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Development and Validation of an Assessment Tool for Senior High School Physical Chemistry

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Abstract

This study examines the necessity for standardized assessment instruments in STEM chemistry for senior high school students, with a focus on four important areas of physical chemistry: thermochemistry, chemical kinetics, chemical thermodynamics, and electrochemistry. Developing such assessment tools is essential to ensure fair assessments, identify learning gaps, and enhance teaching practices. This research has resulted in a 30-item multiple-choice evaluation instrument, which was developed through a rigorous process of design, evaluation, and validation. In addition, the test's content is improved to guarantee reliability and validity. The Programme for International Student Assessment framework's domains of knowledge, cognitive demand level, scientific literacy competency, and Bloom's taxonomy's thinking level were all taken into consideration while evaluating each item question. These enhancements are crucial for accurately assessing student comprehension and addressing educational needs in senior high school physical chemistry. Furthermore, the test was administered to a group of senior high school students in Butuan City with the aim of identifying certain physical chemistry proficiencies that provide difficulty to the students. Most students scored less than 50%, indicating an overall below-average performance that shows knowledge gaps in important concepts. This underscores the necessity to explore the factors contributing to low scores and implement targeted interventions to close knowledge gaps.

Keywords: Senior high school, physical chemistry, assessment tool

1. Introduction

Physical chemistry is a branch of chemistry that explores the interplay of fundamental principles of physics and chemistry in understanding the behavior of matter and energy. Researchers have identified physical chemistry topics in high school chemistry curricula as unique challenges for both educators and learners (Armstrong, 2010; Salame and Khalil, 2023). High school chemistry curriculum can include intermolecular forces to aid students in understanding molecular structure and boiling point trends, enhancing their grasp of physical chemistry concepts (Yuhana and Dewi, 2023). In fact, topics like thermodynamics, kinetics, and equilibrium are essential components of the high school chemistry curriculum, contributing to a well-rounded understanding of chemical principles (Mi et al., 2023).

Mastering competencies is essential for academic success. It is crucial to recognize that higher-level learning is contingent upon a solid understanding of knowledge and skills acquired at basic education levels (Lapitan et al., 2021). The absence of a strong foundation in the basic concept of chemistry often presents challenges for students and can lead to misconceptions (Omiko, 2017). In science education, the accurate assessment of students' comprehension of complex concepts is essential for effective teaching and learning (Ogden, 2017; Chen, 2023). Consequently, the development and validation of assessment instruments play a crucial role in evaluating students' understanding and mastery of subject matter to accurately address misconceptions. Misconceptions are inaccurate or incomplete understandings of concepts that can hinder the learning process and impede students' ability to grasp the fundamental principles (Lucariello and Naff, 2010). Acknowledging and addressing the misconceptions prevalent in chemistry, educators can create a more effective learning environment that promotes conceptual understanding, critical thinking, and application of organic chemistry principles in various scientific disciplines. Accordingly, identifying specific challenging topics through a valid and reliable assessment enables the implementation of pedagogical interventions to address them effectively. Moreover, to ensure effective instruction and assessment in chemistry, it is crucial to employ instructional strategies based on rigorous research studies focused on student comprehension of fundamental chemistry concepts, particularly in light of recent trends in science education, such as augmented reality and gamification strategies (Papadakis et al., 2023; Zourmpakis at al., 2023).

The process of collecting evidence and making judgments on whether competency has been achieved to confirm that an individual can perform to the standards required is generally referred to as assessment (Fisher and Bandy, 2019; Wiliam, 2011). A good assessment instrument can effectively identify misconceptions and learning gaps in students' competency acquisition in heat and temperature and other physical chemistry concepts (Eric et al., 2021). However, assessment instruments often miss knowledge gaps and misconceptions in learning competency acquisition. Transaction-level data analysis is more effective in identifying these issues compared to task-level assessment data (Davies et al., 2015). Hence, the need for developing standard assessment instruments is highly crucial and relevant.

The primary objective of this research is to develop and validate a comprehensive assessment tool tailored for senior high school physical chemistry, with the goal of effectively measuring students' understanding and application of essential concepts within the subject. To achieve this, the developed instrument will be administered to a cohort of senior high school STEM students in Butuan City. Through this process, the research will not only evaluate the efficacy of the assessment tool but also identify the competencies that students have mastered as well as those that require further attention by pinpointing the most and least learned competencies in senior high school physical chemistry.

2. Methodology

The primary objective of this research is to develop a validated and reliable multiple-choice assessment tool expressly designed for senior high school physical chemistry. Each item has undergone expert validation based on several key criteria: the appropriateness of the language used, parallelism, suitability of the response options provided, practical application, and relevance to the posed problem. Additionally, the items are evaluated in terms of their alignment with the domain of knowledge, level of cognitive demand, scientific literacy competency, and the levels of thinking as outlined in Bloom's Taxonomy. Extending this, the instrument developed from validation and reliability testing was initially utilized to identify the specific competencies that are least mastered by senior high school students who are under the STEM (Science, Technology, Engineering, and Mathematics) strand.

Procedures for developing the assessment instrument followed the recommendations provided by research activities in developing a questionnaire instrument to assess teachers' knowledge and understanding of learning evaluation and their ability to develop and analyze problems (Yusrizal et al., 2017; Rosidin et al., 2023). This study adopted a systematic progression of phases for the development of an evaluation instrument (Samarapungavan et al., 2009). These stages encompassed planning and conceptualization, construction and formation, preliminary testing and refinement, and eventual application and assessment (Lou et al., 2015). The assessment instrument was employed to identify specific subject matter in the context of physical chemistry in the general chemistry curriculum established by the Department of Education for the Senior High School STEM (Science, Technology, Engineering, and Mathematics).

2.1 Participants

The research utilized purposive sampling techniques to select suitable participants for the study, with a specific focus on senior high school students in public high schools pursuing the STEM strand. The pilot testing phase of the assessment tool was executed at the Integrated Developmental School of Mindanao State University at Naawan, located in Naawan, Misamis Oriental. The pilot testing was participated in by a total of 81 students. After reviewing all items that passed the evaluation criteria of the pilot testing based on difficulty and discrimination indices, a STEM section from Taligaman National High School situated in Taligaman, Butuan City, was the source of 32 selected students for the initial implementation of the validated test instrument in high school physical chemistry. All evaluation activities were conducted through traditional pen-and-paper methodologies.

2.2 Development of the Assessment Instrument

The teacher-designed multiple-choice examination initially with 50 total items was formulated to comprehensively cover targeted competencies of physical chemistry in the general chemistry curriculum. For thorough structuring, a table of specifications (TOS) was devised (Micheal, 2017;Lei et al., 2015; Smith and Holloway, 2020). The TOS was constructed in accordance with the levels of cognition delineated in Bloom's taxonomy and the science framework of the Programme for International Student Assessment (PISA), which include domain of knowledge, level of cognitive demand, and scientific literacy competency (Makieiev, 2023; Hartono and Siahaan, 2023).

To assess both the external and internal qualities of the test instrument, a rubric was established. This rubric was devised to evaluate the validity of the test's appearance and construct. In this validation endeavor, two adept professionals proficient in the domains of pure chemistry and chemistry education were engaged to review and substantiate the rubric. The insights, suggestions, and corrections furnished by these experts were incorporated into the refinement process, ultimately culminating in the reduction of the

test to a total of 30 items. Subsequent to this refinement, the TOS underwent adjustments to align harmoniously with the revised test components.

The evaluation of the developed test questionnaire for senior high school physical chemistry employed a structured set of criteria to ensure its efficacy, including the “level of difficulty," with the test constructed based on a detailed table of specifications. This ensured that the questions were systematically categorized into varying levels of difficulty to assess the full spectrum of students' scientific literacy. The next criteria was on “directions” provided in the test, confirming that they were appropriately tailored to the learners' level. Clear and precise instructions for each section were essential to minimize misunderstandings and to guide students effectively through the test. Third was on the “length of the test," another critical aspect, ensuring it contained an appropriate number of items to enhance result reliability while also confirming that the allotted time for completion matched the students' grade level capabilities. In terms of "structure," the evaluators verified that the test items were devoid of grammatical errors and faulty stems and that they included effective distractors to adequately challenge students. Finally, the “content” of the test was rigorously examined to confirm its alignment with the content standards of the chemistry curriculum. The test items were crafted to accurately assess students' achievement and proficiency, thereby providing a comprehensive evaluation of their understanding in this critical subject area (Munkh-Erdene et al., 2022; Lowmaster, 2023). Furthermore, validation of items is based on the criteria presented in Table 1.

Table 1 Parameters of Item Validation

Parameters	Description
Appropriateness of the words used	The question is clear, concise, complete, understandable, and not too technical to the target participants
Parallelism	The question is affirmative, unbiased, and neutral in tone, and does not contain leading questions
Appropriateness of responses listed	The choices listed allow the participants to respond appropriately. The responses apply to all situations or offer a way for those to respond with unique situation
Application to praxis	The question asked relates to the daily practices or expertise of the participants
Relationship to the problem	The questions are sufficient to resolve the problem in the study, answer the research questions and obtain the purpose of the study

2.3 Data Analysis

This research involved a descriptive analysis approach where each questionnaire item was thoroughly reviewed by experts using a rubric on the PISA framework and Bloom’s taxonomy. This process ensured a thorough evaluation of the items based on a pre-established framework that included both construct and content validity considerations. The experts assessed each item for clarity, relevance, and alignment with the intended constructs, categorizing them into groups for acceptance, revision, or rejection. Items deemed acceptable directly supported the framework, while those requiring revision were adjusted to better align with the research objectives and validity criteria. Items failing to meet the necessary standards were rejected. This comprehensive analysis provided a systematic approach to refining the assessment tool, ensuring that each item was robust, valid, and effectively measured the targeted constructs.

An item analysis of the pilot group responses was also performed to assess the performance of individual questions, while Cronbach's alpha was calculated to measure internal consistency among the items. The Cronbach's alpha was instrumental in evaluating the internal coherence and dependability of the assessment instrument, as well

as identifying items that could potentially be eliminated to enhance reliability. Moreover, the discrimination index and percentage of correct answers were also analyzed to classify the difficulty level of the items through graphical representation. This comprehensive data analysis ensured the reliability and validity of the developed test questionnaire by confirming that the items consistently measure the intended constructs, as it provided input on how well the items correlate with each other and with the overall score, validating the questionnaire's effectiveness in measuring the desired outcomes.

Visual summaries in tabular format were also used to clearly present the percentage outcomes for each answer choice from the preliminary group to which the developed instrument was administered. These tables included metrics such as frequency counts, the percentage of accurate responses, and the percentage of commonly incorrect answers, offering a comprehensive overview of the results. This analysis aimed to identify specific physical chemistry concepts that posed challenges for the students, thereby highlighting areas where proficiency was lacking. By visually capturing these data points, the study facilitated a deeper understanding of the students' strengths and weaknesses, facilitating the way for targeted instructional improvements.

3. Results and Discussion

3.1 Item Analysis and Validation

The evaluation of the PISA 2018 Science Framework examined its effectiveness in assessing scientific literacy by analyzing three key dimensions. These included: the "domain of knowledge" (content, procedural, and epistemic), the "level of cognitive demand" (low, medium, and high), and scientific literacy competencies (explaining phenomena scientifically, evaluating and designing scientific enquiry, and interpreting data and evidence scientifically). Moreover, the framework of the assessment item analysis discrimination factor and test reliability (Sijtsma et al., 2019; Jiajuan, 2023) in categorizing the difficulty of each item was also employed. This comprehensive analysis provided insights into the framework's ability to cover a wide range of scientific understanding and challenge cognitive abilities.

Table 2 Sample test question with parameters after expert corrections

Learning Competency: Distinguish between exothermic and endothermic processes	
Item question During an exothermic chemical reaction, what happens to the energy? A) Energy is absorbed from the surroundings. B) Energy is released to the surroundings. C) Energy remains constant within the system. D) Energy is converted into matter.	
PARAMETERS	
Domain of Knowledge	Procedural
Level of Cognitive Demand	Medium
Scientific Literacy Competency	Explain phenomena scientifically
Level of Thinking in Bloom's Taxonomy	Applying
Comments & Suggestions	*SLC: Evaluating and designing scientific enquiry*

Additionally, the expert evaluation rated the teacher-made test with a mean score of 4.00 interpreted as "very good," reflecting its strong alignment with curriculum objectives and content accuracy. After incorporating expert feedback, 20 items were removed, resulting in a final 30-item test. The test's reliability was confirmed with a Cronbach's alpha value of 0.9 during pilot testing. According to the revised table of specifications, the test consists of 30% remembering, 30% understanding, 20% applying, 10% analyzing,

6.7% evaluating, and 3.3% creating, emphasizing higher-order thinking skills (80%) over lower-order thinking skills (20%).

3.2 Test Results of the Trial Group of STEM Students

The analysis of student performance in the physical chemistry unit of senior high school STEM Chemistry reveals several topics that students find particularly challenging, as indicated by the low percentage of correct answers. The data highlights that chemical kinetics appears to be the least mastered topic, with correct response rates of 17.2%, suggesting consistent difficulties in understanding the concepts related to reaction rates and the factors affecting them. Similarly, thermochemistry also shows low mastery levels of 20.3%, indicating that topics related to heat changes in chemical reactions are challenging for students. This is followed by electrochemistry's correct answer rate of 25.0%, highlighting that students struggle to understand electrochemical processes and the working of galvanic and electrolytic cells. This finding aligns with the study by Adesoji et al. (2017), which identified electrolysis as one of the most challenging areas in physical chemistry for students. The study compared students perceived and actual learning difficulties, revealing that many students underestimated their struggles with electrolysis. Chemical thermodynamics also showed a low percentage of 26.6, suggesting that the concepts involving the laws of thermodynamics and energy transformations are not well understood. The repeated appearance of these topics at various difficulty levels indicates a need for targeted interventions, such as differentiated instruction or enhanced teaching materials, to help students better grasp these complex concepts.

Table 3 Top Least Mastered Topics in Senior High School STEM Chemistry: Physical Chemistry Section Based on Student Performance

Topics in SHS STEM Chemistry (Physical Chemistry Unit)	**Students Mean Percent Correct (%)**
Chemical Kinetics	17.2
Thermochemistry	20.3
Electrochemistry	25.0
Chemical Thermodynamics	26.6

Also, looking at the average score, it was found that 11.9%, corresponding to 38.30% of the total mark is the measure of central tendency and indicates the overall performance level of the participants. Additionally, the median score, which was 9, aligns closely with the average and suggests that the distribution of scores is reasonably balanced. Moreover, the categorization of questions was observed to include 6 that were classified as hard, indicating a higher level of difficulty. There were 3 items categorized as medium difficulty, while 2 items were classified as easy. This distribution implies that the test primarily consisted of challenging questions, potentially contributing to the participants' lower average scores.

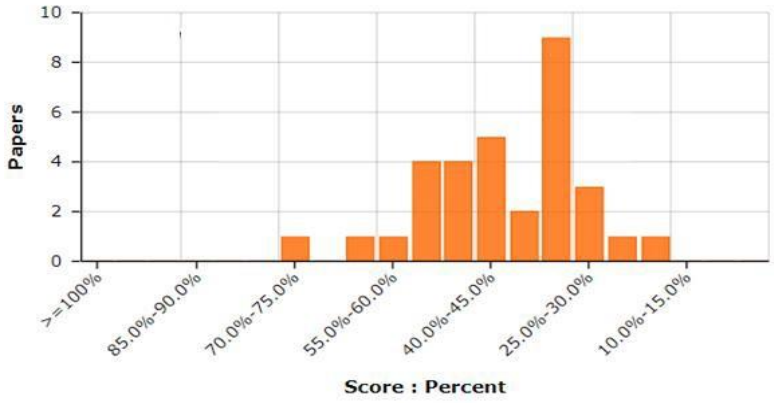

Figure 1. Score Distribution in Percentage

The results of the test instrument revealed interesting findings when analyzing the outcomes in different categories of questions. The scores depicted in figure 1 display that a majority of the participants achieved scores lower than 50%, emphasizing their inadequate performance. The graph demonstrates a noticeable inclination towards the right side, indicating a skewed distribution of scores. The score distribution indicated pronounced skewness towards lower scores, highlighting the unequal performance levels among students. This disparity underscores the significance of identifying contributors to lower scores and implementing targeted interventions to bridge knowledge gaps.

4. Conclusion

The assessment instrument for senior high school physical chemistry has demonstrated strong alignment with curriculum objectives, content accuracy, and reliability, as evidenced by positive expert evaluations, collaborative refinement, and high internal consistency during pilot testing. The dominance of hard and medium-difficulty items contributed to an average score of 11.9. These highlight both the strengths and areas requiring improvement in the assessment process for both the strengths and areas requiring attention in the assessment process. Furthermore, the test item distribution across various cognitive levels, as indicated by taxonomic classifications, revealed a substantial emphasis on higher-order thinking over lower-order thinking skills, a balance that promotes deeper understanding and critical thinking. Revisions of the assessment instrument to incorporate a balanced mix of easy, medium, and hard questions are recommended. Moreover, the results of the preliminary investigation offer valuable insights into the performance of the Grade 12 senior high school students in the context of physical chemistry. The skewed distribution of scores, with a majority scoring below 50%, indicates significant challenges in comprehending physical chemistry concepts. Moreover, instructional interventions should be employed to address the recognized gaps in participants' comprehension, emphasizing the need for targeted instructional interventions to enhance students' grasp of the subject matter.

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