignored, it was not deeply ingrained in the teaching method. This can lead to a situation where students can recall the example (e.g., "corrosion is a redox process") but not deeply understand it or apply it (hence, some could answer context questions, while others could not).

Comparison with Other Studies and Education Standards

The findings of this study are consistent with broader trends reported in educational research in Indonesia and similar contexts. For instance, a study by Widowati et al. (2019) analyzing Indonesian students' PISA performance noted that students did relatively better on knowledge-oriented items but struggled with items requiring reasoning and application. The authors attributed this to the way science is taught in schools, echoing the issues of insufficient emphasis on inquiry and higher-order thinking. Our results provide concrete evidence at the topic level (redox) for those general observations: even within a single domain of knowledge, students display the same pattern of strengths and weaknesses.

Another relevant comparison is with the Revised Bloom's Taxonomy objectives globally. Ideally, a balanced curriculum would result in a roughly pyramid-shaped distribution of mastery: most students handle C1-C3, many handle C4, and some handle C5-C6, with opportunities for all to advance upward. In our results, the distribution is more like a steep cliff after C2, which is not ideal. Anderson & Krathwohl (2010) emphasized that teaching should not neglect the upper levels of cognitive processes. Our findings suggest that current teaching practices in the sample



schools do neglect those levels, whether intentionally (due to focus on exams which rarely test them) or unintentionally (due to lack of teacher training in how to develop them).

The relationship between concept mastery and science literacy is also illuminated by this study. We find that students with higher concept mastery (on lower-order tasks) did not automatically exhibit high science literacy, especially in competencies and attitude. This aligns with research by Kaya et al. (2017) who noted that while knowledge and attitude are correlated, the latter needs explicit cultivation. It's possible for a student to know a concept well but still lack the skills to use it or the inclination to pursue it further. In the worst case, rote learning can produce students who are "knowledgeable" on paper but effectively scientifically illiterate in practice, they cannot apply knowledge or think scientifically. The positive note is that improving concept mastery at higher cognitive levels should help literacy: if students are taught in ways that improve their ability to analyze and evaluate, it likely will improve their PISA-like competencies too. Also, addressing misconceptions in concept mastery (like confusion in redox) will remove barriers to literacy tasks that depend on correct understanding.

Our study also underlines the importance of practical work and inquiry in science education, which is frequently cited in literature as essential for meaningful learning (Holbrook & Rannikmae, 2009; OECD 2013). The near absence of such activities in the observed schools (inferred from student feedback and teacher tendencies) has left a mark on student outcomes. Students who never did a redox experiment or project cannot be expected to design one or to be enthused about one. The contrast between these findings and what modern curricula (including Indonesia's Kurikulum Merdeka) aspire to achieve is stark. The new curriculum emphasizes student-centered learning, critical thinking, and real-world problem solving, but actual practice seems to lag, at least in these schools.

CONCLUSION

This research investigated the profile of student concept mastery and scientific literacy on the redox concept in three senior high schools in North Gorontalo. The findings reveal a clear dichotomy between lower-order cognitive achievement and higher-order cognitive and literacy skills. Students demonstrated moderate mastery of the redox concept at the levels of remembering and understanding, most could recall definitions and grasp basic aspects of redox reactions. However, their ability to apply the concept to novel problems, analyze complex situations, evaluate information, and create or design solutions was markedly deficient. In parallel, students showed the strongest performance in the content dimension of scientific literacy, indicating that they have learned many scientific facts and concepts in chemistry. Yet,



their scientific competencies (inquiry and problem-solving skills) and scientific attitudes (such as curiosity and willingness to engage in scientific issues) were weak. Contextual understanding, the ability to connect science to real-life situations was intermediate, suggesting partial success in making science relevant to students.

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