STEM Learners' Mastery in Electronic Structure of Atoms: Basis for Academic Intervention

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ABSTRACT

This study investigated the conceptual challenges faced by Grade 12 STEM learners in mastering the electronic structure of atoms, encompassing the quantum mechanical model, energy levels, orbitals, sublevels, electron configuration, and quantum numbers. The research also examines learners' self-efficacy in understanding these topics. A needs assessment questionnaire, validated by both subject-matter and methods experts, was administered to evaluate students' comprehension, alongside a self-efficacy survey to measure confidence in mastering the content. Results indicated generally low confidence among learners, with slightly higher self-assurance reported for determining magnetic properties from electron configurations (40% expressing moderate confidence). Analysis of mastery levels revealed that describing the quantum mechanical model of the atom was the least understood competency, averaging 55% mastery, while other topics—including energy levels, orbitals, sublevels, electron configuration, and quantum numbers—scored below 50%, with quantum numbers being the most poorly grasped concept. These findings underscore the need for targeted instructional interventions addressing the least understood topics and strategies to enhance learners' confidence, thereby improving conceptual understanding in electronic structure of atoms.

Keywords: electronic structure of atoms, self-efficacy, content knowledge, mastery level

INTRODUCTION

The electronic structure of atoms is a foundational concept in chemistry, underpinning students' understanding of atomic behaviour, chemical bonding, and periodic trends. Mastery of this topic is essential for meaningful engagement with advanced chemical concepts. However, despite its central importance, numerous studies have documented persistent learning difficulties associated with key subtopics, including energy levels, atomic orbitals and sublevels, electron configuration, and quantum numbers. These concepts are inherently abstract and often require mathematical and theoretical reasoning rooted in quantum mechanics, which many learners find cognitively demanding. As a result, the electronic structure of atoms remains one of the least understood domains in secondary chemistry education (Kiray, 2016).

The complexity of this topic is further exacerbated by traditional instructional approaches that rely heavily on symbolic and mathematical representations, offering limited opportunities for conceptual visualization. Adadan et al. (2016) noted that abstract representations commonly used in teaching electronic structure hinder students' ability to form coherent mental models of atomic phenomena. In particular, quantum numbers and electron configurations have been identified as major sources of conceptual difficulty. Kyado et al. (2021) reported that secondary-level learners struggle significantly with interpreting and applying quantum numbers, which impedes their understanding of electron behaviour and atomic structure. Insufficient comprehension of these concepts often leads to cumulative learning difficulties that negatively affect students' overall performance in chemistry.

Related research has also highlighted the prevalence of misconceptions arising from students' limited understanding of electron arrangement and behaviour. Sampson et al. (2016) emphasized that misunderstandings of electron configuration and hybridization obstruct students' grasp of chemical bonding and molecular geometry. Similarly, Koponen et al. (2017) found that many learners experience difficulty in conceptualizing the probabilistic nature of electrons, frequently interpreting electron behaviour in deterministic rather than quantum terms. Such misconceptions commonly stem from students' inability to connect abstract symbols and models with physically meaningful representations of atomic interactions.

In response to these challenges, the present study seeks to identify the specific subtopics within the electronic structure of atoms that are least understood by Grade 12 STEM learners. By systematically examining students' conceptual understanding, self-efficacy, and content knowledge, the study aims to provide a comprehensive analysis of existing learning gaps. The findings are intended to inform the development of targeted instructional interventions and evidence-based curricular adjustments. These may include the integration of hands-on learning activities, visual and spatial representations, collaborative learning strategies, and alternative assessment approaches designed to enhance conceptual clarity.

Ultimately, this research aspires to improve the accessibility and comprehensibility of abstract chemical concepts, particularly those related to the electronic structure of atoms. By addressing persistent learning difficulties in a systematic and research-informed manner, the study aims to foster deeper conceptual understanding, increase learner confidence, and promote sustained interest in chemistry. In doing so, it seeks to contribute to a more supportive and effective educational environment that equips students with the foundational knowledge and skills necessary for success in advanced science studies and future professional endeavours.

METHODOLOGY

The research design of this study adopts a structured approach to identify the least mastered competencies in the electronic structure of the atom and evaluate learners' self-efficacy in the subject. The process involved several stages: planning and conceptualization, development and creation, initial testing and refinement, and concluding with final implementation and assessment (Lou et al., 2015).

The process begins with the development of a needs assessment questionnaire aimed at evaluating learners' understanding of key concepts under electronic structure of atoms such as quantum mechanical model, energy level, orbitals, and sublevel, electron configuration, and quantum numbers. This questionnaire was validated by experts, including chemistry educators and content experts, to ensure content relevance and clarity. Following validation, the questionnaire undergoes a try-out phase with the larger number of Grade 12 learners to identify any issues with wording or structure. The data from this phase will be subjected to item analysis to determine which questions should be retained or rejected based on their ability to effectively assess learners' competencies. The revised, final version of the needs assessment will then be administered to a smaller group of learners, alongside a separate questionnaire measuring the learners' self-efficacy to the topic. This will assess learners' confidence in mastering key concepts like atomic structure, quantum numbers and electron configuration, identifying areas of struggle. Data from both questionnaires was analyzed to explore correlations between learners' self-efficacy and conceptual understanding, providing valuable insights into how these factors influence academic achievement in this subject.

Participants

The participants of the study consisted of 40 Grade 12 STEM learners from a public secondary school in Iligan City, Northern Mindanao, Philippines. The learners age ranges from 17 to 19 years and represented diverse socioeconomic backgrounds, from low to high socioeconomic status. Given the geographical context of the study, the sample included a mix of Filipino ethnic groups, predominantly Cebuano/Bisaya, with representation from Maranao learners. All participants were enrolled in senior high school chemistry at the time of data collection.

Development of the Instrument

Version I: Initial Development and Face Validation. The first version of the needs assessment questionnaire was developed as an initial draft intended to cover the essential competencies related to the electronic structure of atoms. The instrument consisted of multiple-choice questions (MCQs), designed to assess both factual recall and the application of conceptual knowledge in problem-solving contexts. This version underwent face validation by subject matter experts, including experienced chemistry educators and content specialists. The reviewers evaluated each item for relevance, accuracy, clarity, and curricular alignment. Feedback from the experts identified items that were ambiguous, overly complex, or misaligned with the intended learning outcomes, which informed subsequent revisions.

Version II: Pilot Testing and Item Analysis. The second version of the instrument incorporated revisions based on expert feedback and was subjected to pilot testing with a larger sample of 120 senior high school learners. Pilot testing enabled the researchers to evaluate the performance of each item under authentic testing conditions. Item analysis was conducted to examine question clarity, level of difficulty, and discrimination power. Cronbach's alpha was computed to determine the internal consistency reliability of the questionnaire. Items that demonstrated low discrimination indices or failed to differentiate effectively between high and low performing learners were either revised or removed. The refinement process focused on enhancing item precision and ensuring that all retained questions were directly aligned with the targeted competencies in the electronic structure of the atom. The final version of the questionnaire was thus designed to provide a valid and reliable measure of learners' achievement and proficiency in this core chemistry topic, consistent with established assessment standards (Munkh-Erdene et al., 2022; Lowmaster, 2023).

Final Version of the Instrument. The third version represented the final version of the needs assessment questionnaire. This version was developed after the item analysis from Version II and incorporated all the feedback and revisions made during the previous stages. The revised questionnaire contained only those items that had shown to be effective in assessing learners' competencies. These items were carefully reviewed again to ensure they were clearly worded, unbiased, and aligned with the intended learning outcomes. Additionally, the questionnaire was designed to be balanced in terms of difficulty, with a mix of questions that could assess both basic recall and higher-order thinking skills. Version III was then administered to a smaller sample of Grade 12 learners (40), providing a more comprehensive set of data

Data Analysis

To provide a clearer understanding of the results, visual summaries in tabular format were used to present the percentage outcomes for each answer choice from the preliminary group. These tables included metrics such as frequency counts, percentages of correct responses, and the percentage of commonly incorrect answers. This detailed analysis helped identify specific electronic structure of atoms concepts that were challenging for students, highlighting areas where proficiency was lacking. These analyses provided a detailed description of overall performance of the learners, their self-efficacy, conceptual undertaking of the subject matter and their mastery levels in each competency in each area. Moreover, the data collected from the self-efficacy questionnaire, needs assessment, and mastery level results were interpreted using Tables 1, 2, and 3 respectively.

Table 1. Self-efficacy scale range and interpretation

Range Scale	Interpretation
1.00- 1.79	Not Confident at all
1.80- 2.59	Slightly Confident
2.60-3.39	Somewhat Confident
3.40-4.19	Fairly Confident
4.20-5.00	Completely Confident

Interpretation adapted from the study of Timur and Tasar (2011)

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Table 2. Interpretation on learners' performance on the needs assessment

Percentage Remarks	Remarks
90- 100	Passed
85-89	Passed
80- 84	Passed
75- 79	Passed
Below 75	Failed

Reference: DepEd PPST - Module 11

Table 3. Mastery level and percentage equivalent

Mastery Level	Percent Equivalent
Mastered	80-100
Nearly Mastered	75-79
Least Mastered	51-74
Not Mastered	50 and below

Reference: DepEd PPST - Module11

RESULT AND DISCUSSION

Self-Efficacy Survey Results

The self-efficacy questionnaire consisted of six (6) statements anchored on the Most Essential Learning Competencies (MELCs) for Senior High School General Chemistry under Electronic Structure of Atoms. These statements were designed to assess students' confidence and perceived competence in mastering key chemistry concepts including quantum mechanical model, energy levels, orbitals, quantum numbers, and electron configuration. The instrument was administered to forty (40) Grade 12 STEM learners who were purposely selected to represent the target population of the study.

Each item was carefully aligned with specific learning outcomes to ensure that the questionnaire accurately measured learners' self-efficacy. Following administration, the responses were systematically collected, organized, and analyzed to determine patterns and trends in students' confidence levels and self-perceived understanding of concepts. The summarized results provide a comprehensive overview of learners' self-efficacy and offer meaningful insights into areas requiring targeted instructional strategies to further enhance students' understanding and academic performance in chemistry.

Table 4. Self-efficacy summary of result (N=40)

Statements	Not confident at All (%)	Slightly Confident (%)	Somewhat Confident (%)	Quite Confident (%)	Extremely Confident (%)
1. I can describe the quantum	4 (10%)	15 (37%)	7(17%)	11(27.5)	3 (7.5%)

mechanical model of the atom					
2. I can describe the electronic structure of atoms in terms of main energy levels, sublevels, and orbitals, and relate this to energy.	2 (5%)	11 (27.5%)	8 (205)	11 (27.5%)	8 (20%)
3. I can use quantum numbers to describe an electron in an atom	12 (30)	14 (35%)	7 (17.5%)	7 (17.5%)	0 (0%)
4. I can write the electronic configuration of atoms	1 (2.5%)	10 (25%)	8 (20%)	11 (27.5)	10 (25%)
5. I can determine the magnetic property of the atom based on its electronic configuration	3 (7%)	16 (40%)	8 (20%)	10 (25%)	3 (7.5%)
6. I can draw an orbital diagram to represent the electronic configuration of atoms	1 (2.5%)	8 (20%)	9 (22.5%)	13 (32%)	1 (2.5)

The data presented in Table 4 illustrate varying levels of self-reported confidence among learners regarding key concepts in the electronic structure of the atom. Notably, 37% of participants reported being only somewhat confident in explaining the quantum mechanical model of the atom, suggesting a partial understanding of this complex concept. Similarly, 40% of learners indicated minimal confidence in identifying the magnetic properties of atoms based on their electronic configurations, highlighting difficulties in applying theoretical knowledge to practical contexts. In contrast, 27.5% of learners felt fairly confident in describing the electronic structure through energy levels, sublevels, and orbitals, as well as in writing atomic electronic configurations. An equivalent proportion (27.5%) expressed comparable confidence in drawing orbital diagrams to represent electronic configurations.

However, 30% of learners reported a lack of confidence in using quantum numbers to describe an electron's position, indicating substantial difficulty with this foundational concept. Since quantum numbers are essential for understanding atomic structure, challenges in this area can impede overall comprehension. This finding aligns with Allred and Bretz (2019), who emphasize that mastery of quantum numbers is critical for fully understanding the electronic structure of atoms. Collectively, these results underscore the need for targeted instructional strategies aimed at strengthening learners' conceptual understanding and confidence in handling abstract atomic concepts.

STEM Learners' Performance on the Assessment

Another important aspect being focused on the study is the performance of the students. A needs assessment was conducted, and data were interpreted using the descriptions in Table 2.

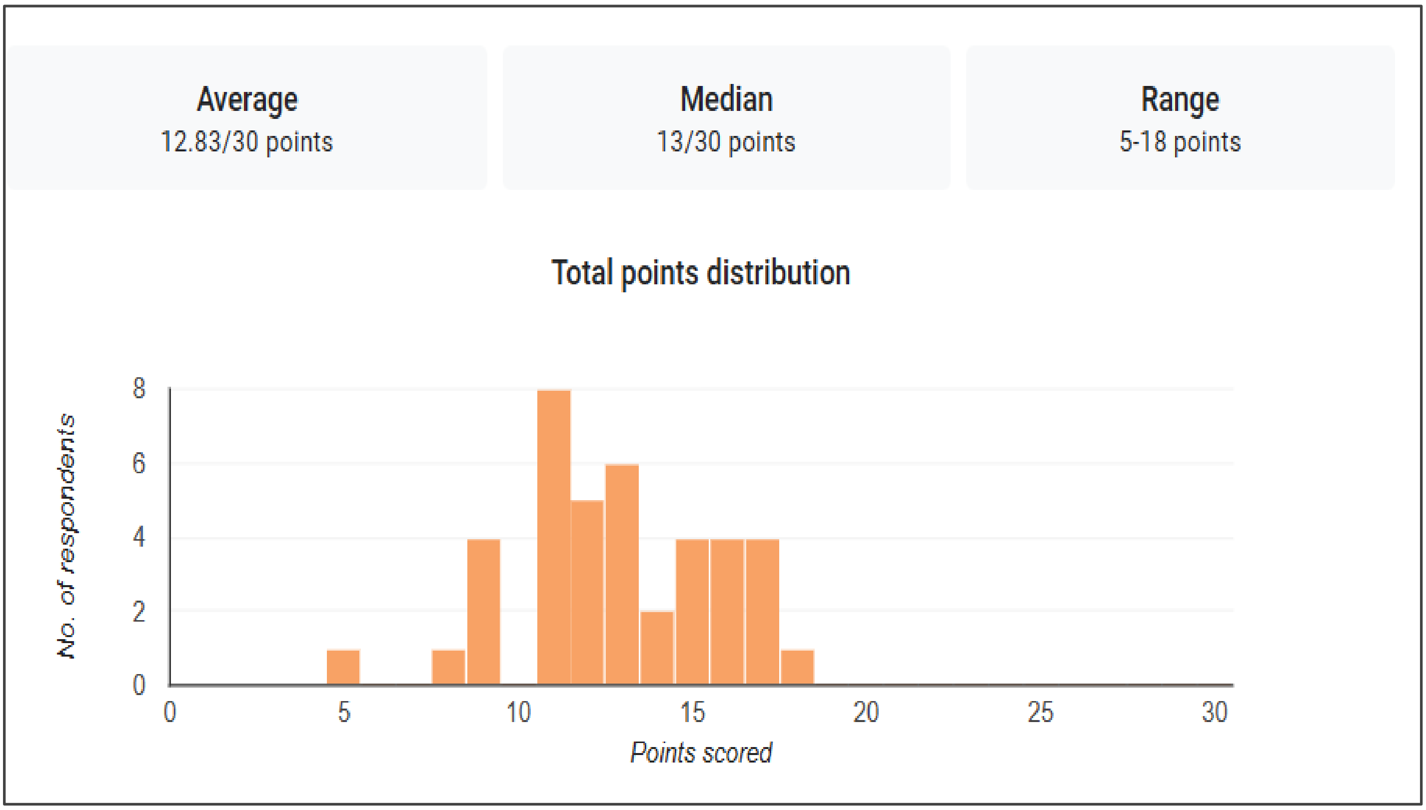

Figure 1. Total Points Distribution

The results of the assessment on the electronic structure of the atom are depicted in Figure 1, which illustrates the distribution of achievement test scores among the participants. Scores ranged from 5 to 18, with the most frequent score being 8 and an overall mean of 12.8. The distribution demonstrates a marked clustering of scores at the lower end of the scale, indicating that a substantial proportion of learners exhibited limited mastery of the topic. These findings highlight the necessity for targeted instructional interventions and additional support to enhance conceptual understanding in this critical area of chemistry.

Table 5. Grade 12 STEM Learners' Individual Performance on the Assessment

Respondents	Scores	Percentage	Interpretation
STEML01	16	56%	Failed
STEML02	15	50%	Failed
STEML03	3	10%	Failed
STEML04	4	13%	Failed
STEML05	11	37%	Failed
STEML06	13	43%	Failed
STEML07	13	43%	Failed

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STEML08	17	57%	Failed
STEML09	12	40%	Failed
STEML10	11	37%	Failed
STEML11	11	37%	Failed
STEML12	9	30%	Failed
STEML13	11	37%	Failed
STEML14	18	60%	Failed
STEML15	13	43%	Failed
STEML16	15	50%	Failed
STEML17	12	40%	Failed
STEML18	17	57%	Failed
STEML19	17	57%	Failed
STEML20	16	53%	Failed
STEML21	16	53%	Failed
STEML22	16	53%	Failed
STEML23	12	40%	Failed
STEML24	13	43%	Failed
STEML25	11	37%	Failed
STEML26	13	43%	Failed
STEML27	12	40%	Failed
STEML28	14	47%	Failed
STEML29	11	37%	Failed
STEML30	5	17%	Failed
STEML31	9	30%	Failed
STEML32	8	27%	Failed
STEML33	13	43%	Failed

STEML34	9	30%	Failed
STEML35	11	37%	Failed
STEML36	11	37%	Failed
STEML37	12	40%	Failed
STEML38	17	57%	Failed
STEML39	9	30%	Failed
STEML40	14	47%	Failed

Interpretation: 75% -100% Passed Below 75% Failed

Analysis of the learners' performance on the needs assessment revealed that the highest score achieved was only 60%, which constitutes a failing mark according to the assessment criteria. This indicates that none of the participants demonstrated mastery of the material, with the majority scoring below 60%, underscoring substantial difficulties with the content. The greatest challenges were observed in tasks requiring the determination of electron configurations and the application of quantum numbers. Such difficulties are often linked to ineffective instructional approaches. This interpretation aligns with the findings of Putri and Azra (2023), who contend that persistent learning challenges in abstract chemistry topics underscore the need for enhanced teaching strategies aimed at improving student engagement and conceptual understanding. Collectively, these results highlight significant gaps in learners' knowledge, indicating a pressing need for targeted interventions to strengthen comprehension and performance in the electronic structure of atoms.

Mastery Level of Grade 12 STEM in Electronic Structure of Atoms

The main highlights of this study were to determine mastery level of learners in the competencies related to electronic structure of atoms. Their performance across these competencies serves as a critical indicator of their understanding of foundational concepts and their ability to apply these concepts effectively. Evaluating learners' proficiency provides meaningful insights into their strengths and areas that require improvement, thereby informing the development of targeted instructional interventions aimed at enhancing learning outcomes and overall academic performance in these challenging and crucial concepts.

Table 6. Mastery Level of Grade 12 STEM in Electronic Structure of Atoms

Learning Competency	Item number	Frequency of error	Mean and %	No. of correct responses	Mean and %	Mastery Level
Describe the quantum mechanical model.	1. 2. 3. 4 5	15 22 22 17 13	18 (45%)	25 18 18 23 27	22 (55%)	Least Mastered
Describe the electronic	6.	22		18		

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structure of atoms in terms of main energy levels, sublevels and orbitals and relate this to energy	7. 8. 9. 10.	21 28 21 21	23 (57%)	19 12 19 19	17 (43%)	Not Mastered
Use quantum numbers to describe an electron in an atom	11. 12. 13. 14. 15. 16. 17 18.	29 28 26 32 27 26 22 29	27 (67%)	11 12 14 8 13 14 18 11	13 (33%)	Not Mastered
Write the electron configuration of an atom	19. 20. 21. 22. 23.	23 25 22 26 21	23 (56%)	17 15 18 14 19	17 (46%)	Not Mastered
Determine the magnetic property of an atom based on its electron configuration	24 25. 26 27.	22 23 20 20	21 (53%)	18 17 20 20	19 (48%)	Not Mastered
Draw an orbital diagram to represent the electronic configuration of atom	28. 29 30.	26 22 16	21 (53)	14 18 24	19 (48%)	Not Mastered

Legend: Not mastered (50% below), Least mastered (51-74%), Nearly Mastered (75-79%), Mastered (80-100%)

The analysis of learners' performance revealed that the competency "Describe the quantum mechanical model of the atom" achieved an average mastery level of 55%, whereas other competencies—including energy levels, orbitals, sublevels, electron configuration, and quantum numbers—were all below 50%. Overall, mastery levels were notably low, with quantum numbers identified as the least understood concept, receiving only 33% correct responses. These findings underscore the necessity for targeted instructional interventions focused on the most challenging topics. Moreover, incorporating strategies to enhance learners' confidence is critical for fostering a deeper conceptual understanding of the electronic structure of atoms.

CONCLUSION AND RECOMMENDATION

This study revealed that Grade 12 STEM learners encounter substantial difficulties in mastering fundamental concepts related to the electronic structure of atoms, including the quantum mechanical model, energy levels, orbitals, sublevels, electron configuration, and quantum numbers. Among these, the quantum mechanical model and quantum numbers were identified as particularly challenging, with learners demonstrating low mastery across most competencies. Additionally, students reported low confidence in their ability to comprehend these complex topics, indicating that both conceptual understanding and self-efficacy are significant concerns in this domain.

To address these challenges, it is recommended that educators implement targeted instructional strategies that emphasize clear and accessible explanations of difficult concepts. The integration of visual aids, interactive simulations, and real-world examples can facilitate learners' understanding of abstract atomic phenomena. Active learning approaches, such as group discussions, peer teaching, and hands-on activities, are also suggested to promote deeper engagement with the material and provide opportunities for immediate clarification of misconceptions.

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