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FACTORS ASSOCIATED WITH FEMALE STUDENTS' CONCEPTUAL UNDERSTANDING OF ATOMIC ORBITALS AND HYBRIDISATION

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Abstract. *Research suggests that students, especially female chemistry students, often struggle with understanding atomic orbitals and hybridisation, sometimes holding misconceptions about these concepts. To add to what is known, we examined factors associated with female chemistry students' conceptual understanding of atomic orbitals and hybridisation. We collected data from 304 female chemistry students in upper-secondary school using a methodological triangulation mixed-methods approach that included questionnaires and interviews. Of these, 50 students participated directly in interviews. Exploratory factor analysis revealed three main factors associated with their conceptual understanding. Thematic analysis and narrative approaches were used to further interpret and support the quantitative findings. Since motivational beliefs emerged as one of the key factors, it is important for governments and organisations working towards Sustainable Development Goal 5 (SDG5) – gender equality – to provide targeted support for female chemistry students. Such assistance should aim to foster their interest and engagement with fundamental chemistry concepts like atomic orbitals and hybridisation.*

Keywords: *All-female schools, factor analysis, female chemistry students, motivation, SDG5*

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Introduction

The concept of atomic orbital hybridisation has a significant place in the history of chemistry education. Introduced in the 20th century by Linus Pauling, both atomic orbitals and the principle of hybridisation have since become fundamental components of upper-secondary school chemistry curricula, where students are introduced to these concepts early in their learning (Ministry of Education, Ghana, 2010; 2023). These foundational ideas not only underpin students' conceptual understanding of chemical bonding and molecular geometry but also serve as a gateway to more advanced concepts in chemistry. As a student progresses through a curriculum, a robust conceptual understanding of orbital hybridisation enables an individual to interpret molecular shapes, predict bond angles, and chemical reactivity (Ministry of Education, Ghana, 2010; 2023). Notwithstanding the centrality of atomic orbitals and hybridisation, many students encounter persistent difficulties in mastering these concepts, prompting chemistry educators and researchers alike to examine the factors associated with these conceptual difficulties and underperformance of students, thereby exploring innovative instructional strategies with the interest of helping students to develop a scientific understanding of atomic orbitals and hybridisation.

There is a lot more theoretical, empirical, and conceptual literature on atomic orbitals and hybridisation because these concepts are essential in predicting the shapes and types of bonds that exist in molecules (Chang, 2010; Ministry of Education, Ghana, 2010; 2023; Petrucci et al., 2016). However, research shows that many students struggle to understand atomic orbitals and hybridisation, often leading to lower performance in these areas (Abukari et al., 2022; Marifa et al., 2023; Mawutor & Adu-Gyamfi, 2025; Salame et al., 2022). Hence, there is a need to explore factors associated with chemistry students' conceptual difficulties in learning atomic orbitals and hybridisation.

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Performance of Female Students in Hybridisation

In Ghana, students in upper-secondary school are reported to perform poorly in chemistry. Results obtained from the West African Examination Council [WAEC] show that the percentage pass (grades A1-C6) score over a decade for students in chemistry does not exceed 70%. The highest mean score recorded is 67.79% in 2019, and the lowest score recorded is 47.17% in 2018, as indicated in Table 1. This raises an alarm as a little over 30% of the students do not achieve the pass mark, which is an important factor for the entry level of students in the tertiary institutions.

Table 1
Students' Percentage Mean Performance in Elective Chemistry in West African Senior School Certificate Examination, 2011-2021

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
% pass A1-C6	52.22	58.94	52.97	50.10	49.17	62.94	65.17	47.17	67.79	59.17	67.0

Furthermore, in relation to gender, female students in the upper-secondary school over the years have been performing poorly in chemistry as compared to their male counterparts in the West African Senior School Certificate Examination [WASSCE]. Results from WAEC show that the percentage pass score over a decade for female students as compared to their male counterparts in chemistry does not exceed 70%. The highest score for females is 65.11% recorded in 2019, and the lowest score is 44.87% recorded in 2014, as compared to the males' score in 2019 and 2014, to be 69.27% and 52.85%, respectively, as indicated in Table 2. Consequently, a little over 30% of the female chemistry students do not meet the entry requirements to the tertiary level for further studies in chemistry. Something that may not help in achieving gender equality and empowering all women and girls (Sustainable Development Goal 5 [SDG5]). That is, empowering the female students is a critical contribution to the progress made across all goals and targets (UN, n.d.).

Table 2
Male and Female Students' Percentage Performance in Elective Chemistry in West African Senior School Certificate Examination, 2011-2021

Year	Male (% pass, A1-C6)	Female (% pass, A1-C6)
2011	55.58	45.86
2012	61.81	53.45
2013	56.06	46.85
2014	52.85	44.87
2015	51.00	45.81
2016	64.67	59.76
2017	66.96	61.90
2018	48.02	45.61
2019	69.27	65.11
2020	60.72	56.59
2021	69.38	63.04

Another alarming aspect is students' performance in atomic orbitals and hybridisation, contributing to these low levels of percentage mean performances in chemistry (WAEC, 2017; 2018; 2019; 2020). That is, students perform poorly in responding to test items related to hybridisation during their chemistry examinations. For instance, in 2017, the chief examiner reported that many of the students who attempted a test item on defining hybridisation

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and indicating how the carbon-carbon double bond, C=C, in an alkene is formed, with the aid of an appropriate diagram, but students could not correctly respond to this item (WAEC, 2017). The report in 2018 revealed that students were unable to draw electronic configurations of beryllium (Be) and calcium (Ca) and could not explain why Be and Ca show similar chemical properties but are different from fluorine (F). Students were unable to respond because they had deficient knowledge that Be and Ca have the same number of valence electrons as two, hence will have similar chemical properties. However, the chemistry of Be and Ca would be different from that of F because F has seven valence electrons (WAEC, 2018). Again, in 2019, it was reported that the majority of the students could explain the significance of the arrows in the box representation of the electron configuration of oxygen (that is, using orbital diagrams) but failed to explain what the letters x, y, and z of the p-orbital are. Although students were able to draw the electron configurations of carbon and phosphorus, they were unable to draw a diagram of the shapes of the orbitals formed and explain how carbon shows the covalency of four equivalent bonds (WAEC, 2019). Similarly, in 2020, the WAEC chemistry chief examiner's report revealed that only a few students were able to explain how molecules assume their shapes. The report further indicated that students failed to explain that pairs of electrons around a central atom repel each other, thereby arranging themselves as far apart as possible to minimise any electron-electron repulsion (WAEC, 2020).

Empirical studies consistently show that students have difficulties in understanding the concept of atomic orbitals and hybridisation leading to misconceptions in the concept (Çalış, 2018; Hanson et al., 2012; Mawutor & Adu-Gyamfi, 2025; Nakiboglu, 2003; Salame et al., 2022). Çalış (2018) reported that most students had difficulty explaining concepts in hybridisation, such as the formation of sigma and pi bonds, and the difference between atomic orbitals and hybrid orbitals. Also, students were unable to identify the type of hybridisation a central atom in a molecule undergoes. In addition, a study conducted by Boachie et al. (2023) in St. Ambrose College of Education revealed that students had fears and perceived chemistry concepts, specifically, chemical bonding, a concept related to hybridisation, as abstract, and this was overcome with the help of computer simulation. However, female students' conceptual understanding and the factors associated with their understanding were not explored.

Similarly, a study conducted by Abukari et al. (2022) in the Upper West Region, Ghana, reported that most students have difficulty in grasping the concept of hybridisation, specifically, explaining the type of hybrid orbitals formed in molecules, how *sigma* and *pi* bonds are formed, and drawing the electron orbital diagram and shapes of molecules. Mawutor and Adu-Gyamfi (2025) then examined the conceptual understanding of atomic orbitals and hybridisation among 304 female upper-secondary school chemistry students using a two-tier diagnostic test. These authors reported that female chemistry students have a partial understanding of atomic orbitals and hybridisation with accompanying misconceptions. These misconceptions are association, reduction, and fixation, with no presence of linear sequencing misconceptions.

Factors Affecting Students' Performance in Chemistry

There are several factors that account for the performance of students in chemistry concepts. That is, beyond foundational knowledge, issues such as students' prior instructional experiences (Azizah et al., 2021; Pajares, 2002), the effectiveness of instructional strategies (Marku et al., 2017), and the relevance of learning environments (Sibomana et al., 2021) are vital for promoting conceptual understanding. These aspects support the development of logical thinking, the ability to form meaningful connections (Jones et al., 2005), and cognitive flexibility when addressing complex problems (Holme, 2022). Collectively, they play a great influence in how students internalise abstract chemistry concepts, like atomic orbitals and hybridisation, ultimately affecting students' performance in chemistry.

Consequently, this underperformance has been attributed to gender (Azizah et al., 2021; Crossdale et al., 2022), motivation (Huda & Rohaeti, 2023), teachers' instructional approaches (Marku et al., 2017), and low prior knowledge (Azizah et al., 2021; Pajares, 2002). For instance, according to Azizah et al. (2021), some factors identified to account for students' poor performance were gender, low self-efficacy, and low prior knowledge. In that, male students had a better conceptual understanding of concepts than female students, who had a fairly good conceptual understanding. However, the female students were weak in determining the right concepts to find solutions to problems and apply them in new contexts. Similar research was conducted by WrigleyAsante et al. (2023) on the influence of gender on students' conceptual understanding and reported that gender influenced students' conceptual understanding in support of female students.

Additionally, Pajares (2002) reported that students' previous knowledge and their instructional experiences impact the instruction process, leading to an enhancement or detriment of their conceptual understanding. Re-

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search by Marku et al. (2017) on factors that influence students' performance in organic chemistry concluded that of 208 respondents, 47% of the students did well in hybridisation. However, most students felt motivated to study organic chemistry and hence recommended that students should be encouraged to utilise e-learning resources to enhance their understanding and that there should be an enhancement in the instructional process (Marku et al., 2017). Furthermore, the learning environment helps students understand chemistry scientifically, as many students fail to see the connection between the chemistry they learn in the classroom and its implications in their daily life (Sibomana et al., 2021). According to Sibomana et al. (2021), the teaching and learning process has an impact on students' academic performance, which helps determine the curriculum's educational objectives.

Some attempts have been made to address difficulties in learning chemistry in schools and colleges using innovative teaching strategies. For instance, incorporating 3D visualisation tools, such as computer-based molecular modelling and augmented reality applications, has proven to be effective in enhancing students' spatial reasoning and conceptual understanding (Rahmawati et al., 2021). These tools allow students to manipulate molecular structures interactively, which fosters a deeper understanding of orbital shapes and hybridisation patterns (Jones et al., 2005; Rahmawati et al., 2021). Additionally, active learning strategies, such as inquiry-based learning and problem-solving activities, encourage students to engage with the material in a more meaningful way, helping them explore the principles of atomic orbitals and hybridisation beyond surface-level memorisation (Jones et al., 2005). By promoting such interactive and reflective learning experiences, educators can guide students toward developing a more comprehensive and nuanced understanding of these challenging concepts (Rahmawati et al., 2021).

Furthermore, contextualising abstract concepts with real-world applications significantly enhances student comprehension (Mills, 2016). Linking hybridisation to familiar molecules, such as water or carbon dioxide, demonstrates the practical significance of these ideas, making them more relatable and relevant (Abukari et al., 2022; Nakiboglu, 2003). That is, scaffolding instruction by gradually introducing mathematical principles (starting with analogies and progressing to more rigorous quantum mechanical frameworks) can bridge the gap between simplified classroom explanations and the complex realities of orbital theory (Hanson et al., 2012). This approach of scaffolding not only helps students better grasp the fundamental concepts but also fosters their ability to apply these ideas to real-world chemical scenarios.

Through the integration of technological tools, active learning methodologies, and real-world context, teachers can effectively address the conceptual difficulties associated with learning atomic orbitals and hybridisation (Oladejo et al., 2021). These approaches not only improve students' mastery of these foundational concepts but also enhance their overall understanding of chemical bonding and molecular behaviour, preparing them to apply their knowledge across diverse chemical contexts.

Despite these strategies, misconceptions about atomic orbitals and hybridisation remain significant barriers to students' conceptual understanding in chemistry. These misconceptions often arise from oversimplified models (Rajpoot et al., 2022), a lack of exposure to quantum mechanical principles (Orchin et al., 2005), over-simplification of concepts of atomic orbitals and hybridisation (Mawutor & Adu-Gyamfi, 2025), and the difficulty in visualising abstract concepts (Necor, 2018). One common misconception is that atomic orbitals are fixed, circular paths for electrons, like planetary orbits (Hanson et al., 2012). This misunderstanding is rooted in early exposure to the Bohr model of the atom, where electrons are depicted as particles moving in defined orbits (Stefani & Tsaparlis, 2009). In contrast, atomic orbitals represent probabilistic regions of space where electrons are most likely to be found, a concept rooted in quantum mechanics. The probabilistic nature of atomic orbitals is challenging for students to grasp, especially when taught using static models that fail to convey the dynamic behaviour of electrons (Dayal & Ali-Chand, 2022).

Additionally, students often misinterpret the shapes of orbitals, assuming that all orbitals share similar geometries, or they misunderstand the concept of nodal planes, confusing them with voids instead of recognising them as mathematical constructs (Nakiboglu, 2003; Stefani & Tsaparlis, 2009; Zoller, 1990). As these difficulties persist, there was the need to explore the factors associated with students underperforming in atomic orbitals and hybridisation, especially among female chemistry students in upper-secondary school.

Underrepresentation of Female Students in Science

Research on gender in education demonstrates that disparities persist, with female students remaining underrepresented. According to a recent United Nations report (2025), women continue to have limited access to educational and career opportunities at the lower and upper-secondary school levels, particularly in sub-Saharan Africa, Northern Africa, and Western Asia. Notably, only 26 out of 121 countries have achieved progress toward

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gender equality, which remains a crucial component of SDG5 (UN, 2025). Bridging this gap is crucial. The report noted a rise in female enrolment, but progress is slow. Student learning outcomes are declining, and gender inequalities, particularly affecting females, persist (UN, 2025).

Furthermore, Siani et al. (2022) asserted that although multiple research interventions have sought to address gender bias, disparities remain evident within science education. Female students continue to be underrepresented in these disciplines, even with female scientists acting as role models for aspiring female learners. Similarly, a study conducted in Nigeria by Rahama et al. (2024) revealed that male students outperformed female students in chemistry concepts. As a result, the authors suggested that teachers participate in workshops on gender-sensitive teaching strategies to help female students improve and find greater motivation in learning chemistry. Irakoze et al. (2021) also indicated that male students performed better than their female counterparts in chemistry. This low performance was attributed to female students' low confidence in learning chemistry concepts and the lack of female role models in science to motivate them.

Hence, this research aimed to examine the factors associated with weak conceptual understanding of female chemistry students in learning atomic orbitals and hybridisation at the upper-secondary school level. The research then answered the following research question:

What factors are associated with female chemistry students' conceptual understanding of atomic orbitals and hybridisation?

Research Methodology

Design

To examine the factors associated with female chemistry students' conceptual understanding of atomic orbitals and hybridisation, a pragmatist approach to scientific inquiry was adopted. Pragmatism was chosen to enable the triangulation of quantitative and qualitative results, thereby ensuring comprehensive findings that will contribute to the attainment of the goals and targets of SDG5. Accordingly, both quantitative and qualitative methods were utilised for data collection and analysis within an 8-week period.

Among pragmatist approaches, this research utilised a methodological triangulation mixed methods design, integrating both qualitative and quantitative methodologies within a single investigation to provide comprehensive insights (Creswell, 2014; Creswell & Plano Clark, 2018) into the factors associated with female chemistry students' conceptual understanding of atomic orbitals and hybridisation. Consequently, multiple research methods were employed to address the study's research question. The advantage of using methodological triangulation was that it allowed the researchers to avoid the flaws in the quantitative methods with the qualitative methods and vice versa in examining the factors associated with female chemistry students' conceptual understanding of atomic orbitals and hybridisation in upper-secondary school. That is, the evidence provided by the quantitative data was only credible in the light of the qualitative data and vice versa. This was the researchers' belief to ensure high-quality data for rigorous research into factors associated with female students' conceptual understanding of atomic orbitals and hybridisation. An illustration of methodological triangulation mixed methods for this exploration can be observed in Figure 1.

Quantitative Phase

In a cross-sectional survey, quantitative data were collected to identify factors associated with difficulties female chemistry students have in learning atomic orbitals and hybridisation. That is, in this cross-sectional survey, a self-developed questionnaire was used to collect quantitative data on students' motivation to learn and factors associated with their understanding of atomic orbitals and hybridisation. The quantitative data collected using questionnaires were explored using means, standard deviations, and factor analysis. Specifically, the exploratory factor analysis was used to explore the dataset on factors associated with female chemistry students' conceptual understanding.

Qualitative Phase

In the cross-sectional survey, following the administration of the questionnaire, the researchers engaged some students in interviews as part of a methodological approach to triangulate data obtained during the quantitative

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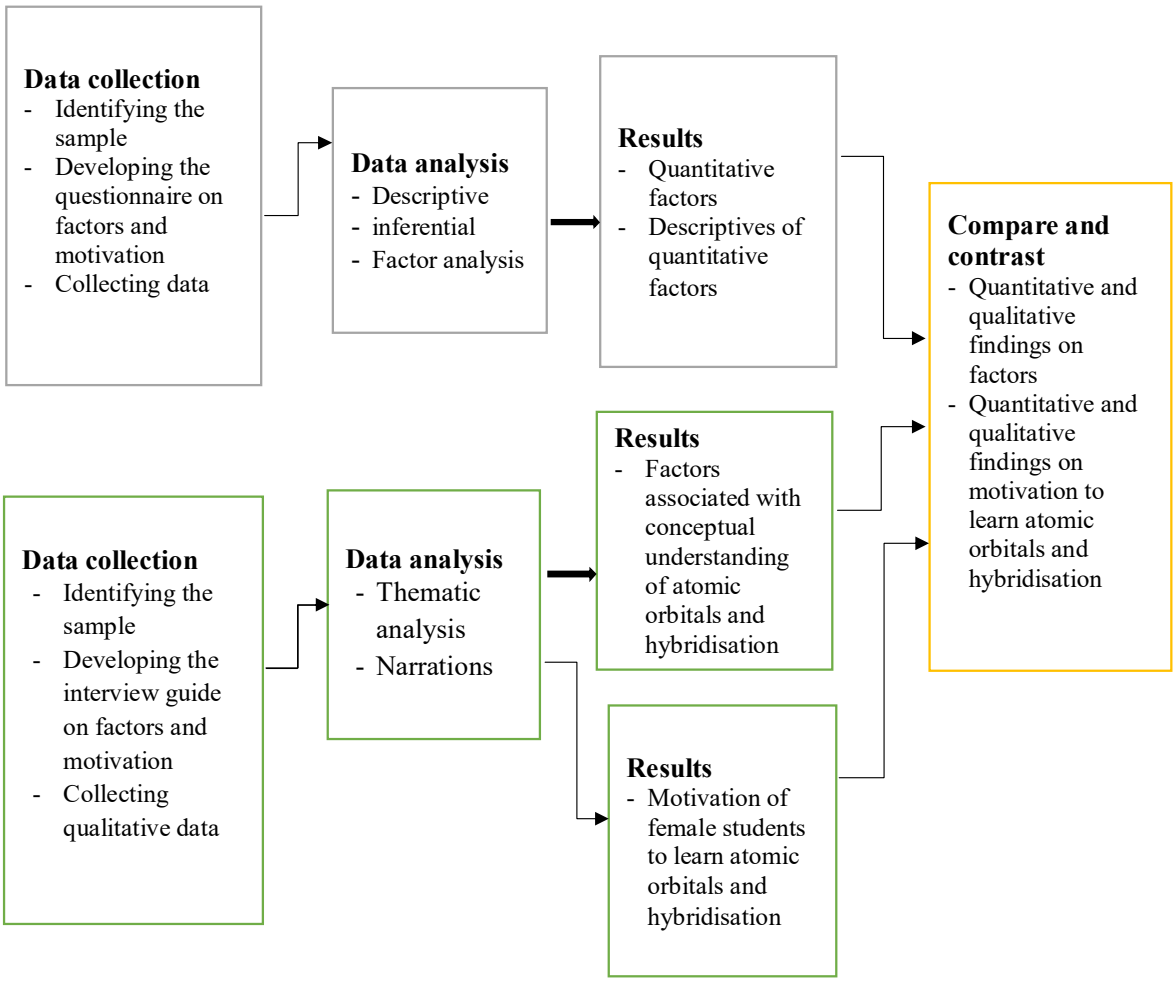
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phase. Ideally, the objective of the researchers was to include all female participants from the quantitative phase in the qualitative component; however, the demands of conducting interviews limited this possibility. Additionally, data saturation was achieved during the interviews, at which point it was no longer methodologically justified to proceed further. The interview dataset was examined using thematic analysis and narrative methods to examine female chemistry students' conceptual understanding, the factors associated with this understanding, and their motivation in learning about atomic orbitals and hybridisation. The qualitative results were integrated with the quantitative results to enhance triangulation of the research.

Interpretation Phase

Initially, quantitative findings from the results of the questionnaires about factors and motivations were analysed alongside relevant literature to identify what influences female chemistry students' conceptual understanding of atomic orbitals and hybridisation. Next, qualitative findings from interviews were interpreted with reference to the same literature. These qualitative and quantitative findings were then integrated by comparing themes and patterns, which served to confirm the quantitative results (Creswell, 2014) and gave deeper insight into the factors associated with students' conceptual understanding. This comprehensive approach supported the research's conclusions.

Figure 1
Methodological Triangulation Mixed Methods for Exploring Factors Associated with Students' Conceptual Understanding of Atomic Orbitals and Hybridisation



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Sample

The research took place in Cape Coast Metropolis, the capital of Ghana's Central Region. As reported by the 2021 population and housing census, the Metropolis has 189,925 residents, comprising 48.9% males and 51.1% females (Ghana Statistical Service, 2024). The area hosted a variety of educational institutions designed to enhance citizens' knowledge, skills, and attitudes. These included two universities, a nursing and midwifery college, and a teacher training college. For secondary education, Cape Coast Metropolis was notable for having two prestigious all-female upper-secondary schools, which were well-known across Ghana among those interested in upper-secondary education.

Seven schools – five co-educational and two all-female – were purposively chosen from 11 possible schools to participate in this research. Additionally, second-year female chemistry students from these seven schools were selected, as their prior experience with atomic orbitals and hybridisation during their first year provided valuable insights. A total of 545 female chemistry students from all-female schools and 295 from co-educational schools, resulted in 840 eligible students for this research. Based on Krejcie and Morgan (1970), an optimal sample size would be 265; however, 304 female chemistry students ultimately took part in this research. Specifically, 178 female chemistry students from the all-female schools and 126 from the co-educational schools were selected using proportionate sampling approaches. After collecting quantitative data, 50 female chemistry students were conveniently selected for interviews to triangulate the findings. This convenience sampling procedure helped to ensure diversity of perspectives from different school types.

Instruments

Two instruments, a questionnaire and an interview guide, were used for this research. These were the atomic orbitals and hybridisation questionnaire and the atomic orbitals and hybridisation structured interview guide.

Atomic orbitals and hybridisation questionnaire (AOHQ)

AOHQ was a self-developed one by the researchers. AOHQ was used to collect data on motivation and other factors associated with female students' learning difficulties in atomic orbitals and hybridisation. AOHQ comprised three sections, A, B, and C, contributing to 63 items (Appendix A). Section A consisted of three items on students' demographics based on their school type and age. Section B comprised 35 closed-ended items to be administered to students. The 35 items helped in examining the relationship between female students' motivation and their academic performance in atomic orbitals and hybridisation. These items were rated on a 7-point Likert scale, with 1 indicating the lowest motivation and 7 the highest. Section C comprised 25 closed-ended items on other factors associated with female students' conceptual understanding of atomic orbitals and hybridisation. The 25 items were also rated on a 7-point Likert scale, with 1 indicating the lowest agreement and 7 the highest.

Validity and reliability of the AOHQ: AOHQ was developed by the researchers, utilising insights from the existing literature. Prior to pilot testing, this instrument underwent proofreading and a critical review by an experienced chemistry educator in the Department of Science Education at the University of Cape Coast to ensure its appropriateness and effectiveness in eliciting accurate responses from female chemistry students. Following these recommendations, both the quality of the items and the scope of the questionnaire were refined. AOHQ was then pilot-tested with 20 SHS 2 female chemistry students from both all-female and co-educational schools in Kumasi Metropolis. Subsequently, the Cronbach alpha coefficient was calculated at .97, indicating a high level of reliability for the instrument.

Atomic orbitals and hybridisation structured interview guide (AOHSIG)

AOHSIG was administered to students as a data collection instrument. Developed by the researchers, AOHSIG comprised five fundamental items (Appendix B). The items addressed challenges encountered by students while learning the concepts of atomic orbitals and hybridisation, resources utilised during the learning process, strategies employed to overcome these challenges, and student motivation in learning atomic orbitals and hybridisation. This qualitative instrument provided comprehensive insights into the factors associated with female chemistry students when learning atomic orbitals and hybridisation.

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Validity and reliability of AOHSIG: AOHSIG was reviewed by colleagues in the Department of Science Education at the University of Cape Coast to assess its clarity and determine whether the items would elicit appropriate responses from students. Researchers read each item verbatim to all participating students during interviews. Student responses were recorded and later transcribed to ensure accuracy in capturing their statements. Themes were extracted from the transcribed data to supplement findings from AOHQ. These themes, along with representative sample statements, were provided to two qualitative researchers for verification of the thematic relevance. Feedback received from the qualitative experts was incorporated into the analysis.

Procedures

Prior to data collection, the research protocols were submitted to the University of Cape Coast Institutional Review Board Secretariat for ethical clearance. The Board approved the research protocols with reference ID, UCCIRB/CES/2024/139. Permission was obtained from both the school principals and the heads of science departments at the selected institutions. The science department heads and chemistry teachers were informed about the research's objectives and procedures to ensure transparency and foster effective collaboration prior to data collection. Data were collected in person by the researchers to maintain integrity and prevent any potential malpractice or compromise.

The researchers administered AOHQ to female chemistry students, ensuring that each student completed the work individually and responded based on their own understanding of conceptual difficulties related to atomic orbitals and hybridisation in upper-secondary school. The quantitative data from the AOHQ helped explore the factors associated with these students' conceptions of atomic orbitals and hybridisation. Additionally, qualitative data collected through AOHSIG narratives provided further depth to the quantitative results concerning the factors associated with female chemistry students' conceptual understanding of atomic orbitals and hybridisation.

Data Analysis

Results for factors from the AOHQ were explored using exploratory factor analysis to answer the research question. For items on other factors on the AOHQ, a calculated mean score of 1.0 to 1.4 indicated lowest level of agreement, 1.5 to 2.4 indicated lower level of agreement, 2.5 to 3.4 indicated low level of agreement, 3.5 to 4.4 indicated moderate level of agreement, 4.5 to 5.4 indicated high level of agreement, 5.5 to 6.4 indicated higher level of agreement and 6.5 to 7.0 indicated highest level of agreement.

The interview data were transcribed and systematically compared to identify patterns and themes. The researchers thoroughly reviewed the responses to gain insights into the contributions of female chemistry students. Student responses were coded and grouped according to thematic similarities, ensuring that comparable responses were categorised under the same theme.

Research Results

Factors Associated with Female Students' Conceptual Understanding of Atomic Orbitals and Hybridisation

To account for the factors associated with female chemistry students' conceptual understanding of atomic orbitals and hybridisation, 25 items (Items 38 to 62) on the AOHQ were subjected to principal component analysis (PCA). To be assured that PCA was the right call in this exploration, first, the Kaiser Meyer Olkin (KMO) measure was assessed and found to be .911, indicating excellent sampling adequacy. Bartlett's test for sphericity was also significant ($p < .001$, $df = 300$), suggesting that the variables exhibited sufficient intercorrelation for analysis. Given the KMO value exceeding *.80* and the significant result of Bartlett's test, the dataset was deemed suitable for factor analysis (Bennett et al., 2023; Pallant, 2020) through PCA. Also, using the Kaiser Criterion (eigenvalue ≥ 1), the data was reduced to 5 components, collectively explaining 62.20% of the total variance. The results are shown in Table 3.

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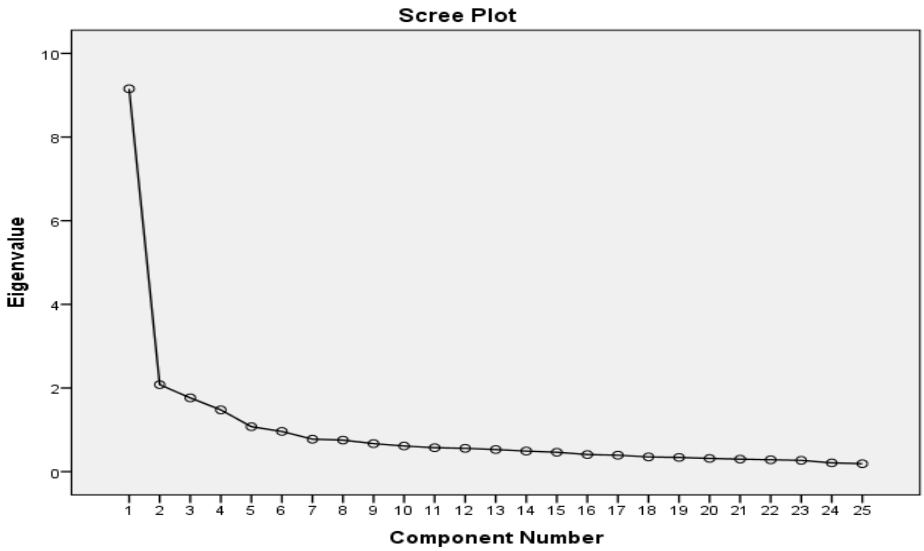
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Table 3
Extraction of Sums of Squared Loadings on Factors Associated with Female Students' Conceptual Understanding of Atomic Orbital and Hybridisation

Component	Total	% of variance	Cumulative %
1	9.154	36.614	36.614
2	2.080	8.321	44.935
3	1.763	7.054	51.988
4	1.476	5.906	57.894
5	1.075	4.300	62.195

To determine the appropriate number of components to retain, the cumulative factor loading 62.20% across five components was evaluated. A scree plot was examined to support this decision, as shown in Figure 2.

Figure 2
A Scree Plot on Female Students' Conceptual Understanding of Atomic Orbitals and Hybridisation



Bennett et al. (2023) and Pallant (2020) suggested that when analysing a scree plot, the inflection point in the plot should be identified, and components above this point should be retained. In Figure 2, the first two components (Components 1 to 2) were selected as the factors explaining female students' conceptual understanding of atomic orbitals and hybridisation. These components, positioned above the elbow, collectively account for 44.94% of the total variance, indicating their stronger explanatory power than the remaining components.

Additionally, to be two double sure of the components to be retained, a parallel analysis (PA) was run to confirm the number of components to be retained (Ledesma & Valero-Mora, 2007). The eigenvalues obtained from the PCA were compared against the criterion values from PA. Components with PCA eigenvalues exceeding the corresponding PA criterion values were retained, while those below the threshold were excluded (Bökeoğlu & Koçak, 2016; Ledesma & Valero-Mora, 2007; Pallant, 2020). The comparative results of the PCA and PA analyses are summarised in Table 4.

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Table 4
Comparing Eigenvalues from PCA to Criterion Values from PA on Factors Associated with Female Students' Conceptual Understanding of Atomic Orbital and Hybridisation

Component number	Actual eigenvalue from PCA	Criterion value from PA	Decision
1	9.154	1.563722	Accept
2	2.080	1.473817	Accept
3	1.763	1.407375	Accept
4	1.476	1.349479	Accept
5	1.075	1.297318	Reject

Of the 5 factors, only four were retained, as seen in Table 4. This was done by comparing the actual eigenvalue from PCA to the criterion value from PA, and factors whose eigenvalues were greater than the criterion values from PA were retained. Hence, four factors were retained to determine the conceptual understanding of female chemistry students in learning atomic orbitals and hybridisation.

Another factor analysis with the help of varimax rotation was performed to give a better interpretation of the factors retained (Pallant, 2020). The results of this varimax rotation are presented in Table 5. To make the final decision on the number of components to retain as the factors associated with female chemistry students' conceptual understanding of atomic orbitals and hybridisation based on Table 5, all loadings with eigenvalues above *.5* and of no negative and cross loadings were considered.

Table 5
Factors Evolving from the Component Matrix on Female Students' Conceptual Understanding of Atomic Orbitals and Hybridisation

Item	Factors			
	1	2	3	4
My chemistry teacher explains extensively on atomic orbitals and hybridisation for students to understand	.791			
My chemistry teacher adopts various strategies when teaching atomic orbitals and hybridisation	.749			
My chemistry teacher makes us solve more problems when teaching atomic orbitals and hybridisation	.735			
I get feedback on time from my chemistry teacher which enhances my strengths in atomic orbitals and hybridisation	.722			
My chemistry teacher explains more about difficult concepts on hybridisation and atomic orbitals when I do not understand	.695			
My teacher uses teaching and learning materials when teaching atomic orbitals and hybridisation	.688			
My chemistry teacher relates well with students	.650			
I gain instructional guidance from my chemistry teacher when I find some concepts difficult in learning hybridisation and atomic orbitals	.628			
I am given a lot of assignments on hybridisation and atomic orbitals to give me better understanding	.627			
I am given a lot of class exercises on hybridisation and atomic orbitals in class to give me better understanding	.621			
My chemistry teacher recommends textbooks on atomic orbitals and hybridisation for further studies	.596			
My chemistry teacher engages us in small group discussions during teaching and learning hybridisation and atomic orbitals	.558			

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Item	Factors			
	1	2	3	4
I use my textbook as reference when learning hybridisation and atomic orbitals		.747		
I believe hybridisation helps explain molecular shapes		.719		
I believe understanding atomic orbitals is essential for chemistry		.610		
I do have access to reading materials on atomic orbitals and hybridisation		.575		
I make summary notes on atomic orbitals and hybridisation to review before exams		.524		
I revise concepts such as atomic orbitals before learning hybridisation		.502		
I find hybridisation theory interesting			.707	
I solve more problems on hybridisation and atomic orbitals after class to give me better understanding			.603	
It is easy to solve problems on hybridisation and atomic orbitals			.594	
Atomic orbitals diagrams help me visualise bonding			.591	
Understanding atomic orbitals improves my overall chemistry knowledge			.530	
I perceive hybridisation as a difficult subject				.873
I perceive atomic orbitals as a difficult subject				.864
% variance explained	**23.874**	**14.272**	**12.997**	**6.752**
Cumulative % Variance explained	**57.894**			

Following the parallel analysis (PA), the results presented in Table 5 indicated the retention of four factors. However, the fourth factor included only two items. According to Sarmento and Costa (2017), a factor should comprise at least three items to be retained. Consequently, the fourth factor was excluded, resulting in the retention of three factors associated with female chemistry students' conceptual understanding of atomic orbitals and hybridisation. After a thorough and systematic review of the items associated with each of these three factors, appropriate thematic labels were assigned to reflect the key aspects associated with female chemistry students' conceptual understanding of atomic orbitals and hybridisation. The themes identified were teachers' pedagogical practices, self-directed learning, and motivational beliefs.

Teachers' Pedagogical Practices

This theme addresses the comprehensive utilisation of instructional strategies, pedagogical methods, and educational resources by chemistry teachers to enhance female chemistry students' conceptual understanding of chemistry concepts, such as atomic orbitals and hybridisation, as well as their academic performance. These practices include providing thorough explanations, employing a variety of teaching techniques, posing insightful questions, assigning targeted exercises, and recommending supplementary materials. The objective of effective pedagogy is to elucidate complex concepts and promote active student engagement, thereby supporting a scientific understanding of difficult concepts like atomic orbitals and hybridisation.

Results from Table 6 showed that for items under pedagogical practices, female chemistry students had a moderate agreement with an average mean of 4.2 (*SD* = 2.037). From the perspective of the standard deviation, which happened to be very large compared to the mean, students could be described as varying in their agreement on how teachers' pedagogical practice relates to learning atomic orbitals and hybridisation. This is in line with the study of Sibomana et al. (2021) that teachers' teaching practices contribute to the achievements of students. For instance, the item on 'my chemistry teacher explains extensively on atomic orbitals and hybridisation for students to understand', revealed that at a mean of 4.3 (SD = 2.053), female chemistry students had a moderate level of agreement with their chemistry teachers explaining extensively concepts on atomic orbitals and hybridisation.

To confirm this finding, 50 students were selected to participate in a structured interview using AOHSIG on problems encountered when learning atomic orbitals and hybridisation. Some female chemistry students revealed that some practices adopted by teachers influence their studies. For instance, a student reported that:

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Table 6
Female Students' Level of Agreement on Pedagogical Practices of their Teachers (N=304)

Item	*LSA*	*LWA*	*LA*	*MA*	*HA*	*HRA*	*HSA*	*M*	*SD*
	n (%)								
My chemistry teacher explains extensively on atomic orbitals and hybridisation for students to understand	42 (13.8)	29 (9.5)	37 (12.1)	49 (16.1)	44 (14.4)	40 (13.1)	64 (21.0)	4.3	2.053
My chemistry teacher adopts various strategies when teaching atomic orbitals and hybridisation	33 (10.8)	24 (7.9)	45 (14.8)	48 (15.7)	42 (13.8)	47 (15.4)	66 (21.6)	4.5	1.983
My chemistry teacher makes us to solve more problems when teaching atomic orbitals and hybridisation	35 (11.5)	23 (7.5)	40 (13.1)	37 (12.1)	45 (14.8)	46 (15.1)	79 (25.9)	4.6	2.050
I get feedback on time from my chemistry teacher which enhances my strengths in atomic orbitals and hybridisation	59 (19.3)	30 (9.8)	52 (17.0)	54 (17.7)	43 (14.1)	30 (9.8)	37 (12.1)	3.8	1.971
My chemistry teacher explains more about difficult concepts on hybridisation and atomic orbitals when I do not understand	51 (16.7)	31 (10.2)	34 (11.1)	53 (17.4)	44 (14.4)	39 (12.8)	53 (17.4)	4.1	2.060
My teacher uses teaching and learning materials when teaching atomic orbitals and hybridisation	51 (16.7)	31 (10.2)	33 (10.8)	46 (15.1)	43 (14.1)	48 (15.7)	53 (17.4)	4.2	2.084
My chemistry teacher relates well with students	32 (10.5)	13 (4.3)	31 (10.2)	41 (13.4)	46 (15.1)	37 (12.1)	105 (34.4)	4.9	2.027
I gain instructional guidance from my chemistry teacher when I find some concepts difficult in learning hybridisation and atomic orbitals	46 (15.1)	25 (8.2)	40 (13.1)	63 (20.7)	43 (14.1)	37 (12.1)	51 (16.7)	4.1	1.985
I am given a lot of assignments on hybridisation and atomic orbitals to give me better understanding	71 (23.3)	35 (11.5)	46 (15.1)	40 (13.1)	41 (13.4)	32 (10.5)	40 (13.1)	3.7	2.083
I am given a lot of class exercises on hybridisation and atomic orbitals in class to give me better understanding	74 (24.3)	40 (13.1)	37 (12.1)	52 (17.0)	43 (14.1)	33 (10.8)	26 (8.5)	3.5	1.984
My chemistry teacher recommends textbooks on atomic orbitals and hybridisation for further studies	39 (12.8)	22 (7.2)	28 (9.2)	34 (11.2)	44 (14.5)	50 (16.4)	87 (28.6)	4.7	2.103
My chemistry teacher engages us in small group discussions during teaching and learning hybridisation and atomic orbitals	46 (15.1)	32 (10.5)	39 (12.8)	44 (14.4)	44 (14.4)	45 (14.8)	55 (18.0)	4.2	2.059
Average								4.2	2.037

***LSA* = Lowest Agreement, *LWA* = Lower Agreement, *LA* = Low Agreement, *MA* = Moderate Agreement, *HA* = High Agreement, *HWA* = Higher Agreement, *HAS* = Highest Agreement**

The explanations I personally receive are not really understood by me. Personally, I am a person who like to learn and understand and not just have to chew it and unfortunately, that method used by my teacher is not helpful for me (Aba).

Atomic orbitals are a really difficult topic, but I really don't get the fact we have to be learning all this like I can't relate to any of these. And for hybridisation, it's a pain in the neck. Since our teacher never bothered to teach us. Always giving us vacation assignments which they wouldn't explain in class. Hybridisation is really not for me (Sandra).

Additionally, Beauty also mentioned that teaching and learning resources should be used to make the concept easier to understand. She recorded that:

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The concept is made to be more abstract which makes it understanding difficult. Therefore, a lot of visual learning skills should be used in teaching atomic orbitals and hybridisation, but visual learning is not common in my school (Beauty).

For items such as, I am given a lot of assignments on hybridisation and atomic orbitals to give me better understanding and I am given a lot of class exercises on hybridisation and atomic orbitals in class to give me better understanding, students also had a moderate level of agreement with means of 3.7 (SD = 2.083) and 3.5 (SD = 1.984) respectively. However, a student, Esther, stated that her chemistry teacher did not give enough examples to explain the concepts to their understanding. She explained that:

Apparently, hybridisation was not taught to our satisfaction. The teacher taught it raw without any examples to work on our own, and we did not understand it very well, therefore, we were not able to answer the questions (Esther).

Others also reported on the fact that they did not see the relevance of the concept learnt in their lives because the teaching of the concept of atomic orbitals and hybridisation lacked the linkage between the classroom setting and everyday life. An excerpt is:

Atomic orbitals are a really difficult topic, but I really don't get the fact we have to be learning all this like I can't relate to any of these. And for hybridisation, like it's a pain in the neck. Since our teacher never bothered to teach us. Always giving us vacation assignment which they wouldn't explain in class. Hybridisation is, really, not for me (Joy).

On the contrary, one of the students shared that the teacher links the concept of atomic orbital and hybridisation to everyday life happenings. An excerpt is:

It sometimes hard to understand but my teacher links it up to our life so there are no issues involved (Adobea).

Self-Directed Learning

This describes how students take charge of their own learning, making use of available resources and seeking help to track and enhance their progress. When students accept such personal responsibility, it can lead to better academic achievement. Results on students' agreement with self-directed learning are presented in Table 7.

The results revealed that students generally had a high level of agreement on their self-directed learning that influences their learning of atomic orbitals and hybridisation (M = 5.0, SD = 1.930). This explains that students had a high level of agreement that their self-directed learning significantly influences their academic performance, as evidenced by the various items in Table 7. For instance, concerning the item, 'I make summary notes on atomic orbitals and hybridisation to review before examinations' revealed that of 304 female chemistry students, 55.4% at a high mean of 4.6 (SD = 1.969) agreed that they make summary notes in aid of reviewing prior to examinations. Similarly, female chemistry students reported a high level of agreement that they use their textbook as a reference when learning hybridisation and atomic orbitals (M = 5.4, SD = 1.857). This explains that female chemistry students believe that using textbooks for revision leads to constructing their knowledge and enhances their understanding of chemical concepts such as atomic orbitals and hybridisation.

Table 7
Students' Level of Agreement on Self-directed Learning (N=304)

Item	LSA		LWA		LA		MA		HA		HRA		HSA		M	SD
	n	%	n	%	n	%	N	%	n	%	n	%	n	%		
I use my textbook as reference when learning hybridisation and atomic orbitals	22	7.2	9	3.8	13	4.3	43	14.1	49	16.1	37	12.1	132	43.3	5.4	1.857
I believe hybridisation helps explain molecular shapes	25	8.2	10	3.3	27	8.9	25	8.2	40	13.1	51	16.7	127	41.6	5.3	1.946
I believe understanding atomic orbitals is essential for chemistry	19	6.2	11	3.6	16	5.2	56	18.4	35	11.5	56	18.4	112	36.7	5.3	1.818
I do have access to reading materials on atomic orbitals and hybridisation	36	11.8	24	7.9	28	9.2	40	13.1	33	10.8	52	17.0	92	30.2	4.8	2.103

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Item	LSA		LWA		LA		MA		HA		HRA		HSA		M	SD
	n	%	n	%	n	%	N	%	n	%	n	%	n	%		
I make summary notes on atomic orbitals and hybridisation to review before exams	34	11.1	24	7.9	26	8.5	52	17.0	55	18.0	46	15.1	68	22.3	4.6	1.969
I revise concepts such as atomic orbitals before learning hybridisation	33	10.8	17	5.6	38	12.5	62	20.3	47	15.4	57	18.7	49	16.1	4.4	1.885
Average															5.0	1.930

Regarding self-directed learning, qualitative results were also presented as a means of methodological triangulation of the quantitative results so far presented. That is, a lot more issues came up as we interacted with the 50 female chemistry students using the AOHSIG. For instance, a student emphasized that:

> *… finding time in my timetable to sit down and learn the atomic orbitals … it helps a lot at times when you learn on your own based on personal notes (Rebecca).*

Another female chemistry student also reported that she used several textbooks for revision to enhance her understanding of atomic orbitals and hybridisation. She recorded that:

> *… I use multiple textbooks and … some personal notes to revise (Ama).*

Similarly, some students, including Aba, explained that there was a need to dedicate more time to personally learn atomic orbitals and hybridisation. She stated that;

> *… read over and use my own reading materials, dedicate more time … to understand better … (Aba).*

Motivational Beliefs

This theme describes female chemistry students' confidence in their ability to overcome challenges and reach their goals. Motivational beliefs are the internal drive to engage in activities and pursue objectives that are meaningful, enjoyable, and aligned with personal values. This perspective shapes how female chemistry students tackle learning tasks, their level of classroom engagement, their perseverance through difficulties, and ultimately, their academic achievements. The means of the level of agreement on motivational beliefs are presented in Table 8.

As shown in Table 8, students on average had a moderate level of agreement regarding their motivational beliefs (M = 4.3, SD = 1.960). This suggested how moderate intrinsically motivated female chemistry students were when learning atomic orbitals and hybridisation. However, the relatively high standard deviation indicated significant variation in their motivational beliefs, reflecting diverse experiences and attitudes among students. For instance, students had a relatively moderate agreement on finding hybridisation as an interesting concept to learn at a mean of 4.1 (SD = 2.099). This implied that the female chemistry students had variable motivational beliefs about learning the concept of hybridisation, with some students finding it interesting, while others did not. In that, factors such as teaching strategies or prior knowledge may play a significant role in shaping students' interest and engagement. Also, female chemistry students had relatively moderate self-determined motivation regarding how easy it was to solve problems on hybridisation and atomic orbitals, with a mean of 3.8 (SD = 1.809). This was further evident by responses reported by female chemistry students on our interactions during interviews using AOHSIG. From the interviews, the variability in the moderate motivational beliefs came up strongly. Some excerpts are:

> *Atomic orbitals and hybridisation are interesting topics. Though not so complex, it is a bit difficult to remember since we keep learning new things. However, after doing revision and learning some strategies such as forming acronyms, it becomes very easy for me (Abiba).*
>
> *… difficulty to understand the hybridisation but I just push myself sometimes (Akua).*
>
> *Atomic orbitals I would say it is cool but with the hybridisation, I would say it is virtual so understanding it is difficult, I will learn it with time (Ama).*

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Table 8
Students' Level of Agreement on Self-determined Motivation (N=304)

Item	LSA		LWA		LA		MA		HA		HRA		HSA		M	SD
	n	%	n	%	n	%	n	%	n	%	n	%	n	%		
I find hybridisation theory interesting	57	18.7	25	8.2	44	14.4	47	15.4	35	11.5	45	14.8	52	17.0	4.1	2.099
I solve more problems on hybridisation and atomic orbitals after class to give me better understanding	33	10.8	30	9.8	48	15.7	70	23.0	54	17.7	31	10.2	39	12.8	4.1	1.806
It is easy to solve problems on hybridisation and atomic orbitals	45	14.8	36	11.8	46	15.1	75	24.6	43	14.1	34	11.1	26	8.5	3.8	1.809
Atomic orbitals diagrams help me visualise bonding	39	12.8	24	7.9	31	10.2	54	17.7	41	13.4	45	14.8	71	23.3	4.8	2.041
Understanding atomic orbitals improve my overall chemistry knowledge	35	11.5	22	7.2	27	8.9	51	16.7	44	14.4	40	13.1	86	28.2	4.7	2.043
Average															4.3	1.960

Discussion

Findings on teachers' pedagogical practices reveal that female chemistry students generally show moderate agreement with the effectiveness of teachers' pedagogical practices in aiding their understanding of atomic orbitals and hybridisation. This finding is consistent with the work of Sibomana et al. (2021), where diverse and active teaching strategies help in improving student academic performance, as detailed explanations, probing questions, and interactive teaching methods contribute positively to female chemistry students' conceptual understanding. No wonder female chemistry students agree that when their chemistry teachers explain extensively on atomic orbitals and hybridisation, they understand. This addresses the significant role that clear and comprehensive instruction plays in making complex concepts accessible, aligning with research suggesting that active engagement through teaching enhances student understanding (Cardullo et al., 2018). Also, teacher pedagogical practices are a factor in female chemistry students' learning of atomic orbitals and hybridisation, possibly because of the feedback provided to them by teachers. That is, feedback is a form of motivation to students (Azizah et al., 2021), especially if it is timely (Cardullo et al., 2018), where female chemistry students in this current study moderately agree that it is timely. As teachers provide students with timely feedback, they will need to recommend the most appropriate textbooks on atomic orbitals and hybridisation because female chemistry students highly agree that one of the pedagogical practices of their teachers is the recommendation of the most appropriate textbooks, which they will rely on (Hashweh, 2005) in learning chemistry concepts. However, the concepts of atomic orbitals and hybridisation are not covered in detail in textbooks. They just look simplistic, and textbook presentations on atomic orbitals and hybridisation do not help students to scientifically understand the concepts (Salame et al., 2022). In addition, regarding teachers' pedagogical practices, students most highly agree that teachers relate well with them. Students perceive this relationship as a contribution to their learning of atomic orbitals and hybridisation. Hence, chemistry teachers should adopt the most appropriate relationship techniques that will positively influence female chemistry students' learning of atomic orbitals and hybridisation, and chemistry in general. Such relationships create a learning environment, where inclusivity is assured, eliminating gender stereotypes to motivate students learn (Cheong, 2010; Dweck, 2020) atomic orbitals and hybridisation.

Similarly, the finding that female chemistry students' self-directed learning is at a high level of agreement among students is worth noting as one of the factors associated with students' learning atomic orbitals and hybridisation. That is, students believe in the importance of their efforts in contributing to an improved academic

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performance. Hence, chemistry teachers are recommending the most appropriate textbooks for female students to make references to when learning atomic orbitals and hybridisation could be one of the important steps to be taken. Students agree that their self-directed learning is based on making references to textbooks. Female chemistry students have a high level of agreement to their attempt of referring to reference notes and using textbooks to aid in understanding chemical concepts such as atomic orbitals and hybridisation. This highlights the importance of strategies to encourage self-directed classroom learning where students take responsibility for their academic performance, as supported by Khalid et al. (2020) and Yurdal & Toraman (2023), who found that self-directed learning has a positive influence on the academic performance of students.

Motivational beliefs, as a factor associated with female chemistry students' conceptual understanding of atomic orbitals and hybridisation, are moderately associated with students' agreement that they can participate in classroom activities, achieve their goals, overcome learning-related challenges, and improve their academic performance in atomic orbitals and hybridisation. This reflects a sense of self-efficacy, which is known to be a powerful motivator for academic achievement (Bandura, 1997). However, the relatively high variability in motivational beliefs among students points to individual differences in confidence levels, which may be associated with factors such as teaching strategies or prior knowledge (Schunk & DiBenedetto, 2020). For example, when students are asked whether they find hybridisation interesting, some find the concept engaging, while others do not, suggesting that engagement with the material can vary widely. This variation is consistent with the findings of Pajares (2002) that self-confidence can vary significantly based on prior academic experiences, hence a moderate agreement among female chemistry students on motivational beliefs with high variability is something worthy of considering by other researchers interested in learning atomic orbital and hybridisation in schools and colleges. Also, seeing motivational beliefs as a factor of students' conceptual understanding of atomic orbitals and hybridisation, contributes to students' ability to visualise the atomic and hybrid orbitals. Consequently, female chemistry students who find it difficult to visualise molecular structures (Necor, 2018) fail to scientifically understand the chemistry therein (Konicek-Moran & Keeley, 2016), which could be demotivating to them because visualisation tools help to bridge the gap between abstract concepts, like atomic orbitals and hybridisation and tangible visualisations (Boachie et al., 2023). If female chemistry students see visualising chemistry abstract concepts as motivational beliefs, then chemistry teachers should adopt instructional strategies that make use of visualisation tools to help female chemistry students develop the scientific understanding of atomic orbitals and hybridisation.

Conclusion and Implications

In this research, female chemistry students self-reported on factors associated with their difficulties in conceptualising atomic orbitals and hybridisation in upper-secondary school. In doing so, the research has shown that there are some factors that are associated with female students' conceptual understanding of atomic orbitals and hybridisation. These included teachers' pedagogical practices, self-directed learning, and motivational beliefs as revealed. Hence, female chemistry students' conceptual understanding may not only be affected by the school type that individual attended but the instructional strategies and resources available to the chemistry teacher (being the pedagogical practices), female chemistry students taking responsibility of their learning (being self-directed learning), and female chemistry students with the belief or assurance that they can overcome any learning difficulties (motivational beliefs) in atomic orbitals and hybridisation.

Given that three key factors, teacher pedagogical practices, self-directed learning, and motivational beliefs, were identified as associated with students' conceptual understanding, it is recommended that chemistry educators and researchers further investigate the dynamics of teacher-student interactions involving these factors. Such inquiry may provide valuable insights for enhancing the conceptual understanding of female chemistry students, particularly in the context of learning atomic orbitals and hybridisation. Furthermore, educators and researchers may investigate the primary factors that most strongly predict conceptual understanding of atomic orbitals and hybridisation among female chemistry students. It is essential that governments and non-governmental organisations committed to achieving the goals and targets of SDG5 offer appropriate support to female chemistry students. Such support should be designed to encourage their engagement with concepts such as atomic orbitals, hybridisation, and other key chemistry concepts.

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Limitations

Using a cross-sectional survey to gather both quantitative and qualitative data on factors associated with upper-secondary school female students' conceptual understanding of atomic orbitals and hybridisation in Cape Coast Metropolis limits the generalisability of these findings to all Ghanaian female chemistry students. Additionally, although interviews were conducted, the study primarily relied on self-reported data from the participants, hence female chemistry students could have been biased and may not have fully disclosed their challenges and experiences on learning atomic orbitals and hybridisation. Future research could address these limitations by employing longitudinal designs, expanding the sample to include diverse geographical locations.

Declaration of Interest

The authors declare no competing interest.

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Appendix A

Atomic Orbitals and Hybridisation Questionnaire

Dear student,

This questionnaire seeks to solicit your perspectives on motivation and other factors attributing to female students' understanding of atomic orbitals and hybridisation. Your participation will imply you consenting to be part of this study.

Please **DO NOT** write your **name** and the **name of your school,** as your responses will be confidential and used for research purposes only.

You are required to tick in the box against each statement by ranking from LOWEST to the HIGHEST.

Your contributions are greatly appreciated.

Section A: Demographics

1. School Type: Single-sex [ ] Co-educational [ ]
2. Age: 10 – 15 years [ ] 16 – 20 years [ ] Above 20 years [ ]

Section B

No.	Statements	1	2	3	4	5	6	7
		Arrange from lowest (1) to highest (7)						
4	I find it exciting to study atomic orbitals.							
5	I find it exciting to study hybridisation.							
6	I see the relevance of atomic orbitals and hybridisation in my everyday life.							
7	My colleagues encourage me to study atomic orbitals and hybridisation hard.							
8	I dedicate more time to study atomic orbitals.							
9	I dedicate more time to study hybridisation.							
10	I learn hard to get a good grade in atomic orbitals.							
11	I learn hard to get a good grade in hybridisation.							
12	I feel motivated when my teacher teaches atomic orbitals.							

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No.	Statements	1	2	3	4	5	6	7
13	I feel motivated when my teacher teaches hybridisation.							
14	I am confident when I am discussing with my peers on hybridisation and atomic orbitals concepts.							
15	I use various strategies to enhance learning hybridisation well.							
16	I am confident I will do well in atomic orbitals.							
17	I am confident I will do well in hybridisation.							
18	I am confident when I am solving problems in atomic orbitals.							
19	I am confident when I am solving problems in hybridisation.							
20	I set goals before I do my personal studies.							
21	I do well in atomic orbitals because I follow my written goals for the term.							
22	I do well in hybridisation because I follow my written goals for the term.							
23	I like to do better than other students in atomic orbitals tests.							
24	I like to do better than other students in hybridisation tests.							
25	I set goals before the term begins.							
26	My chemistry teacher involves all students during teaching and learning to make us focused.							
27	My chemistry teacher motivates us to learn through our interactions as students in the lessons.							
28	My chemistry teacher urges us on by allowing students to ask questions.							
29	I get the opportunity to solve problems on atomic orbitals in the classroom.							
30	I get the opportunity to solve problems on hybridisation in the classroom.							
31	I do well in atomic orbitals because my chemistry teacher involved us in group discussion.							
32	I do well in hybridisation because my chemistry teacher involved us in small group discussion.							
33	I do well in atomic orbitals and hybridisation as I have access to instructional materials such as notes, reference books, and the internet.							
34	I do well in hybridisation because my chemistry teacher links it to previous lessons, such as atomic orbitals.							
35	During chemistry lessons, I can participate freely as my teacher creates a positive environment.							
36	My chemistry teacher asks probing questions on atomic orbitals and hybridisation to motivate us learn chemistry.							
37	I get good scores (marks) in hybridisation and atomic orbitals test because of my attitude towards my chemistry teacher.							
38	Scoring a high mark in hybridisation and atomic orbitals matters to me.							

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No.	Statements	1	2	3	4	5	6	7
Section C Factors Affecting students' performance		**Arrange from lowest (1) to highest (7)**						
39	My chemistry teacher adopts various strategies when teaching atomic orbitals and hybridisation.							
40	My teacher uses teaching and learning materials when teaching atomic orbitals and hybridisation.							
41	I get feedback on time from my chemistry teacher which enhances my strengths in atomic orbitals and hybridisation.							
42	My chemistry teacher explains extensively on atomic orbitals and hybridisation for students to understand.							
43	I make summary notes on hybridisation and atomic orbitals to review before exams.							
44	I revise concepts such as atomic orbitals before learning hybridisation.							
45	My chemistry teacher relates well with students.							
46	My chemistry teacher makes us solve more problems when teaching atomic orbitals and hybridisation.							
47	I use my textbook as reference when learning hybridisation and atomic orbitals.							
48	My chemistry teacher recommends textbooks on atomic orbitals and hybridisation for further studies.							
49	I believe hybridisation helps explain molecular shapes.							
50	My chemistry teacher engages us in small group discussions during teaching and learning hybridisation and atomic orbitals.							
51	I do have access to reading materials on hybridisation and atomic orbitals.							
52	My chemistry teacher explains more about difficult concepts on hybridisation and atomic orbitals when I do not understand.							
53	I perceive hybridisation as a difficult concept.							
54	I perceive atomic orbitals as a difficult concept.							
55	It is easy to solve problems on hybridisation and atomic orbitals.							
56	I believe understanding atomic orbitals is essential for chemistry.							
57	I solve more problems on hybridisation and atomic orbitals after class to give me better understanding.							
58	I am given a lot of class exercises on hybridisation and atomic orbitals in class to give me better understanding.							
59	I am given a lot of assignments on hybridisation and atomic orbitals to give me better understanding.							
60	I gain instructional guidance from my chemistry teacher when I find some concepts difficult in learning hybridisation and atomic orbitals.							
61	I find hybridisation theory interesting.							
62	Atomic orbital diagrams help me visualise bonding.							
63	Understanding atomic orbitals improves my overall chemistry knowledge.							

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Appendix B

Atomic Orbitals and Hybridisation Structured Interview Guide

This interview guide seeks to solicit from students your conceptions of atomic orbitals and hybridisation. Your responses will be used for research purposes only and will be handled confidentially.

1. What are some problems you encounter when learning atomic orbitals and hybridisation?
2. How do you overcome the problems you encounter when learning atomic orbitals and hybridisation?
3. What motivates you to learn atomic orbitals and hybridisation?
4. Are there any other ways to learn atomic orbitals and hybridisation?
5. What resources do you use to learn atomic orbitals and hybridisation?

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