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Effects of Blended Learning on þÿUndergraduate Students Conc Understanding, Engagement, and Epistemological Beliefs in Learning Chemical Bonding and Molecular Geometry Concepts: The Case of Bashir Dar University, Ethiopia

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BAHIR DAR UNIVERSITY

COLLEGE OF EDUCATION

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By

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August, 2026

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A Dissertation Submitted to the Department of Science and Mathematics Education in Fulfillment of the Requirements for the Degree of Doctor of Education in Chemistry Education

By

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August, 2026

Bahir Dar, Ethiopia

Declaration

This is to certify that the thesis entitled "Effect of Blended Learning on Undergraduate Students' Conceptual Understanding, Engagement, and Epistemological Beliefs in Learning Chemical Bonding and Molecular Geometry Concepts: The Case of Bahir Dar University, Ethiopia," was submitted in fulfillment of the requirements for the degree of Doctor of Education in Chemistry Education of the Department of Science and Mathematics Education. Bahir Dar University is a record of original work carried out by me and has never been submitted to this or any other institution to get any other degree or certificate. The assistance and help I Received during the course of this investigation have been duly acknowledged.

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Name of the Candidate	Signature	Date

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Approval of Dissertation for Defense

I hereby certify that I have supervised, read, and evaluated this dissertation entitled "The Effects of Blended Learning on Undergraduate Students' Conceptual Understanding, Engagement, and Epistemological Beliefs in Learning Chemical Bonding and Molecular Geometry Concepts: The Case of Bahir Dar University, Ethiopia" by Woretaw Atinaf Mihretu, prepared under my guidance. I recommend that the dissertation be submitted for oral defense.

Signed by the Examiner Committee

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Approval of Dissertation for the Defense Result

As members of the board of examiners, we examined this dissertation entitled፡ “Effects of Blended Learning on undergraduate Students’ Conceptual Understanding, Engagement, and Epistemological Beliefs in Learning Chemical Bonding and Molecular Geometry Concepts: The case of Bahir Dar University, Ethiopia” by Woretaw Atinaf Mihretu. This is to certify that the dissertation has been accepted in fulfillment of the requirements for the award of the degree of Doctor of Education in Chemistry Education.

Board of Examiners

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Abstract

The main purpose of this study was to examine the effects of Blended learning (BL) on undergraduate students' Conceptual Understanding (CU), engagement (SE), and epistemological beliefs (EBs) in learning Chemical Bonding and Molecular Geometry (CBMG) concepts. To achieve this goal, a mixed research approach was employed. For the quantitative approach, a pretest-posttest non-equivalent control group quasi-experimental design was employed. For the qualitative phase, a phenomenological design was used. The study was conducted at Bahir Dar University in the Amhara National Regional State of Ethiopia. A total of 86 undergraduate students (Male = 59 and Female = 27) participated, with the intervention group (IG; n = 42) taught via the BL approach and the comparison group (CG; n = 44) taught via the Conventional Teaching Method (CTM). A total of nine participants, six from IG and 3 students from CG, participated in the semi-structured interviews. The Three-tier Conceptual Understanding Diagnostic Test (TTCUDT), Student Engagement Scale (SES), and Colorado Learning Assessment and Science Survey (Class-Chem) were administered to both groups as pretest and posttest. Moreover, semi-structured interview questions were administered regarding CU, SE, and EBs after the treatment. The study employed quantitative and qualitative data. Quantitative data were analyzed using IBM SPSS Statistics version 26 and were examined using descriptive and inferential statistics, while qualitative data were analyzed thematically. Findings from both approaches indicated that students who engaged with the BL approach demonstrated greater CU, SE, and more sophisticated EBs than their peers who experienced CTM while learning CBMG concepts. Furthermore, the findings revealed that the BL approach significantly reduced students' MCs and enhanced their confidence. However, no statistically significant gender differences were observed in CU, SE, and EBs within either the intervention or comparison groups. The BL approach has been shown to substantially enhance students’ CU, SE, and EBs regarding scientific knowledge acquisition. Furthermore, the findings of this study revealed that, within the BL environment, students’ CU was significantly correlated with their engagement and EBs; moreover, increased SE contributed to the development of more sophisticated EBs. Although the implementation of BL has a significant positive effect on students' CU, SE, and EBs related to knowledge, various challenges were encountered in the learning environment due to technological, pedagogical, student-related, and institutional factors. Adopting carefully designed

BL approaches enables educational institutions to improve teaching effectiveness and SE, while contributing to the growing evidence on the pedagogical impact of BL in Science, Technology, Engineering, and Mathematics (STEM) education. Drawing on these findings, further implications for practice and recommendations for future research are advanced.

Keywords: *Technology-enhanced learning; Conceptual change; Active learning; Three-tier Diagnostic assessment; Science Beliefs; Quasi-experimental design*

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LISTS OF ABBREVIATIONS AND ACRONYMS

AMPC	Atomic and Molecular Perspective of Chemistry
ANCOVA	Analysis of Covariance
AT	All Tiers
BehSE	Behavioral Student Engagement
BL	Blended Learning
BT	Both Tiers
CBMG	Chemical Bonding and Molecular Geometry
CC	Conceptual Connection
CL	Conceptual Learning
CLT	Cognitive Load Theory
CLASS-Chem	Colorado Learning Attitudes about Science Survey for Chemistry
CogSE	Cognitive Student Engagement
CTM	Conventional Teaching Method
CU	Conceptual Understanding
EBs	Epistemological Beliefs
EmSE	Emotional Student Engagement
HEIs	Higher Education Institutions
IBM SPSS	International Business Machines Statistical Package for Social Sciences
ICT	Information Communication Technology
ILIAS	Integrated Learning, Information and Cooperation System
KR-20	Kuder-Richardson Reliability Index
LCMS	Learning Content Management System
MCs	Misconceptions
LMS	Learning Management System
MoE	Ministry of Education
MOODLE	Modular Object-Oriented Dynamic Learning Environment
NEAEA	National Educational Assessment and Examinations Agency
OECD	Organization for Economic Co-operation and Development
OverallEBs	Overall Epistemological Beliefs

OverallSE	Overall Student Engagement
PDF	Portable Document Format
PI	Personal Interest
PISA	Programme for International Student Assessment
PPT	PowerPoint Presentation
PSC	Problem-Solving Conception
PSG	Problem Solving General
PSS	Problem Solving Sophisticated
RWC	Real World Conception
SDT	Self-determination Theory
SE	Student Engagement
SocSE	Social Student Engagement
SME	Sense Making/Effort
STEM	Science, Technology, Engineering, and Mathematics
TTCUDT	Three Tier Conceptual Understanding Development Test
VSEPR	Valence Shell Electron Pair Repulsion Theory

CHAPTER ONE

1. INTRODUCTION

This chapter of the dissertation includes the background of the study, the statement of the problem, the objectives of the study, and the research questions. It also outlines the significance and the delimitation of the study, as well as the operational definitions of key terms. The background of this study provides context by reviewing the relevant literature and how the research problem emerged. It then presents the problem statement, which clearly identifies the gap the study seeks to address. This chapter also outlines the study's objectives, which define the aims to be achieved, and formulates the research questions that guide the investigation. In addition, it highlights the significance of the study by explaining its potential contributions and beneficiaries and specifies the delimitations of the study by clarifying its scope and boundaries. Finally, this chapter provides operational definitions of key terms to ensure clarity and consistency in the use of concepts throughout the study.

1.1. Background of Study

In today’s complex and dynamic world, nations' development increasingly depends on advancements in science and technology. Consequently, knowledge of science and technology has become indispensable for citizens worldwide to address societal challenges and improve their quality of life. In this context, science education serves as a vital vehicle for cultivating knowledgeable and skillful individuals in nations striving to remain competitive (Gongden et al., 2020). Central to this mission is the development of scientifically literate citizens, which is essential for advancing scientific knowledge and enabling informed decision-making. Learning science supports individuals in understanding and interpreting the natural world, managing risks, contextualizing uncertainty, guiding technological innovation, and planning for the future (Hazelkorn et al., 2015). Accordingly, students’ learning experiences in science education should focus on enhancing scientific literacy to enable meaningful comprehension of scientific phenomena.

Chemistry, as a branch of physical science, examines the composition, structure, and changes that matter undergoes under various conditions. Through continuous scientific and technological advancement, it has emerged as a cornerstone of material progress and an indispensable foundation for modern development (Gluck et al., 2014). In contemporary society, fields such as technology, agriculture, pharmacy, and other production industries are fundamentally built on chemical principles (Eilks et al., 2017). Given its strong connection to everyday life, chemistry offers unique opportunities to understand how science operates and how it relates to society. In this context, chemistry education plays a crucial role in equipping students with the knowledge, skills, and attitudes necessary for self-reliance by applying chemical concepts to real-world processes **(**Udofia & Ekong, 2017**)**. However, students' effectiveness in learning chemistry depends not only on acquiring knowledge but also on their level of engagement and the beliefs they hold about learning.

Conceptual understanding (CU), student engagement (SE), and epistemological beliefs (EBs) are foundational constructs in chemistry education, and recent literature highlights their interdependence in shaping meaningful learning outcomes. CU refers to a deep comprehension of principles and relationships beyond rote memorization; engagement reflects learners' attention, curiosity, motivation, and active participation; and EBs concern learners' views about the nature of knowledge and how it is acquired. Together, these constructs form a triad that determines the depth and quality of student learning. Research indicates that CU enables students to transfer knowledge across contexts and solve novel problems (Claesgens et al., 2009; Holme et al., 2015). SE sustains persistence and promotes deeper cognitive investment, with behavioral, emotional, and cognitive dimensions playing key roles (Wong & Liem, 2022; Zusho, 2017). Meanwhile, EBs shape how learners approach scientific inquiry, with more sophisticated beliefs associated with higher-order reasoning and reflective thinking (Green & Hood, 2013). Collectively, these perspectives suggest that effective chemistry education extends beyond the acquisition of factual knowledge to include the development of critical thinking, motivation, and epistemic awareness, enabling students to apply their understanding in real-world contexts.

Although chemistry has made enormous contributions to our world, its concepts are difficult for students to understand in learning environments (Tümay, 2016a). For this reason, most students may dislike ideas that require more focus when learning chemistry (Ardiansah, 2018). This might influence students' future learning and make them disinterested in chemistry. Therefore, it is important to identify and figure out effective ways of addressing the students' learning difficulties and misconceptions (MCs) in chemistry education (Tsaparlis et al., 2018). Several scholars have identified areas of students' learning difficulties in chemistry education over the past few years. For instance, chemical bonding (Tsaparlis et al., 2019), chemical reactions (Du Toit, 2017), atomic structure (Yan & Talanquer, 2015), chemical equilibrium (Yamtinah et al., 2019), and acid-base reactions (Goss, 2018) were some of the basic themes identified by scholars in the field. These areas share a common connection in the application of chemical phenomena, such as the development of chemical bonds between substances through chemical reactions.

Chemical bonding is one of the key content areas in the chemistry curriculum taught at secondary and tertiary levels (Hunter et al., 2022; Tsaparlis et al., 2019). It is the fundamental concept for understanding all other concepts of chemistry (Mamlok-Naaman et al., 2017). Understanding chemical bonding is associated with many chemistry concepts, such as chemical reactions, molecular structures, thermodynamics, chemical equilibrium, and some physical properties (Vrabec & Prokša, 2016). Understanding chemical bond concepts is important to comprehend the entire chemical process, particularly chemical reactions, and the properties of the substance. Thus, the concepts of chemical bonding must be understood to study most other topics in chemistry (Nahum et al., 2013). Furthermore, molecular geometry constitutes a critical dimension of chemical bonding, as it provides the spatial framework through which the arrangement and interactions of atoms in molecules can be visualized and understood (Gillespie & Popelier, 2003). For this reason, other concepts of chemistry cannot be understood if the learners don't conceptualize the materials of chemical bonding and molecular geometry (CBMG). In this regard, CBMG topics require emphasis to help students develop a deep understanding of these fundamental chemistry concepts within learning environments.

Even though CBMG has tremendous importance, its concepts are abstract and difficult for students to understand (Bergqvist, 2017; Gillespie & Popelier, 2003; Tsaparlis et al., 2019). These learning difficulties have different sources. For instance, the lack of integration across macroscopic, submicroscopic, and symbolic representations of chemical phenomena (Bergqvist et al., 2013; Nimmermark et al., 2016), coupled with students' failure to comprehend the emergent nature of chemical entities, their properties, and interactions (Tümay, 2016a), as well as the absence of appropriate instructional approaches (Beichumila et al., 2022b), constitute major sources of learning difficulties and misconceptions in chemistry, particularly in the domain of CBMG. Moreover, within CBMG, the challenge is compounded by the invisibility of chemical phenomena, since the processes by which atoms, ions, or molecules are held together to form compounds cannot be directly observed (Abd Halim et al., 2013). Thus, the visual representations of chemical phenomena are difficult for students to understand when the appropriate instructional approach is not used (Bergqvist et al., 2013). Similarly, conventional pen-and-paper drawings of molecules are inadequate in capturing the three-dimensional shapes and spatial representations needed to accurately predict their molecular geometry (Kiernan et al., 2021). Furthermore, conducting experiments in the laboratory is one of the most effective ways to acquire in-depth knowledge of chemistry (Satam et al., 2019). However, merely listening to theoretical lectures and performing related laboratory experiments may not help students clearly understand concepts, as this approach often lacks sufficient opportunities for repetition and visualization of abstract concepts. Therefore, the teaching and learning of CBMG require visual representations of chemical phenomena to enable students to construct mental models that support their CU (Hanson et al., 2017; Kiernan et al., 2021).

Students' understanding of concepts can be significantly hindered by learning difficulties and misconceptions (Salame et al., 2022). Similarly, students' learning difficulties and MCs are the root causes of low performance in science, particularly chemistry, and constitute major obstacles to meaningful scientific understanding (Osman & Sukor, 2013). Consequently, learning difficulties with CBMG can affect students' further learning (Pabuçcu & Geban, 2012). These learning difficulties ultimately lead to poor achievement in chemistry (Adesoji et al., 2017). The Conventional Teaching Method (CTM) also does not promote CU of chemistry or facilitate conceptual change (Salame & Casino, 2021). This is because CTM mainly relies on the transmission of information to learners, which often leads students to memorize content rather than develop a deep conceptual understanding of chemical bonding (Eymur & Geban, 2017). Such instruction discourages deep learning. CU of chemistry may not be achieved without active engagement of learners in the learning process (Hadzigeorgiou & Schulz, 2019). Consequently, learning environments should encourage students to participate in activities that enable them to apply their conceptual knowledge to understand and solve meaningful problems (Gresalfi et al., 2009).

Student engagement (SE) is the key element in learning activities and in determining a student's overall success in higher education institutions (Xerri et al., 2018). SE in learning is likely to be improved by concepts that are relevant to them, which will aid in their construction of knowledge and comprehension, as well as the development of skills and competencies that will increase their level of personal scientific literacy (Anor et al., 2022). Accordingly, SE plays a crucial role in the construction of scientific knowledge in the teaching and learning processes. Students who are actively engaged in their learning are more likely to succeed in higher education (Kahu & Nelson, 2018), making engagement a critical prerequisite for effective learning. However, learning delivery styles that do not align with students' preferences or interests may negatively influence their level of engagement (Kahu & Nelson, 2018).

Moreover, the CTM doesn't fully engage students in chemistry learning, particularly in teaching chemical bonding concepts (Cormier & Voisard, 2018; Tsaparlis et al., 2018). Besides, the lack of appropriate instructional media and the way the concepts can be portrayed in media are the reasons for the strongly positive attitude and SE in chemistry education (Parchmann et al., 2020). Students who experience learning difficulties often perceive themselves as having lower self-mastery and autonomy, reduced interest and engagement in daily activities, and less social support compared with their peers (Lombardi et al., 2021). Furthermore, SE is also influenced by their scientific epistemological beliefs (EBs) (Ondap & Hornejas, 2022). Therefore, inappropriate learning approaches may discourage students, hinder their ability to learn effectively, and limit the development of positive beliefs about their academic capabilities.

EBs are personal beliefs about the nature of learning and knowledge (Lin et al., 2013). Strong EBs about science and scientific knowledge are essential for understanding the evolving nature of science, critically evaluating new scientific findings, and comprehending the empirical evidence that underpins scientific knowledge (Kampa et al., 2016; Yang et al., 2016). Students' EBs are important constructs that influence the chemistry teaching and learning process, and naïve or underdeveloped EBs can make learning chemistry more difficult (Yıldıran et al., 2011).

In the context of science learning, EBs guide specific learning objectives and are crucial for effective knowledge acquisition (Kampa et al., 2016). Understanding students' beliefs and attitudes toward a subject is therefore essential to supporting the development of expert-like thinking. Empirical studies have shown that students with sophisticated EBs are more likely to achieve higher grades (Evans et al., 2023) and perform better academically in schools and universities compared with students with naïve EBs (Mirana, 2016). Fostering appropriate instructional approaches that consider students' EBs can positively influence their understanding of and engagement with science in higher education (Kampa et al., 2016; Rodríguez & Cano, 2006). For instance, preservice teachers instructed through a constructivist pedagogy are more likely than those taught via CTM to cultivate more robust EBs in the domain of chemistry learning (Çetin-Dindar et al., 2014). Thus, understanding how students perceive knowledge and learning is crucial for designing effective instructional strategies that enhance CU and academic performance in chemistry.

Despite efforts made in educational reforms to improve the quality of education, students' learning outcomes, particularly in science education, have worsened globally. For instance, many countries with the highest mean Programme for International Student Assessment (PISA) in science scores rank low regarding students' interest in science (Bybee & McCrae, 2011). Similarly, STEM education systems in African countries are underperforming, which limits local scientific expertise (Mudaly & Chirikure, 2023; Oyelekan, 2016). This issue is also a common problem in the Ethiopian context (Bekalo & Welford, 2000; Negassa, 2014). Among many reasons, the practice of inappropriate instructional approaches in learning settings might significantly contribute to students' underperformance in science education. The CTM often leads students to develop a superficial understanding of scientific concepts and an inaccurate grasp of the scientific inquiry process (Osisioma, 2017), emphasizing rote memorization and passive learning rather than fostering critical thinking and real-world application. Consequently, students may experience learning difficulties and hold MCs, which negatively affect their understanding of scientific concepts.

Researchers suggest that students' learning difficulties in understanding CBMG are associated with poor practice of the CTM in visualizing abstract concepts (Bergqvist & Chang Rundgren, 2017). The CTM, which emphasizes knowledge transfer, is insufficient to prepare learners for the demands of a complex modern society (Assefa, 2017). Furthermore, teachers' content knowledge is crucial for students' understanding of chemistry concepts, as MCs held by teachers often contribute to students' MCs (Kaya, 2013). Teachers who struggle with learning and retaining MCs themselves are unlikely to conduct effective instruction or positively impact their students' learning. In this regard, the teaching and learning of CBMG should be aligned with current scientific and pedagogical knowledge to address students' learning difficulties and foster CU (Mamlok-Naaman et al., 2017).

Many conventional and commonly used pedagogies have proven ineffective, highlighting the need to implement innovative and practical teaching approaches in classroom settings (Lalima & Dangwal, 2017). Technological advancements have created new opportunities, enabling a variety of innovative approaches that enrich teaching and learning experiences (Edem & Anari, 2021). Educational technology is a pedagogically active tool widely employed to enhance students' learning in educational environments (Scanlon, 2021). Through the facilitation of knowledge exchange, collaborative problem‑solving, and interactive engagement, technology enables students to cooperate more productively and effectively in their learning processes (Shatri, 2020). Similarly, its effective use in the classroom can improve learning outcomes, foster social interactions, motivate students, provide access to up-to-date knowledge, and increase SE with critical thinking and problem-solving skills (Costley, 2014). However, inappropriate use of technology in educational settings negatively impacts the academic performance and social interaction of students (Vázquez Cano et al., 2022). Therefore, students must be guided to use digital tools effectively and ethically, ensuring that their engagement with technology supports their educational objectives.

Recently, the advancement in computer and web-based technologies has had a significant impact on the educational environment (Van Laer & Elen, 2017). However, unlike CTM, the online learning approach has limitations, such as a lack of face-to-face interactions with teachers and peers (Kintu et al., 2017), while CTM lacks self-paced learning time. Both conventional and online learning modes have their own merits and demerits in addressing the diverse demands of educational systems (Dangwal, 2017). Consequently, relying on a single instructional approach is often insufficient to effectively enhance students' learning, as a one-size-fits-all approach alone fails to accommodate the students’ diverse needs. To address these challenges, researchers have increasingly embraced the blended learning (BL) approach, which integrates face‑to‑face instruction with online modalities in a coherent and complementary manner (Graham, 2013; Hege et al., 2020). Thus, the design of BL seeks to create a harmonious and coherent balance between face-to-face interaction and online access (Anthony et al., 2019), while encouraging the use of innovative strategies in both pedagogy and technology.

Higher education systems worldwide are increasingly adopting BL to engage students and enhance their learning outcomes. The implementation of BL is closely linked to the economic development of nations and the availability of skilled human resources to establish and maintain information and communication technology (ICT) infrastructure in educational institutions. The widespread use of the internet has contributed to BL becoming the preferred mode of instruction in many developed nations (Gaol & Hutagalung, 2020). Research indicates that the United States, the United Kingdom, China, and Australia are the nation’s most frequently cited in BL studies across various disciplines (Betül, 2023). In contrast, universities in developing nations, particularly those in sub-Saharan Africa, are only gradually adopting BL for teaching, research, and student support (Aguti et al., 2015). However, due to limited infrastructure, BL has not been widely implemented in many developing nations, despite its potential to improve learning experiences and outcomes.

BL has considerable potential for structuring differentiated instruction in higher education, as it integrates in-person and online activities (Boelens et al., 2018). It represents a fundamental redesign of the instructional model, shifts from lecture-centered to student-centered instruction, and transforms students into active and interactive learners (Poon, 2013). Through BL, students gain access to online materials and resources that are aligned with their interests and prior knowledge (Anthony et al., 2022). Through leveraging the strengths of both conventional face-to-face and online learning, BL mitigates the limitations of each format (Hege et al., 2020). For instance, face-to-face instruction compensates for the lack of personal interaction in online learning, while online components provide opportunities for self-paced study that are not always available in CTM. BL facilitates multiple types of interactions, including student-student,

student-lecturer, student-content, and student-technology interactions (Stanley, 2014). Consequently, BL incorporates direct and indirect instruction, cooperative learning, and individualized online learning to address the diverse needs of students.

Several intervention studies have been conducted to examine the effect of BL on students' CU, SE, and EBs across different fields of study. For instance, compared with the CTM, tertiary-level students demonstrated better CU when taught through BL in courses such as basic computer networks (Hawi & Sudira, 2019) and software engineering concepts (Alam & Mohanty, 2023). Similarly, empirical studies reported that students taught through BL achieved better CU than those who were taught through CTM in secondary school mathematics (Setyaningrum, 2018) and physics courses (Novita, 2022). A review of technology- enhanced learning studies in higher education also indicated that BL enhances SE (Serrano et al., 2019). In addition, empirical research has shown that BL increases secondary school SE in earth and space science courses (Martinsen et al., 2015). Likewise, a non-experimental quantitative study reported a high level of SE in BL across disciplines such as social sciences, natural sciences, engineering, and medicine courses at the tertiary level of education (Adams et al., 2020). Furthermore, research on BL has shown that preservice teachers develop sophisticated EBs in computer technology teaching practice courses at the tertiary level (Erdem, 2008).

BL provides students with opportunities for online learning experiences that promote deep learning and foster changes in their habits, patterns, and EBs, and shifts students' roles and learning identities in chemistry courses (Rolé, 2020). However, previous interventional studies on BL have reported inconsistent results regarding students' learning performance compared to CTM across different fields of study. For instance, research suggests that students in a BL environment experience more conceptual change and achieve higher performance compared to CTM in physics courses (Bazelais & Doleck, 2018). Similarly, students taught organic chemistry through BL performed better than their counterparts taught through CTM (Idika et al., 2012). In addition, students exposed to the BL model achieved better performance than those taught through CTM in public health courses (Kiviniemi, 2014). Likewise, a study found that students taught mathematics using a BL approach had a better CU than their counterparts taught through CTM (Setyaningrum, 2018). Furthermore, an experimental study reported that BL leads to higher student achievement and greater engagement compared to CTM in business courses (Sahni, 2019).

In contrast, some studies have reported that BL does not significantly improve students' learning compared to CTM. For example, BL was found to negatively influence students' performance, with no significant difference in academic success between BL and CTM in health courses (Berga et al., 2021). Similarly, students performed equally in BL and CTM in statistics courses (Kwak et al., 2015). Another study reported no meaningful statistical difference in SE between those taught through BL and CTM in social studies courses (Sarıtepeci & Çakır, 2015). Likewise, research has shown no statistically significant differences between BL and CTM regarding students' critical thinking skills in professional courses (Alotaibi, 2013). Furthermore, findings indicate that learning styles, learning approaches, and academic achievements have no significant relationship with students' EBs (Jena & Chakraborty, 2018). Similarly, a study on flipped BL revealed that students' EBs did not influence pre-class and post-class engagement, although academic capability affected both pre-class and in-class engagement in general biology and chemistry courses (Lee et al., 2022). In addition, a meta-analysis conducted in the USA found no significant differences in student performance between BL and non-BL (Yu, 2021). Given these inconsistent findings, further research is needed to clarify the effectiveness of BL in classroom instruction.

The modern educational system in today's dynamic society promotes individualized, collaborative, and interactive learning strategies for knowledge construction. Active learning strategies allow students to think critically, solve problems, and apply what they've learned to real-life situations (Dogani, 2023). BL can support these changes through personalized learning, discussion forums, cooperative learning, and immediate feedback. As a differentiated instructional approach, BL can address the diverse needs of students and enhance their learning outcomes. However, the successful integration of ICTs into instructional practices remains a challenge for many developing nations, resulting in a slower adoption of digital learning pedagogies (Reyes et al., 2022). In the African context, the implementation of BL is still constrained by infrastructure and policy challenges, among other limitations (Okocha, 2019). Nevertheless, the African Union has introduced the digital education strategy and implementation plan 2023 and 2038, which provides a comprehensive framework for an integrated and transformative regional approach aimed at digitalizing the education sector across African countries (African Union, 2022). Moreover, countries such as Ethiopia view technology integration as a potential solution to address persistent educational challenges (Assefa, 2017).

The Ethiopian Education and Training Policy of 2023 aimed to promote modern technological competitiveness by implementing an education and training system grounded in modern technology and innovation. In Article 3.2.2, the policy emphasizes the use of educational technology while effectively utilizing modern technology. This policy emphasizes the blending of established and modern knowledge and education within the educational system. This implies that existing educational needs need improvement and development through integration with modern technology. In line with this direction, the Ministry of Education, Ethiopia, intends to expand ICT integration in its sixth Education Sector Development Program (ESDP VI) 2020/21–2024/25 plan to transform the quality of teaching at all levels of education (Ministry of Education, 2021). However, even though the policy emphasizes the practice of ICT in the Ethiopian educational system, digital technology instruction has not been fully implemented and is still largely at the investigation stage at the university level. As a result, the CTM remains the predominant mode of instruction in Ethiopian higher education, leading to superficial learning in classroom lesson delivery(Abebe, 2015; Alemu et al., 2021). In this mode of instruction, the teacher is the primary source of knowledge, and students are often required to memorize facts and theories without a deep understanding of course concepts, acting mainly as passive listeners (Idika et al., 2012).

Furthermore, the CTM discourages learners' critical thinking, lacks flexibility and collaboration, and limits opportunities for interactive learning (Singh & Malik, 2022). This passive instructional strategy restricts students' interactivity and inquiry-based learning, preventing them from developing a critical understanding of course concepts. In this approach, students rely mainly on teachers' lecture notes and course materials in a cookbook style of instruction, which restricts them from acquiring the necessary knowledge, skills, and attitudes. As a result, their engagement in classroom activities diminishes, and they may develop naïve EBs about the course. Besides, to the best of the researcher's knowledge, studies in chemistry that simultaneously examine students' CU, SE, and EBs remain limited, particularly in the higher education contexts in Ethiopia. Empirical studies have also revealed that CTM is inadequate for improving students' CU, SE, and EBs. Consequently, it becomes challenging for students to comprehend abstract and complex topics such as CBMG through CTM alone. To develop a meaningful understanding of chemistry, higher education students need to be actively engaged in the learning process so that they can relate complex concepts to real-life situations and construct meaningful EBs about the subject. In this context, learning CBMG requires an innovative instructional approach integrated with CTM in the learning environment. Therefore, this study investigates the effects of BL on undergraduate students' CU, SE, and EBs in learning CBMG concepts at Bahir Dar University. In this study, BL is considered a differentiated instructional approach among other technology-supported instructional methods.

1.2. Statement of the Problem

Chemistry education is vital for preparing competent professionals who contribute to modern society. Yet, despite its importance, students' academic performance in chemistry has declined globally and remains persistently poor (Cardellini, 2012; Mihindo et al., 2017; Musengimana et al., 2021). Ethiopian students face similar challenges, with recent studies confirming that chemistry continues to be a difficult subject (Bewota et al., 2024; Hagos, 2026; Simesso et al., 2024). Several factors contribute to this problem, including ineffective instructional strategies, limited visualization of macroscopic, submicroscopic, and symbolic representations, and difficulties in grasping both basic and abstract concepts (Alemu, 2015; Tilahun & Tirfu, 2016). Among these, CBMG concepts are particularly problematic: they are fundamental yet abstract, and misunderstanding them often leads to MCs that hinder learning across other areas of chemistry (Tsaparlis et al., 2018; Zohar & Levy, 2019).

Students' difficulties are compounded by low engagement and reliance on rote learning, which weakens CU (Shridhar et al., 2021). Empirical evidence shows that poor SE further undermines attitudes and achievement in chemistry (Ross et al., 2020). The widespread use of CTM, which emphasizes memorization over active participation, exacerbates these problems by failing to foster meaningful engagement (Satam et al., 2019). Consequently, students require opportunities for active learning that promote critical thinking and deeper CU. Equally important are students'

EBs, which shape how they perceive and engage with scientific knowledge. Sophisticated EBs enhance learning outcomes (Choung et al., 2020), yet teacher-centered instruction often restricts epistemological development (Zhang & Ding, 2013; Zhu et al., 2008). Ethiopian students, in particular, tend to hold naïve beliefs about knowledge and learning (Kahasay, 2019), which negatively affect their attitudes toward chemistry (Mujtaba et al., 2018). Understanding and addressing these beliefs is therefore essential for fostering scientific literacy and more expert-like approaches to learning.

National examination results further highlight the severity of the problem. In 2022 and 2023, only 3.3% and 3.2% of students scored above 50% in the Ethiopian university entrance examination, with average chemistry scores around 30% (Tamrat, 2023) . At the secondary level, chemical bonding remains one of the most challenging topics, with only 34.3% of grade 12 students achieving 50% or higher in chemistry (NEAEA, 2017). Studies also reveal widespread misconceptions, with nearly 28% of students demonstrating a superficial understanding of the core concepts of chemistry (Lemma, 2012). These alarming findings underscore the urgent need for effective instructional approaches to improve chemistry learning outcomes.

Despite Ethiopia's expansion of higher education, concerns about quality persist. Research shows that students struggle with chemistry due to its abstract nature and inadequate learning environments (Gebremeskel et al., 2017; Woldeamanuel et al., 2014). Heavy reliance on CTM and limited use of instructional technologies contribute to low performance and weak SE (Ajayi & Ogbeba, 2021). Moreover, the two-dimensional representations of molecules in textbooks often fail to convey their three-dimensional nature, making CBMG particularly difficult to grasp (Engida, 2012). These challenges highlight the need for innovative strategies that integrate visualization and technology to support CU.

BL, which combines online and face-to-face instruction, has emerged as a promising approach. While global studies report mixed results depending on design and implementation (Berga et al., 2021; Botts et al., 2018; Kwak et al., 2015). BL has shown positive effects in Ethiopian universities in disciplines such as English writing, mathematics, and computer programming (Bati et al., 2014; Geta & Olango, 2016). However, its impact on chemistry, particularly on CU, SE, and EBs, remains underexplored. Given the persistent difficulties in chemistry learning, the abstract nature of CBMG concepts, and the limitations of CTM, investigating the potential of BL in the Ethiopian context is both timely and necessary. This study seeks to address the gap by investigating whether BL can enhance undergraduate students' CU, SE, and EBs in CBMG concepts of Chemistry at Bahir Dar University.

1.3. Objectives of the Study

1.3.1. General Objective

The main purpose of this study is to investigate the effects of BL on undergraduate students' CU, SE, and EBs in learning CBMG concepts.

1.3.2. Specific Objectives

1. To evaluate the effect of BL on undergraduate students' CU of chemical bonding and molecular geometry (CBMG) concepts.
2. To assess the impact of BL on undergraduate SE in learning CBMG concepts.
3. To investigate how BL influences undergraduate students' EBs in learning CBMG concepts.
4. To examine whether statistically significant gender differences exist in students' CU, SE, and EBs in learning CBMG across the two instructional groups.
5. To analyze the relationships among CU, SE, and EB in undergraduates in learning CBMG concepts.
6. To examine the challenges associated with implementing BL for teaching and learning of CBMG concepts at Bahir Dar University.

1.4. Research Questions

The present study aims to answer the following research questions

1. What is the effect of BL on undergraduate students' conceptual understanding of CBMG concepts, and in what ways does their understanding change?
2. What is the effect of BL on undergraduate SE in learning CBMG concepts?
3. What is the effect of BL on undergraduate students' EBs about CBMG concepts?
4. Are there statistically significant gender differences in students' CU, SE, and EBs within and between the instructional groups?

5. Is there a statistically significant relationship among undergraduate students' CU, SE, and EBs in learning CBMG concepts through the BL approach?
6. What are the challenges associated with implementing BL to teach CBMG concepts at Bahir Dar University? Why have challenges emerged at this stage?

1.5. Significance of the Study

The findings are expected to make meaningful contributions to improving teaching and learning practices in higher education, particularly in chemistry education. By promoting deeper CU, enhancing SE, and fostering the improvement of sophisticated students' EBs, the BL approach offers a student-centered environment that supports self-paced and active learning. This study also provides implications for instructors and teacher educators by highlighting the value of integrating innovative, technology-enhanced instructional strategies into their teaching practices. The results may guide educators in designing and implementing effective BL that encourages students to ask questions, explore learning resources, and receive timely feedback through online platforms.

Furthermore, the findings may inform schools, teacher education colleges, and universities on how to effectively adopt and implement the BL approach in classroom settings. The study may also support the professional development of educators by strengthening their pedagogical skills in integrating instruction. At a broader level, policymakers, curriculum developers, and experts in higher education, including those in the Ministry of Education (MoE) may use the findings to design or revise curricula that emphasize students' CU, SE and the development of EB Finally, this study may serve as a foundational for future research on the application and impact of BL approach in science education and other educational contexts.

1.6. Delimitation of the Study

This study was conducted at Bahir Dar University in the Amhara Regional State of Ethiopia over nine weeks. Other universities in the same region and other parts of Ethiopia are not included in this study. It focused on first-year undergraduate students enrolled in General Chemistry (Chem 1012) courses, specifically covering topics of CBMG. Students who were not enrolled in this course were excluded from the study. The instructional content included fundamental CBMG topics, such as ionic bonding, covalent bonding, metallic bonding, Lewis structures, formal charges, resonance, strengths of ionic bonds, covalent bonds, and molecular structures and polarity, and valence bond and molecular orbital theory, which were taught in both intervention and comparison groups. Other content in the course is not included in this study. The selection of CBMG content was based on its fundamental, abstract, and complex nature, which often leads to learning difficulties and MCs among students at higher education levels. This study was delimited to examining the effect of the BL approach on first-year undergraduate students' CU, SE, and EBs. Although various instructional approaches may enhance students' learning experiences, this study specifically employed the BL approach, integrating face-to-face instruction with online components. This is because it combines the strengths of face-to-face classroom learning with online learning.

1.7. Operational Definition of Terms

Abstract Concepts: are entities that have no physical or spatial constraints because they have no direct representation in the physical world (Dijkstra et al., 2014).

Blended Learning**:** is the combination of face-to-face and web-based/online learning environments (Graham, 2013) .

Chemical bonding concepts: the concepts that interpret the chemical phenomena of atoms, ions, and molecules, and how they interact in chemical reactions, as well as the properties that emerge after their transformation into new chemicals.

Conceptual Understanding: refers to generalizations learners can develop about the nature or properties addressed in chemistry (Mills, 2016)

The conventional method of Teaching: is an approach that is characterized by passive student participation, where the teacher is the primary source of knowledge and students are expected to absorb information rather than actively construct it.

Chemistry education: is the study of teaching and learning chemistry, aiming to improve the quality of education (Teo et al., 2014).

Educational Technology: is the integration of computer hardware, software, and educational theory and practice in tandem to support teaching and learning. (Mastellos et al., 2018)

Epistemological Beliefs: are an individual's personal beliefs about what chemistry knowledge, knowing, and learning are (Baydar, 2020).

Face-to-face Instruction: is the traditional method of instruction where course content and learning material are taught in person to a group of students in an F2F setting (Morgan, 2014).

Learning Difficulties: are comprehension issues or emotional challenges that interfere with the student's ability to learn (Febliza & Yulis, 2018).

Learning environment: is the setting and practices of an educational institution that are likely to help or hinder learning during a specific classroom delivery (Ellström et al., 2008).

Learning platform: is an online e-learning platform known as a learning management system (LMS) that provides an interface between trainers, students, and administrators toward a common objective of learning (Jain et al., 2024)**.**

Learning Management System(LMS): refers to a variety of software and systems used to manage, track, and deliver educational materials, as well as manage student records (Rosário & Dias, 2022).

Molecular geometry: is the three-dimensional arrangement of the atoms that constitute a molecule.

Online Learning: a type of learning that occurs through an internet-based platform in which the teacher sets up lessons and assignments beforehand, and students learn and interact through the platform (Horn & Staker, 2014).

Student Engagement: the degree of attention, effort, participation, curiosity, interest, and passion shown by students when they are learning or being taught (Olson & Peterson, 2015).

Students' misconceptions: are used to describe any conceptual or propositional knowledge that is different from or inconsistent with the accepted, scientific concepts (Nicoll, 2001).

Undergraduate students: Undergraduate students are those who are enrolled in a first-degree program at Bahir Dar University.

False positive: the proportion of students incorrectly classified by the assessment as achieving the target competency among those who have not actually achieved it according to the established criterion

False negative: an assessment classifies a student as not having mastered a specified learning outcome or competency when the student has actually achieved it according to an established criterion or reference assessment**.**

First-tier: the traditional multiple-choice question that measures the content-concept

Second-tier: the reasoning tier that assesses the reasons or explanations underlying students' responses to the first-tier question

Confidence-tier: the tier that measures students' confidence in their responses to the first- and second-tier questions.

Both-tiers: A tier type that assesses the combination of students' responses to the first- and second-tier questions

All-tiers: A tier type that assesses students' responses through the combined results of the first, second, and third tiers.

Challenges: Difficulties encountered by students during the implementation of blended learning (BL) in the learning setting.

Gender: the student's self-identified gender, recorded as reported by the student in the research questionnaire within groups**.**

CHAPTER TWO

2. REVIEW OF RELATED LITERATURE

2.1. Introduction

This chapter reviews the literature relevant to the study, beginning with the nature of chemistry education and students' learning difficulties, with particular emphasis on MCs in CBMG. It then examines the role of educational technology in chemistry education, followed by an overview of BL, including its definitions, features, advantages, and global trends, as well as its application in higher education and science classrooms. The chapter further discusses the design, implementation, and learning environments of BL, along with associated challenges and the use of platforms such as Moodle. In addition, the review explores key learning constructs, including students' CU, SE, and EBs in science and chemistry education, and the impact of BL on these outcomes. It also addresses the conceptualization of CLASS-Chem (EBs) dimensions and examines the relationships among conceptual CU, SE, and EBs. Finally, the chapter considers gender differences in BL contexts and concludes with the theoretical and conceptual framework underpinning the study.

2.2. Nature of Chemistry Education

Education is the process of developing problem-solving abilities and training through problem identification, critical thinking, mature judgment, and changing attitudes, values, and beliefs (Udofia & Ekong, 2017). In schools, colleges, and universities, chemistry education is the study of chemistry teaching and learning (Amuda & Yahaya, 2020; Kiviniemi, 2014). The field of chemistry education is newer and somewhat different, and has a practice as long as there has been chemistry, in one form or another (Taber, 2015). The improvement of teaching, research, and development in chemistry education is essential to making sure that students in schools, colleges, and universities have the necessary knowledge (Draman & Mohd, 2021). Understanding the nature of chemical thought and action, as well as its applications and effects on our environment, is the main objective of chemistry education at all levels of schooling (Freire et al., 2019). Chemistry education researchers are looking at a wide range of topics related to teaching and learning chemistry, such as how students acquire knowledge and understand chemistry, as well as the barriers that stand in the way of this process (Berisha, 2020). The study of chemistry education is a somewhat hybrid field that heavily emphasizes teaching and learning the scientific discipline of chemistry while incorporating ideas and methods from other disciplines. (Taber, 2015).

However, most students are uninterested in learning chemistry because they do not perceive it as relevant to both themselves and the society in which they live (Eilks & Hofstein, 2015). To make the students more interested and motivated, the teaching and learning of chemistry must be relevant and related to their real-life experiences. The teaching and learning of chemistry through the CTM are not adequate to satisfy the needs of all students (Komisia & Leba, 2018). Therefore, how to teach chemistry is the key to addressing the issue of global scientific literacy because the CTM in chemistry education involves memorizing and reciting facts that can be counterproductive in many ways and lead to negative perceptions by students (Ippoliti et al., 2022). To overcome this challenge, researchers have emphasized the need for context-based pedagogical approaches that could be practiced and make chemistry learning more relevant to students in chemistry education (King, 2012).

The Johnstone model of chemical concepts is categorized into three levels of chemical phenomenon (macroscopic, submicroscopic, and symbolic) that can offer insights into how best to teach chemical knowledge (Taber, 2013). On the other hand, the researcher (Mahaffy, 2015) introduced the fourth element, human activity, in addition to the elements of the Johnston's triplet, to convey the difference between chemical education and chemistry education. This notion transforms Johnstone's triplet perspective into Mahaffy tetrahedral chemistry. Due to the limited relevance and transferability of CTM to learning chemistry, educators are increasingly striving to integrate a human-centered dimension into chemistry instruction (Sjöström & Talanquer, 2014). The researcher suggested that the overview of tetrahedral chemistry education emphasizes the significance of contextualizing scientific concepts, symbolic interpretations, chemical elements, and chemical reactions in meaningful human contexts. Through visualization and representation of the chemical phenomena of substances, the tetrahedral perspective plays a critical role in bridging chemistry science with pedagogical aspects as the basis of chemistry education (Sjöström & Talanquer, 2014). However, the lack of a tetrahedral perspective might make it difficult for students to comprehend the concepts. Despite the importance of integrating multiple representations and contextualized learning in chemistry education, limited research has investigated how BL environments can support students in connecting chemical representations, developing CU, and improving SE and EBs, particularly in abstract topics such as CBMG in Ethiopian higher education.

2.3. Students' Learning Difficulties in Chemistry Education

Chemistry is a fundamental science taught at all levels of education that underpins other science disciplines, equipping students with the knowledge, skills, attitudes, and competencies necessary for technological, agricultural, and economic development (Udofia & Ekong, 2017). To foster a complete grasp of current sustainability development, chemistry must be taught in a relevant context (Jegstad & Sinnes, 2015). However, chemistry is widely regarded as a challenging subject for students and teachers because it involves numerous complex concepts and abstract theories (Bhola & Parchoma, 2015; Laudonia & Eilks, 2018; Valdez & Bungihan, 2019). The lack of scaffolding, learning implementation, relevance, and difficulty are the main challenges that all students expect in chemistry education (Taber, 2019b). Giving students with learning difficulties positive feedback in the classroom, praising them for their accomplishments, but more so for their efforts, encourages them to be more active and to participate more freely in all activities (Enes & Ernest, 2022).

Chemistry is a difficult subject to learn and understand because of the specific language used by practitioners in professional and scientific communications (Wood, 2013). The language and methods of representing chemical interactions have been classified into three modes of representation, such as macroscopic, submicroscopic, and symbolic, to help students understand the discipline. Chemical representations are widely recognized as powerful and necessary tools for communicating chemical content (Taskin et al., 2017). The abstract and complex concepts of chemical phenomena in chemistry education can be understood by these modes of representation, with their relationship (Taber, 2013). The fundamental barrier and obstacle that students may face while studying chemistry is connecting what they can see in a lab to what they cannot directly see (Aldosari & Marocco, 2015). Because chemistry is abstract and uses symbolic language to describe interactions at an invisible particulate level that lead to macroscopic phenomena (Smith, 2022). Accordingly, the students' MCs in chemistry can be caused by difficulties connecting the macroscopic, submicroscopic, and symbolic levels of understanding (Rahmawati et al., 2022).

Students in schools and universities approach their studies with erroneous or incomplete ideas about the subject matter, particularly in complex subjects such as chemistry (Taber, 2019a). The primary cause of students' learning difficulties and MCs in chemistry education is their inability to comprehend the features, interactions, and emergent nature of chemical substances (Tümay, 2016b). By immersing students in courses, chemistry teaching and learning strategies must address MCs and improve students' CU of key chemistry concepts (Salame & Casino, 2021). The key issue in chemistry education is identifying students' learning challenges and MCs, and coming up with practical solutions (Shidiq et al., 2019; Tümay, 2016b). The process of identifying students' learning difficulties and MCs and developing new instructional strategies is the solution to improving students' CU of chemistry (Pabuçcu & Geban, 2012; Stroumpouli & Tsaparlis, 2022). Therefore, teacher educators should be aware of the difficulties and MCs, design appropriate instructions and scaffolds for different levels of learning, and motivate students to learn the language of chemistry in addition to the content it represents (Taskin et al., 2017).

Numerous factors influence how students learn chemistry, which may be the root of MCs and learning difficulties in the subject. Students faced a variety of challenges when learning chemistry, from human aspects to the fundamentals of the subject. (Upahi & Ramnarain, 2019). In general, several learning difficulties that influence the students' CU of chemistry are portrayed in many works of literature. These are the abstract nature of concepts (Gafoor & Shilna, 2013; Üce & Ceyhan, 2019), the lack of curriculum content and logical order of macroscopic, submicroscopic, and symbolic (Donkoh, 2017; Olić & Adamov, 2018), the lack of students' commitment, motivation, engagement, and communication problems, poor learning strategies, and poor background knowledge (Donkoh, 2017; Woldeamanuel et al., 2014), lack of appropriate instructional media (Kebede, 2021), lack of lab facilities, lack of teachers' commitment (Tilahun & Tirfu, 2016). Thus, chemistry learning requires considerable attention to overcoming students' learning difficulties.

Researchers identified the content areas of chemistry where the students' learning difficulties and MCs are observed. Some of these identified content areas are chemical bonding (Tümay, 2016b), chemical changes (Ayyıldız et al., 2022), chemical reactions (Yan & Talanquer, 2015), atomic structure (Yan & Talanquer, 2015), chemical equilibrium (Yamtinah et al., 2019), redox reactions (Ferouni et al., 2012), acid-base reactions (Bayrak, 2013; Goss, 2018), and energy and matter (Liu, 2013). The abstract concepts of atoms, electrons, elements, molecules, and compounds are difficult for students to grasp, as young learners often struggle to connect them to a suitable mental model (Herga et al., 2015). Accordingly, the abstract and complex concepts of chemistry require appropriate instructional approaches, including the use of innovative technologies to help students overcome learning difficulties. Despite extensive evidence on students' MCs and learning difficulties in chemistry, limited empirical research has examined the effectiveness of BL approaches in supporting the visualization of abstract chemical phenomena and improving undergraduate students' CU, SE, and EBs, particularly in CBMD within Ethiopian higher education contexts.

2.3.1. Students' Misconceptions in Chemistry Learning

Chemistry is a crucial science that is abstract and complex. Although the learning activities tried to connect the material with how the world functions, students still have a lot of learning challenges and MCs about chemistry (Niroj & Srisawasdi, 2014). Students' learning MCs are conceptions that contradict the scientifically accepted theories about learning concepts (Gurel et al., 2015). They also stated that accurately identifying MCs is essential since they are difficult to dispel and hinder the advancement of science. Learning MCs can be described in other terms, such as alternative conceptions, alternative frameworks, intuitive beliefs, and preconceptions (Luxford & Bretz, 2014; Sands, 2014; Soeharto et al., 2019; Vosniadou, 2020). Students' learning MCs are linked to their difficulty in understanding the learning material. MCs may arise when students struggle to understand the concepts of the learning material (Rahayu et al., 2024). Thus, students' MCs about what they are learning in the classroom lead to their insufficient understanding. The abstract concepts of chemical bonding have frequently been associated with MCs, misunderstandings, and learning difficulties(Tsaparlis et al., 2018). The difficulty of understanding abstract concepts impacts the formation of alternative conceptions (Sibomana et al., 2020). The lack of visual representations of chemical phenomena in learning settings at a microscopic level is one of the sources of students' MCs. Generally speaking, macroscopic and symbolic representations are used to convey chemical concepts, but submicroscopic representations are disregarded (Rahayu et al., 2024; Rahmawati et al., 2022). Additionally, students were unable to distinguish between explanations that are macroscopic and those that are submicroscopic (Chang & Linn, 2013). This indicates that they struggle with linking the molecular-level interactions to visible phenomena. Therefore, chemistry is considered difficult for students to learn, which requires visualization at the submicroscopic level of representation (Salame & Makki, 2021).

The students held MCs about learning science, particularly chemistry, from various sources. The student's inability to understand the emergent nature of chemical entities, their properties, and their interactions is the primary source of learning difficulties and MCs in chemistry education (Tümay, 2016a). Additionally, researchers reported various reasons for these learning difficulties that contribute to students' MCs about science, such as poor teaching methods, lack of organizational skills, improper exposure to laboratory activities, inadequate exposure to problem-solving procedures, and disconnection between science subjects and personal life (Hanson, 2017); being incapable of associating science concepts with everyday life (Bilgin et al., 2017). Multiple representations may be employed by teacher educators to convey concepts conventionally, and students may hold MCs that hinder their ability to learn chemistry in the future (Luxford & Bretz, 2014). Chemical bonding is a fundamental concept in understanding other topics in chemistry; however, its concepts are abstract and difficult for learners to grasp (Mellyzar, 2021; Rohmah et al., 2022). Similarly, the concepts of electrons, chemical bonding, electronegativity, and geometry are fundamental to many other ideas covered in the chemistry curriculum(Hunter et al., 2022). The concepts of chemical bonding, such as bonds between atoms and/or molecules, are far removed from daily life and invisible to the naked eye, resulting in MCs (Rohmah et al., 2022). These MCs about chemical bonding occur at all educational levels. MCs about chemical bonding can impede students' understanding of later chemistry topics, potentially impacting their academic performance (Putri et al., 2024). Nonetheless, the majority of chemistry subjects where students hold MCs are fundamental to the subject (Timilsena et al., 2022).

The teachers' practice of CTMs is unable to overcome these MCs (Fumador & Agyei, 2018; Halim et al., 2014). Compared to CTMs, constructivist learning approaches can be more effective in reducing student MCs (Vrabec & Prokša, 2016). A comparative study between the

USA and Korea indicated that CTM, which is predominantly practiced by science teachers, causes students to hold MCs (Seo et al., 2016). MCs about science persist, are challenging to address, and are deeply rooted in specific concepts (Soeharto et al., 2019). Consequently, students with MCs about scientific concepts may struggle to build the scientific knowledge necessary for meaningful learning. Thus, it is essential to identify students' MCs and determine effective solutions to address them during the learning process. The identification of MCs has had a significant impact on scientific education, research, and instruction because it showed that students are engaged and innovative learners, and that their thoughts and understandings must be taken into consideration when creating instruction (Vosniadou, 2020). Thus, learning should focus on the elimination of students' MCs. Thus, adapting the appropriate instructional approach is needed to overcome the students' MCs. The constructivist approach in learning emphasizes student activities to construct a CU (Resbiantoro & Setiani, 2022). Despite the recognized potential of technology-integrated instruction to support visualization and reduce MCs, limited studies have examined the effectiveness of BL in addressing undergraduate students' MCs and improving CU of CBMG, particularly within Ethiopian higher education settings. This gap necessitates empirical investigation of BL as an alternative instructional approach for promoting meaningful chemistry learning.

2.3.2. Students' Learning Difficulties in Chemical Bonding and Molecular Geometry

Chemical bonding and molecular geometry (CBMG) are the complementary aspects of the same chemical phenomena, each informing and explaining the other. Without a doubt, chemical bonding is a fundamental concept for chemists and is required for understanding chemistry concepts (Burrows & Mooring, 2015; Nahum et al., 2013; Nimmermark et al., 2016). Chemical bonding is emphasized throughout the secondary and tertiary chemistry curricula (Hunter et al., 2022). The knowledge of chemical bonding is fundamental and necessary for understanding almost every topic in chemistry; however, its concepts are extremely difficult to learn (Yayon et al., 2012). Moreover, chemical bonding is a fundamental yet intricate subject that has been linked to MCs, learning challenges, and learning difficulties (Tsaparlis et al., 2018). According to the researchers (Nahum et al., 2013), concepts related to chemical bonding and structure, including giant lattices, molecules, ions, hydrogen bonds, and covalent bonds, are quite abstract. The abstract and microscopic nature of the concepts, as well as the types of chemical bonding, create conceptual difficulties that lead to numerous MCs and may have significantly reduced the interest and confidence of many students (Gumonan & Bug-os, 2021). Moreover, the abstract nature of chemical bonding, the chemical phenomenon in which atoms, ions, or molecules are held and bonded together to form compounds, is not observable (Abd Halim et al., 2013). This means the visual representations of the chemical phenomenon make it difficult for students to understand the concepts of chemical bonding in instructional strategies (Bergqvist et al., 2013).

Students perceived different learning difficulties and MCs about the concepts of chemical bonding in their experience. Students commonly held learning difficulties and MCs of chemical bonding (Tsaparlis et al., 2018). They view ionic and covalent bonds as entirely distinct from one another. Various students misunderstand the role of ions and molecules, wrongly generalizing concepts such as molecular structure, electronegativity, and polarity as exclusive to covalent bond systems. Additionally, chemical bonding is conceptualized as involving only attractive forces, with repulsive interactions overlooked. The octet rule is overgeneralized as a universal predictor of chemical bonding type and stability. Furthermore, students struggle to connect chemical bonding with periodic trends and macroscopic properties such as melting point and solubility. On the other hand, students had a great deal of wrong information and various MCs in relation to molecular geometry (Uyulgan et al., 2014). They overgeneralized the concepts of molecular geometry, assuming that molecules with the same shape (e.g., trigonal pyramidal in NH_3 and NF_3) must have identical bond angles. They also wrongly believed that equal numbers of electrons on the central atom led to identical bond angles. These MCs indicate a limited understanding of how factors such as electronegativity, bond-pair-lone-pair repulsion, and electron distribution influence bond angles beyond simple geometric classification.

The learning difficulty of students in understanding the concepts of chemical bonding is not only because of its abstract concepts, but also the practice of CTM alone (Bergqvist & Chang Rundgren, 2017). This lack of practicing differentiated and appropriate instructional strategies that transform information for learners leads them to memorize facts and theories and doesn't help them to acquire the necessary knowledge with applicable concepts. To address challenges, chemical bonding instruction should be in line with the most recent research in science and education (Mamlok-Naaman et al., 2017). Learning difficulties and MCs of chemical bonding can be improved by designing an appropriate teaching environment with suitable models and representations of the chemical phenomenon (Bergqvist et al., 2013; Dhindsa & Treagust, 2014). In particular, proper depictions, such as dynamic metaphors employing computer simulations, are necessary to comprehend the invisible, counterintuitive, and dynamic phenomena of chemical bonding (Zohar & Levy, 2019). Therefore, visual representations play a crucial role in helping students to build mental models for CU (Hanson et al., 2017). Despite the importance of CBMG and the potential of technology-supported visualization to address students' MCs, limited empirical evidence exists regarding the effectiveness of BL in improving undergraduate students' CU of CBMG, particularly in Ethiopian higher education contexts. This highlights the need to examine how a systematically designed BL environment can support students' understanding of these abstract chemistry concepts.

2.4. The Role of Educational Technology in Chemistry Education

Educational technology is the use of up-to-date computer tools and related technologies along with procedures to address needs and solve problems in education (Roblyer & Hughes, 2019). Educational technology is a broad term that encompasses a wide range of technological tools used in the teaching–learning environment to enhance students' learning outcomes. These tools include, for example, overhead projectors, PowerPoint presentations, audio CDs, laptop computers, smartphones, and tablets. These technological tools can create interactive instruction in lesson delivery. Thus, educational technology is the current innovative pedagogically active tool utilized widely to improve students' learning experience in educational environments (Cabaleiro-Cerviño & Vera, 2020; Scanlon, 2021). The use of technology in the classroom enhances students' learning and improves their comprehension of abstract chemistry concepts, thereby reducing learning difficulties (Ianoş & Oproiu, 2018). Moreover, educational technology leads teachers to bring chemistry to life, allowing students to visualize abstract concepts and test newly learned ideas (Kristen et al., 2017; Patron, 2022). It has the ability not only to incorporate the essential content of instruction but also to move students to higher-order thinking and teach lifelong learning skills (S. Kaur, 2013).

The advancement of technology has been integrated into classroom instruction in various ways; however, Computer animations and interactive simulations are among the most widely utilized instructional tools in chemistry education, as they facilitate the visualization of abstract concepts and enhance students' CU, engagement, and knowledge transfer (Hu et al., 2024) The application of innovative instructional strategies integrated with the learning materials can promote more meaningful learning and improve students' achievement in chemistry (Sugano & Nabua, 2020). The usefulness of instructional technology and the idea that supports students' involvement, perceptions, and learning are far more realistic when it comes to the practical study of chemistry (Nnadi, 2019). However, using technology alone does not guarantee effective learning, and many of its aspects make it easier to create environments that extend the principles of learning through practical applications in chemistry education (Gupta & Belford, 2019). Thus, new technologies are now easier to incorporate into teaching, allowing students to learn by doing, receive feedback, continually refine their understanding, build new knowledge, and assist students in visualizing difficult concepts. For this reason, one of the ways that many governments have responded to the educational demands of the twenty-first century in chemistry is through the employment of technology in the classroom (Beichumila et al., 2022a).

Conventional teaching method (CTM) is increasingly difficult to adapt to the new era's development, and its quality is difficult to ensure (Xu et al., 2020). Nowadays, technology-integrated instruction has emerged to overcome this difficulty in educational environments. Online learning, on the other hand, entails using the Internet to access learning material without the physical presence of an instructor (Güzer & Caner, 2014). Technology-integrated instruction allows for greater flexibility and easier access to content at any time and from any location (Means et al., 2013). They also suggested that it is still highly debated because online instruction cannot be compared to CTM, that promote communication and social skills. Technology and CTM strategies have their own merits and demerits; both provide different needs, demands, and expectations from the educational system (Dangwal, 2017; Karacop & Doymus, 2013). Because BL incorporates the benefits of both types of learning, it becomes an important alternative modality for reducing the limitations of both face-to-face and online learning. Accordingly, BL is a student-centered approach with differentiation as a main feature that provides the appropriate balance between conventional instruction and e-learning instruction (Nazarenko, 2015). Therefore, it is important to practice BL in lesson delivery rather than utilizing CTM or computer-mediated instruction alone to alleviate the drawbacks of these instructional strategies.

Although educational technologies, such as simulations and computer-based tools, have shown potential for improving students' visualization, CU, and SE in chemistry learning, technology alone does not ensure effective learning. The integration of technology with appropriate pedagogical approaches, such as BL, remains underexplored, particularly in addressing the limitations of CTM in complex chemistry topics. Therefore, further research is needed to examine the effectiveness of well-designed BL environments in enhancing undergraduate students' chemistry learning outcomes.

2.5. Blended Learning and Its Definition

BL is a rapidly spreading educational format around the world (Nazarenko, 2015). Since its inception, BL has been defined in a variety of ways, and its significance has changed over time (Alsobhi, 2021). It has also been referred to as dispersed learning, mixed-mode learning, open learning, flexible learning, and hybrid learning(Graham & Halverson, 2023). As a result, the term evolved into a catch-all phrase for various combinations, including different pedagogical approaches, technological tools, instructional approaches, and instructional techniques, even when these don't align with conventional definitions of BL (Hrastinski, 2019). Accordingly, teachers who are unfamiliar with BL may find themselves facing significant challenges due to different understandings of the term and design approaches resulting from the ongoing debate regarding its meaning (Alammary et al., 2014). This lack of conceptual clarity has been regarded as a significant concern, as it obscures a precise understanding of how BL operates in practice. Moreover, this conceptual ambiguity has been regarded as a limitation of BL research because it may lead to misinterpretations of BL effectiveness and discourage its use as a meaningful construct for distinguishing instructional approaches (Hrastinski, 2019). To address this issue, researchers have proposed well-established, unambiguous concepts, models, and conceptualizations for implementing BL. Additionally, some researchers argue that the BL definition should be grounded in learning theory and include a combination of direct instruction and learning-by-doing, as some definitions neglect the concept of learning altogether (Cronje, 2020).

Regarding this, BL has no universally agreed-upon definition, which influences the design and implementation of the learning delivery (Hrastinski, 2019). The proliferation of definitions can be attributed to the fact that BL is a popular trend and widely considered to be a primary teaching strategy for the future (Zhang, 2021). Nowadays, BL is generally conceptualized as a combination of online and face-to-face instruction, although recent perspectives emphasize the need to integrate learning theories and pedagogical approaches rather than merely combining delivery modes (Bouilheres et al., 2020). Similarly, it is described as the thoughtful integration of classroom F2F learning and online learning experiences (Garrison & Kanuka, 2004). Thus, BL, characterized by the integration of face-to-face and online instructional modalities, is increasingly recognized as a major technological advancement in contemporary education and a natural progression in the evolution of instructional practices in response to digital transformation (Cheung et al., 2023; Helsa et al., 2023). It has emerged in response to the limitations of both CTM and e-learning (PambudiWidiatmaka et al., 2021). In this regard, BL overcomes the limitations of conventional F2F and online learning alone (Alammary et al., 2014). Consequently, BL combines the benefits of conventional and online instruction for the same students studying the same course (Cleveland-Innes & Wilton, 2018; Dangwal, 2017). On the other hand, BL is widely recognized as a flexible and potentially cost-effective instructional approach that enhances pedagogical practices; however, its effectiveness depends on thoughtful design and implementation due to the inherent complexity of integrating online and face-to-face learning environments (Müller & Mildenberger, 2021) Therefore, BL must be carefully planned to support important course characteristics, specific learning objectives, and the diverse needs of students (Lim & Wang, 2016).

Although BL has gained widespread recognition, its conceptual ambiguity remains a major challenge that affects its design, implementation, and evaluation. Existing literature provides diverse definitions and models of BL, leading to inconsistent practices and difficulties in determining its effectiveness. Moreover, limited studies have examined how clearly defined and theoretically grounded BL models are applied in specific educational contexts, particularly in chemistry education. Therefore, further research is needed to establish effective BL frameworks and investigate their implementation in discipline-specific learning environments.

2.6. Features and Advantages of Blended Learning

BL makes learning more enjoyable with better involvement of students and has more advantages over other instructional approaches (M. Kaur, 2013). Additionally, BL provides distinct benefits over CTM. One of its primary advantages is course flexibility, which enables students with different learning styles, non-CTM course access needs, and varying pacing preferences to effectively participate in the learning process (Poon, 2013). The researchers (Hancock & Wong, 2012) reported several advantages of BL in learning environments, including:

i) BL transforms passive teaching into active learning by shifting the lecture-led teaching to an active learning approach. It provides the students with the opportunity to read, speak, listen, and think.
ii) BL provides the students with the flexibility to learn both collaboratively and independently. By integrating F2F and online components, it enables access to materials through multiple modes, accommodating diverse learning styles.
iii) BL adds a human dimension to the teaching. Its interactive nature enables the instructor to foster a high level of interest, accountability, and meaningful assessment.
iv) BL enhances individualization, personalization, and relevance by enabling instructors to tailor learning content to meet the diverse needs of different groups of students.
v) BL provides the best of both worlds, offering greater flexibility and accessibility while maintaining essential F2F interaction. It is considered an effective and low-risk strategy addressing the transformational challenges posed by technological developments in higher education.

BL accommodates various learning styles, thereby enhancing and democratizing education (Gu, 2017). These learning styles are often supported through visual, auditory, reading, writing, and kinesthetic (VARK) methods to address the students' varied needs and interests (Roni, 2020). In the Visual mode, learners prefer maps, charts, graphs, diagrams, pictures, videos, simulations, and animations related to the material being learned. Aural learners benefit from explaining ideas and engaging in discussions with peers and instructors. Learners who favor reading and writing typically enjoy essays, reports, textbooks, and manuals available on online platforms. Kinesthetic learners, on the other hand, prefer hands-on and experiential activities, such as demonstrations, educational games, and tasks involving physical interaction with materials.

Teaching and learning in BL environments foster real-time interaction with learning materials, as well as continuous discussions with instructors and peers, and enable timely and actionable feedback, unlike CTM environments, where feedback is delayed (Keengwe & Agamba, 2015).

Furthermore, BL enables instructors to personalize learning experiences, thereby improving student engagement and academic achievement (Powell et al., 2015). It also promotes meaningful learning, supports deep-level understanding, and contributes to better learning achievement in chemistry (Niroj & Srisawasdi, 2014). In addition, BL contributes to the development of critical thinking skills in various areas (Lu, 2021) and facilitates the transfer of knowledge (Demirer & Sahin, 2013). Accordingly, BL has a lot of potential for structuring differentiated instruction in higher education because it combines in-person and online activities (Boelens et al., 2018). Its practice enables students to learn at their own pace through technology-supported, differentiated instruction. Consequently, a well-designed personalized BL environment provides learners with optimal conditions for knowledge acquisition (Lim & Wang, 2016). These advantages and features contributed to the growing interest in and widespread adoption of BL in educational contexts in recent years. Although BL offers several advantages, including flexibility, personalization, active engagement, and improved learning experiences, most studies have emphasized its general benefits rather than examining how these advantages translate into specific learning outcomes in chemistry education. Moreover, limited research has explored how BL supports diverse learners and promotes meaningful understanding of complex chemistry concepts, particularly in undergraduate CBMG learning contexts. Therefore, further empirical studies are needed to investigate the effectiveness of BL in enhancing chemistry learning experiences and outcomes.

2.7. International, Continental and national perspectives of Blended Learning

Conventional F2F instructional strategies in educational contexts are typically conducted in the physical presence of students within classroom settings. However, for individuals with conflicting demands and priorities that make regular on-campus attendance difficult or impossible, this teaching paradigm may be perceived as inequitable (Poquet et al., 2015). In contrast, online education allows students to pursue courses against CTM (Güzer & Caner, 2014). Despite this flexibility, the effectiveness of this instructional model has been questioned due to its perceived lack of individualized support. For this reason, the growth of the internet led to a rise in the popularity of BL as well as the development of new technologies like e-learning in educational environments (Zawacki-Richter & Jung, 2022). Both conventional F2F and online learning have inherent limitations, including a lack of self-paced learning and social interaction, respectively. To address these challenges, the contemporary educational system has increasingly adopted BL, which integrates the strengths of both conventional F2F and online learning (Hege et al., 2020). BL effectively bridges these two approaches, which reduces their drawbacks while enhancing the overall learning experiences.

At the beginning of the 2000s, BL became a widely accepted pedagogical strategy in educational settings (Güzer & Caner, 2014). The World Wide Web and the internet in general have naturally led to BL becoming the preferred style of instruction in many developed countries. Due to the expense of constructing ICT infrastructure or the lack of a reliable internet connection, many of the pedagogical advances that are regularly employed in developed countries have not yet been widely implemented in classrooms in developing nations (Reyes et al., 2022). Thousands of articles have been published on BL globally, with a substantial number originating outside of North America. This means North America is the leading country in which numerous articles have been published worldwide (Spring et al., 2016). They also identified and examined the most influential publications using the United Nations' regional classification from each of the following seven regions: Asia, Africa, Europe, Latin America, the Middle East, North America, and Oceania. A systematic review study revealed that BL adoption studies were carried out in Malaysia and the USA, followed by Australia, the UK, and Canada, respectively, among other countries (Anthony et al., 2022). However, BL is growing globally, and every region plays a significant role in the community.

Due to the popularity and growth of BL, Universities are fostering individualized learning plans for various student populations to meet the most desired learning objectives (Feng, 2022). The development and integration of ICTs to improve teaching and learning practices in a BL environment is particularly well-suited to tertiary science education (Reyes et al., 2022). Asia's higher education institutions adopted BL to replace interactive instruction. Higher education institutions in China, Korea, and Japan have experimented with BL and e-learning, with differing degrees of success (Tham & Tham, 2013). For instance, BL is highly received in China, but its predominance of CTMs makes it difficult for e-learning to become widespread. On the other hand, the findings of a systematic review study stated that little is known about BL and digital transformation in Latin America (Nunes & Malagri, 2023). Thus, it was discovered that the scarcity of research in the area makes it difficult to comprehend how this process occurs in Latin America.

The practice of BL strategies is still struggling in African countries due to the limitations of infrastructure and policy challenges, among other challenges (Okocha, 2019). However, universities in developing nations, particularly those in sub-Saharan Africa, are gradually using BL technologies for teaching, research, and student support (Aguti et al., 2015). In 2009, Kenya was the first country in sub-Saharan Africa to implement digital content for electronic learning, or e-learning, in schools, followed by South Africa and Nigeria (Redempta & Elizabeth, 2012). South Africa is the leading African country in the implementation of BL instruction (Tshabalala et al., 2014). However, several challenges persist, including perceptions related to BL policies, limited computer skills of lecturers and students, and inadequate computer access for students. Similarly, trends of BL and online learning in Ghanaian education are not well understood (Kumi-Yeboah et al., 2014). This adoption of BL is focused on F2F instruction with less emphasis on technology (i.e., 80% F2F and 20% online learning).

A summative evaluation of Partnership for BL and Enhanced Learning (PEBL) conducted in April 2021, indicated that 17 universities in East Africa are delivering PEBL BL modules, including seven in Kenya, four in Rwanda, three in Uganda, and three in Tanzania (Young, 2021). Ethiopia's technology strategy is strategically focused on ensuring that technology is an essential component of training and education at all levels and on promoting technology as a vital element in education (Tezera, 2019). Due to several issues, Ethiopia, as a developing nation, has not integrated ICT in teaching and learning to the same extent as higher education institutions in developed countries (Ergado et al., 2022). Moreover, few empirical research works have been published on BL in the context of Ethiopian higher education institutions. The purpose of these studies was to investigate the effect of BL on students' learning outcomes in instructional practices. Existing research studies focused on assessing the status of ICT-integrated technology and its implementation in educational settings at the secondary and tertiary levels.

Assessing technological readiness is imperative to measure the level of technological development at the macro level (Balkan & Akyüz, 2023). Technological readiness is directly related to the intervention of e-learning in the transformation of teaching and learning. In contrast, Figure 2.1 shows that developed countries such as Asia, Europe, and North America consistently rank at the top of the Inclusive Internet Index, both overall and across its four key dimensions: Availability, Affordability, Relevance, and Readiness (EIU, 2017). Their strong economic development facilitates the establishment of high-quality digital infrastructure, affordable internet services, relevant online content, and well-developed digital skills and literacy.

Figure 2.1: Pillars of the inclusive internet index: source (EIU, 2017)

According to the Economist Intelligence Unit (EIU, 2018), countries are ranked based on their e-readiness globally. In the report, 164 countries were ranked in 2013-2017, with Finland and Sweden in the top ten, also including a few Western European countries, Australia, and the advanced economies of Asia for the period of (2018–2022), which considers the predictions of analysts for the upcoming five years, the US and France join the top 10, while Australia, Singapore, and Sweden become the top-scoring places. According to this report, some African countries have also shown a considerable level of e-readiness. South Africa ranked 38^{th}, Kenya 67^{th}, Egypt 69^{th}, and Libya 81^{st} in 2013-2017. In the period (2018-2022), South Africa ranked 42^{nd}, Tunisia 63^{rd}, Egypt and Kenya 71st, Algeria 74^{th}, Nigeria $80^{th,}$ Libya 81^{st}, and Angola 82^{nd}. However, Ethiopia was not included in this survey on digital progress or e-readiness, nevertheless. Nonetheless, the Economist Intelligence Unit's Inclusive Internet Index report shows that Ethiopia ranked 69th globally and 20th in Africa in digital development and readiness, as indicated in Table 2.1. Although BL has expanded globally as an approach that combines the strengths of face-to-face and online learning, its adoption and effectiveness remain uneven across regions. Existing BL research is concentrated mainly in developed countries, while evidence from African and Ethiopian higher education contexts remains limited. Furthermore, few empirical studies have examined the implementation and effectiveness of BL in Ethiopian universities, particularly in discipline-specific areas such as mathematics, English language, and computer programming. Therefore, further context-specific research is needed to understand the potential of BL in improving undergraduate chemistry learning outcomes.

Table 2.1: E-readiness ranks of countries worldwide

Country	**Rank**	**Country**	**Rank**	**Country**	**Rank**
Singapore	1	Colombia	26	Kenya	51
Sweden	1	South Africa	27	Algeria	52
United States	3	Saudi Arabia	28	Pakistan	53
United Kingdom	4	China	29	Myanmar	54
Japan	5	Mexico	30	Cambodia	55
South Korea	6	Turkey	31	Nepal	56
France	7	Vietnam	32	Tanzania	57
Canada	8	Peru	33	Senegal	58
Netherlands	8	Morocco	34	Angola	59
Italy	10	Indonesia	35	Côte D'Ivoire	60
Australia	11	India	36	Cameroon	61
Germany	12	Egypt	37	Sudan	62
Poland	13	Iran	38	Rwanda	63
Spain	14	Mongolia	39	Uganda	64
Russia	15	El Salvador	40	Mozambique	65
Taiwan	16	Sri Lanka	41	Yemen	66
Romania	17	Venezuela	42	Burkina Faso	67
Brazil	18	Philippines	43	Zambia	68
Chile	19	Maldives	44	Ethiopia	69
Argentina	20	Nigeria	45	Malawi	70
Malayasia	21	Bangladesh	46	Madagascar	71

Ukraine	22	Uzbekistan	47	Mali	72
Thailand	23	Seychelles	48	Liberia	73
Oman	24	Ghana	49	Niger	74
Kazakhstan	25	Guatemala	50	Congo (DRC)	75

Source: EIU, 2017

2.8. Blended Learning in Higher Education Institutions

In higher education institutions (HEIs), learning involves acquiring knowledge, skills, and attitudes to solve problems effectively (Anthony et al., 2022). Nowadays, the demands on HEIs are rising globally, even though it is frequently criticized for their high costs, accessibility issues, dropout rates, and course quality (OECD, 2014). Additionally, HEIs frequently face challenges such as enhancing intercultural integration, lowering dropout rates, promoting smooth transitions from education to first jobs, and putting in place adaptable and pertinent lifelong learning processes (Castro, 2019). These challenges can be overcome through innovative structural transformations in educational environments (Redecker & Punie, 2013). Accordingly, approaches like BL and HEIs could offer several ways to address these issues and respond to external demands to successfully implement technological advancements in the classroom (Castro, 2019). BL is an innovative instructional approach that combines F2F instruction with online learning and is significantly changing teaching and learning in HEIs (Anthony et al., 2022). BL is becoming increasingly popular as a method for delivering knowledge in these institutions **(**King & Arnold, 2012**)**. HEIs are rapidly implementing BL programs, which are clear examples of organizational, pedagogical, and technical innovation (Castro, 2019). Thus, BL is an important instructional approach to foster SE and learning outcomes in the educational environment.

HEIs are striving to create engaging learning opportunities that meet the diverse needs of a digitally oriented generation **(**Tshabalala et al., 2014**)**. BL has recently emerged to address these needs and has been adopted in HEIs. Because BL combines the benefits of both conventional F2F and online approaches, it is widely used in HEIs **(**Poon, 2014**;** Smyth et al., 2012**)**. HEIs require individualized engagement and self-regulated learning because their students are adults. The development of digital technology has forced HEIs to implement online education as a supplement to their regular conventional F2F instruction (Oshima et al., 2024). Additionally, young learners are digital natives and can easily access learning materials and information via the internet, leveraging their familiarity with technology to enhance their educational experiences (Thompson, 2013; Xu et al., 2020). Students in HEIs are expected to develop higher-order thinking skills through their learning materials and concepts, and need to have access to innovative learning for their future careers. Students in HEIs are increasingly knowledgeable about internet resources and technologies, recognizing their utility for academic purposes (López-Pérez et al., 2011). As young learners, students in HEIs may use online learning regularly and responsibly to increase their flexibility by letting them work at their own pace and time. Therefore, undergraduate students who are familiar with technology require a digital learning platform to enhance accessibility in their learning environment.

Most universities are reluctant to use high-risk strategies, either alone or in combination, because there is a lack of clear guidance on how the higher education system would need to adapt to meet the demands of students (Rusman, 2016). In light of this, this researcher also stated that it is crucial to set out to develop a conceptual framework for teaching science that targets upper secondary and lower-level university students and integrates formal and informal learning contexts in BL scenarios using BL, new pedagogies, and formative assessment techniques. Furthermore, Universities are increasingly using the BL strategy because of its apparent efficacy in delivering flexible, continuous, and timely learning **(**Prasad et al., 2018**)**. They also reported that blended learning (BL) is widely used as a teaching tool in Western universities; however, this may not have been the case in institutions that educate international students from regions such as Asia, Africa, or the Middle East. Furthermore, over 80% of HEIs in developed nations are actively engaging in the use of e-learning systems to support their teaching and learning (Aguti et al., 2015). They noted that HEIs in developing countries, particularly in sub-Saharan Africa, are increasingly adopting e-learning technologies for teaching, research, and enhancing student learning, aiming to achieve the same benefits enjoyed by developed economies. However, universities in sub-Saharan Africa face various challenges, such as large class sizes, limited ICT infrastructure, high illiteracy rates, ineffective maintenance of computer systems, and inadequate ICT support (Brenya, 2024; Ololube et al., 2013; Reyes et al., 2022). This problem might also be commonly known in the Ethiopian context.

The research studies conducted in HEIs regarding BL profoundly affect the growth of BL literature (Platonova et al., 2022). The study's findings have shown that, compared with teacher support, digital support better engaged students in BL by satisfying their needs **(**Chiu, 2021**)**. This is because learning through digitalization tends to visualize the invisible phenomena of learning concepts. Furthermore, the findings of studies in many works of literature asserted that BL may positively impact student learning engagement and learning outcomes (Anthony et al., 2022; Lim & Graham, 2021). However, other research findings on BL have shown contradictory outcomes. For instance, the findings of a meta-analysis indicated that there was no significant difference in students' academic performance between BL and CTMs in quantitative literacy courses in the USA (Cao, 2023). Similarly, the findings of a quasi-experimental study revealed that no significant difference was found between undergraduate students' achievement and motivation in a computer technology course taught via BL and CTM (Meşe & Dursun, 2019). On the other hand, the study findings asserted that there was no statistically significant difference between the two groups of undergraduate students who were taught mathematics through BL and CTM in their achievement (Yudt et al., 2024). BL could enhance the quality of learning when implemented effectively. Although BL has been increasingly adopted in HEIs and has shown potential to improve learning experiences, existing findings regarding its effectiveness remain inconsistent across contexts. Moreover, most BL research has focused on general academic outcomes, with limited attention to discipline-specific applications in chemistry education. In particular, the effectiveness of BL in enhancing undergraduate students' learning of complex chemistry concepts such as CBMG remains underexplored, especially in the Ethiopian higher education context.

2.9. Blended Learning in Science and Chemistry Classrooms

The advancement of science and technology has significantly improved the quality of education(Good, 2021). However, contemporary classrooms struggle to provide high-quality formative feedback and personalized instruction while offering engaging and interactive opportunities for students to explore scientific phenomena (Horn et al., 2014) . Additionally, the researcher suggested that 21st-century skills, such as critical thinking, application of knowledge, and real-world problem-solving, can be developed and strengthened with the help of BL. BL is an instructional approach frequently utilized in higher education institutions, combining F2F instruction with online learning activities and feedback (Schettini et al., 2020). BL has the potential to make science real in the lives of students. Although BL represents an emerging paradigm for science education, it has not yet been thoroughly evaluated (Stockwell et al., 2015).

Chemistry is one of the core STEM disciplines require a deep understanding of numerous abstract and complex concepts (Stanley, 2022). As an empirical science, understanding the various concepts requires a lot of visualization and modeling at the molecular level of chemical phenomena (Jones & Kelly, 2015). However, the limited time allocation and the practice of CTM make chemistry learning less effective (Fitriyana et al., 2020). To enhance academic performance and retention, chemistry instruction must adopt effective instructional strategies that promote an interactive learning environment for meaningful learning and understanding of concepts (Edem & Anari, 2021). Due to the complexity of these concepts, chemistry instruction needs an innovative instructional approach. The evolution of BL has transformed education in all disciplines, but its implementation in a chemistry course presents a promising issue to improve the quality of chemistry education (Nugraheni et al., 2020). Integrating computer-based technologies, such as simulations and virtual environments, with model-based instructional strategies is an effective approach for enhancing students' visualization and CU of unobservable scientific phenomena (Haraldsrud & Odden, 2024). Furthermore, a computer-based instructional approach enables the dynamic visualization of the nature of atoms, ions, and molecules, making it more effective than the CTM in chemistry learning (Khoshouie et al., 2014).

Over the past few decades, the use of BL in chemistry has grown significantly (Nugraheni et al., 2020). Aside from other restrictions, policy challenges, and infrastructure issues continue to hinder the use of BL in Africa (Okocha, 2019). Although BL in chemistry is still underutilized, it increases students' efficacy by increasing their interest and motivation in this discipline (Fitriyana et al., 2020). Besides, numerous studies have shown that one of the best ways to improve the standard of chemistry education is through BL. For instance, the study revealed that BL, significantly more than CTM, supports a shift in students' CU of the rate of chemical reaction topics (Olakanmi, 2017). Exam results reveal a considerable increase in BL in general chemistry modules utilizing a Moodle platform, and there is a correlation between the amount of time students spend on the site and their achievement. (Schettini et al., 2020).

BL has also been implemented in specific fields of chemistry to evaluate its effectiveness in students' learning. For instance, the findings of a qualitative study of BL showed that the F2F component was appreciated for providing a thorough explanation and opportunities for questions, while the online component was valued for its adaptability and for giving students multiple chances to practice or review concepts in organic chemistry courses (Tekane et al., 2020). Similarly, the use of BL with Android-based educational games has significantly enhanced students' self-efficacy and performance in secondary school chemistry lectures (Fitriyana et al., 2020). In another study, BL improves students' learning achievement and critical thinking skills in biochemistry courses (Yennita & Zukmadini, 2021). All students were able to meet the mastery learning outcome, according to a study on the efficacy of BL in a physical chemistry creative media course (Yonata & Novita, 2021). An experimental study showed that problem-based learning aided by BL improves students' cognitive knowledge more than BL alone in an analytical chemistry lesson (Dumanaw et al., 2020). Despite BL having shown promise in improving chemistry learning outcomes, existing studies have mainly focused on general chemistry topics and broad academic outcomes. Limited research has examined the effectiveness of BL for teaching complex and abstract chemistry concepts, particularly CBMG, which require visualization across multiple levels of representation. Therefore, further empirical investigation is needed to determine the effectiveness of BL in enhancing undergraduate students' understanding of CBMG concepts.

2.10. Design and Implementation of Blended Learning

BL in higher education can be a means to provide all learners with equitable access to educational experiences that are more engaging and effective than face-to-face learning alone. However, universities may lack the capacity to take up these opportunities to design and implement BL that engages students and supports them in meeting the learning outcomes of the course (Lim & Graham, 2021). Even though BL can improve the flexibility and engagement of the student learning experience, it might be challenging to successfully redesign current courses. Moreover, the lack of specific guidelines for mixing up the ingredients, clear goals, and objectives (Smith & Hill, 2019) and an agreed-upon definition (Alammary et al., 2014; Mirriahi et al., 2015) influences the design and implementation of BL in educational settings.

The relative effectiveness of BL versus CTM is determined by the degree of blending of the course and the nature of the blended materials **(**Kiviniemi, 2014**)**. The successful implementation of a high-quality BL approach needs careful planning and instructional design to ensure learning effectiveness and support students' transition to new approaches of teaching and learning (Posey & Pintz, 2017). Recent studies highlight that effective implementation of BL requires the intentional integration of face-to-face and computer-mediated instructional strategies, grounded in pedagogical principles that promote meaningful student–teacher, student–student, and student–content interactions to enhance engagement and learning outcomes(van der Stap et al., 2024). Well-designed and implemented BL is very powerful and enables more authentic learning by allowing individuals to learn, recall, and apply what they learned (Hofmann, 2018). Hence, a comprehensive plan for technology infrastructure, implementation strategies, and ongoing operations must be developed to effectively integrate BL into the existing teaching and learning methods in HEIs (Lim & Wang, 2016). Systematic implementation of the BL approach requires dynamic leadership, teacher commitment, peer mentoring, systematic planning, and continuous monitoring at the institutional level (Shinde, 2020).

BL represents a fundamental redesign of the instructional model that shifts from lecture-centered to student-centered instruction, transforming students into active and interactive learners (Poon, 2013). However, designing an effective BL environment remains a significant challenge because it requires the careful alignment of pedagogical approaches, technological tools, and learning activities to create meaningful and integrated learning experiences(van der Stap et al., 2024). Poor BL design and implementation, such as a lack of instructional variety and insufficient support, can negatively affect the learning experience (Müller & Mildenberger, 2021). To address these challenges, understanding the purpose of BL design is essential. The researchers (Huang et al., 2008) identified three fundamental reasons for BL implementation in classroom settings: to support large-group learning through blended curriculum design, to engage students beyond the classroom, and to foster the development of professional development skills. Furthermore, the researchers (Alammary et al., 2014) have proposed different design strategies to guide the implementation of BL, which are categorized into three distinct BL design approaches based on how they modify existing curriculum and influence students' learning process (Alammary et al., 2014).

1. **Low-impact blend: adding extra activities to an existing course. T**his approach involves supplementary online activities to the conventional face-to-face instructional approach without eliminating any of the existing activities. This approach is mostly established when inexperienced teachers build their first BL courses.
2. **Medium-impact blend: replacing activities in an existing course:** this strategy involves redesigning an existing course by replacing online components with some of the in-person activities. This method is predicated on the idea that some course material would be better served as online exercises.
3. **High-impact blend: building the blended course from scratch. I**n this model, the BL course is built from scratch. This category of BL designs is recommended for exploring the potential transformation in the existing teaching program and student learning experience within the educational environment. In general, it is widely recommended that instructors begin with a low-impact approach to BL. As they can gradually gain experience with the medium-impact approach. Only after developing sufficient expertise, experience, and familiarity with BL should they adopt a high-impact approach (Alammary et al., 2014).

The BL approach lacks a universally accepted definition, leading educators to adopt a variety of models tailored to their classroom environments (Alammary et al., 2014; Ashraf et al., 2021). This diversity in implementation reflects the flexibility of BL, which combines conventional F2F instruction with online learning components to enhance SE and learning outcomes. However, such variation also results in inconsistencies across implementations, particularly in terms of the design, pedagogical approaches, the proportion of online to F2F time, the purpose of blending, and the role of technology (Mirriahi et al., 2015). For a better understanding of these variations, the BL approach can be categorized into different course design models such as supplemental, replacement, emporium, fully online, and buffet (Tekane et al., 2020). Each of these models possesses distinct features and characteristics that guide the design and implementation of BL environments.

Replacement Model: This kind of BL model reduces the F2F lectures by partially or completely replacing F2F lectures with online learning components. In such models, in-person lectures are often replaced with video lectures made available online, while scheduled class time is repurposed for problem-solving activities and addressing students' questions. Due to the shift to online learning, settings are typically used for problem-solving and answering questions about the lecture. However, there is no standard approach to blending autonomous online learning, synchronous or asynchronous online learning, and a conventional F2F instruction-based classroom learning approach (Kumar et al., 2021). As a result, the proportion of blending conventional F2F and online learning varies in different practices of learning experiences. For instance, a meta-analysis study stated that the instructional condition of BL should have at least equal proportions (50% F2F and 50% online) or 25% online and 75% F2F (Bernard et al., 2014). Other studies indicate different optimal balances, such as 30% F2F and 70% online (Anthony et al., 2019). Some findings indicate that successful BL comprises 80% online learning integrated with a 20% F2F approach (Owston et al., 2019). These variations indicate that BL doesn't follow a one-size-fits-all model; the proportion of F2F and online learning should be based on instructional goals, course design, and educational settings.

Supplemental Model: This model retains regular F2F meetings while providing additional learning materials through online platforms. In this approach, students are expected to use technology-based learning resources, complete homework, or engage further with the course content. The supplemental form of BL was created to help students benefit from an online homework system that offers real-time feedback, encouraging them to engage more deeply with their assignments and stay on track with the course (Tekane et al., 2020).

Emporium Model: This type of BL model replaces F2F class meetings with a learning resource center that offers online materials and on-demand personalized support. In this model of BL, learning is facilitated through technology-rich environments rather than scheduled classroom sessions. This model relies heavily on instructional software, including interactive tutorials, computational exercises, electronic hypertext books, practice exercises, answers to frequently asked questions, and online quizzes.

Buffet Model: This blended model provides a variety of in-person and virtual learning experiences, allowing students to select any combination that best suits their needs, schedule, or lifestyle. In the present study, the design aligns with the supplemental model of the BL approach that comprises the integration of conventional F2F learning and additional learning materials and supports available online. BL implementation usually involves conventional F2F and other corresponding online learning delivery methods. BL is not limited to merely integrating F2F and online learning environments, but rather it involves a methodological reconstruction of several components, including learning materials, teaching methodologies, learning strategies, learning settings, learning technologies, and teaching and learning models (Li et al., 2024). Figure 2.2 presents the Key aspects of BL in the learning environments. Although BL has considerable potential to enhance flexibility, engagement, and learning outcomes in higher education, effective design and implementation remain challenging. Existing studies highlight the importance of instructional planning, pedagogical alignment, and institutional support; however, limited research has examined how specific BL design models and implementation strategies influence learning outcomes in discipline-specific contexts. Furthermore, the absence of a universally accepted BL framework has resulted in inconsistent practices, particularly in developing higher education settings. Therefore, context-specific research is needed to determine effective of BL designs for enhancing chemistry learning.

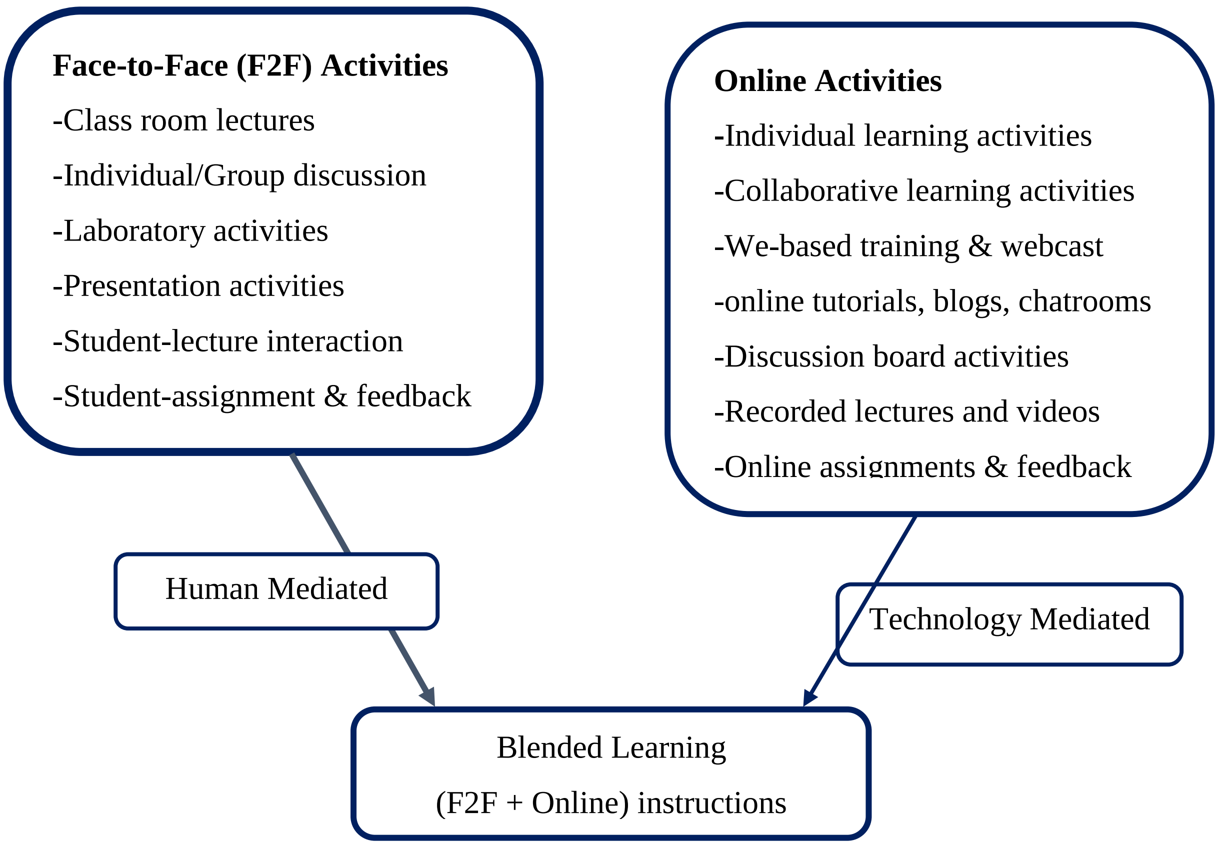


Figure 2.2: Key aspects of blended learning

2.10.1. Blended Learning Environment

Establishing an effective learning environment in contemporary educational institutions involves multiple factors, combining high-quality instruction with efforts to enhance these elements (Tezera, 2019). Nowadays, the technological innovation paradigm has integrated online learning resources with conventional F2F classroom instruction. Technology-mediated instruction employs ICT to mediate the learning experience and interactions without requiring that students and teachers be in the same location, while conventional F2F instruction involves interactions between instructors and students in a shared setting (Graham & Dziuban, 2008). Furthermore, the BL approach integrates multiple modes of communication, such as synchronous, asynchronous online, and F2F, to foster SE in deep learning through reflection (Oshima et al., 2024).

Pedagogical transformations prioritizing student-centered approaches and maximizing active engagement, such as competency-based education and flipped classrooms, are becoming essential components of hybrid learning settings (Mulenga & Shilongo, 2025). BL promotes higher-order learning skills, active learning, and self-regulated learning (Horn & Staker, 2014; Varthis, 2016). Besides, it is an adaptable teaching approach that addresses students' diverse needs while providing the necessary support to help them achieve their full potential (Varthis, 2016). BL also offers flexible learning, enabling students to regulate their learning activities in terms of time, place, path, and pace, which facilitates interactions with peers and instructors(Michael & Heather, 2015). Moreover, students in a BL environment are given additional opportunities to monitor and manage their progress, thereby developing capacity for self-directed learning (Lim & Graham, 2021). Therefore, the BL environment fosters social interaction and collaboration features that are often limited in a fully online learning system.

BL promotes a dynamic learning environment in the classroom or online that allows students to interact with the material in a targeted, sophisticated, and engaged manner (Olatunde-Aiyedun & Adams, 2022). By combining multiple instructional modalities with a flexible schedule, BL seeks to minimize the drawbacks of online and F2F learning while examining student engagement and promoting sustainable learning outcomes (Ali et al., 2023). In doing so, it capitalizes on the advantages of conventional F2F and online learning and can reduce the drawbacks of both learning formats (Dangwal, 2017; Hege et al., 2020). Furthermore, BL has supported the development of students' problem-solving, collaborative, and other higher-order thinking skills (Li et al., 2024). It is closely aligned with constructivist learning theory, which views learning as an active process in which learners construct knowledge through experience and interactions (Sachin & Pathak, 2024). An environment encourages a more dynamic classroom environment that engages students with the subject matter in a focused and well-organized manner (Olatunde-Aiyedun & Adams, 2022). In contrast, CTM discourages the learner's critical thinking and lacks flexibility, collaboration, and group learning (Singh & Malik, 2022). Furthermore, CTMs struggle to adapt to the rapidly evolving knowledge landscape and the diverse ways in which information is accessed in the 21st century (Li et al., 2024). Therefore, BL emerges as a pedagogical approach that responds effectively to these contemporary educational demands.

The modern educational system in today's dynamic society emphasizes individualized, collaborative, and interactive learning strategies to enhance students' learning outcomes. BL environments support deep learning by facilitating student-student, student–teacher, and student–content interaction (Eren & Dökme, 2022). Accordingly, BL represents the redesign of an instructional model, shifting from a lecture-centered to a student-centered approach, where students become active and interactive learners (Poon, 2014). It serves as a vehicle for delivering individualized and competency-driven learning (Horn & Staker, 2014). Furthermore, BL aligns with the constructivist approach to education, which highlights the active role of the learner in constructing knowledge rather than merely absorbing information from the teacher (Lee et al., 2016). Through active learning strategies, students are encouraged to think critically, solve problems, and apply knowledge in real-life situations(Dogani, 2023). BL facilitates these changes through personalized learning, discussion forums, cooperative learning, and immediate feedback. Thus, it functioned as a differentiated instructional approach capable of addressing diverse learner needs of all students and improving overall learning outcomes (Boelens et al., 2018; Horn & Staker, 2014). However, despite these advantages, the effective integration of ICTs into instructional practices remains a significant challenge in many developing nations, resulting in slower adoption of digital and BL pedagogies (Reyes et al., 2022).

Adapting an effective BL environment is essential for enhancing students' learning experience and addressing their diverse needs and interests. An effective BL paradigm encompasses several key elements, including STEM instruction that emphasizes inclusivity, follows effective constructive alignments, and harmoniously incorporates e-learning into F2F instruction (Hains-Wesson & Tytler, 2015). According to the researcher (Torrisi, 2011), the development of effective BL is based on three dimensions:

1. **Learning experience**: learner-centered experiences that lead to active participation, addressing the diversity of needs among learners, and supporting learners to take a deeper approach to learning.
2. **The strategies**: constructive alignment regarding learning outcomes, teaching methods, assessment tasks, and a focus on universal design that is flexible with variation in learning environments; and
3. **The tools are used to implement strategies**: ICT to implement and improve innovation.

Although BL has been recognized as a student-centered approach that integrates the strengths of face-to-face and online learning, limited research has examined how BL environments are effectively designed and implemented to support meaningful learning in specific disciplines. Moreover, challenges remain regarding the integration of ICT, pedagogical alignment, and learner-centered practices, particularly in developing higher education contexts. Therefore, further research is needed to explore effective BL environments that enhance students' learning experiences in chemistry education.

2.11. Challenges of Designing and Implementing Blended Learning

BL represents a new pedagogical paradigm with significant potential to enhance learning outcomes; however, its successful implementation faced several challenges in instructional strategies. The existence of any challenges in the BL design and implementation leads learners and teachers to discourage them within learning settings. A key challenge for BL designers is determining how to effectively bring the real-world context into the classroom settings. Emerging learning technologies offer the potential to embed learning within authentic contexts within the contexts, problems, and environments and work environments, thereby bridging theory and practice (Kirkley & Kirkley, 2005). Despite increased internet access and availability of educational technology in learning environments, many teachers still struggle to integrate these technologies into instructional strategies due to a lack of knowledge of technology, time, and support (Guzey & Roehrig, 2012). Additionally, technological barriers such as a lack of integration, interoperability, and convergence among platforms can hinder the adoption of innovative tools (Castro, 2019). Other reported challenges include inadequate facilities (e.g., computer labs, reliable internet), insufficiently trained teachers, limited access to computers at home, and a lack of parental support, all of which can negatively affect BL implementation (Kotienieva & Kurlishchuk, 2019).

Moreover, limited social interaction and influence during learning hinder the active engagement of students, representing a significant challenge in the design and implementation of BL (A. N. Amiruddin et al., 2022). This suggests that students easily become discouraged when instructors and their peers are not readily available in the classroom. Additionally, inadequate facilitating conditions, such as limited technological skills among students and instructors, as well as insufficient infrastructure, are the major challenges in the implementation of BL. Furthermore, despite the widespread adoption of BL, the absence of a universally agreed-upon definition remains a challenge because varying conceptualizations of BL affect how educators design, implement, and evaluate BL environments (Hrastinski, 2019). This lack of a universally accepted definition of BL leads to inconsistent practices among educators. Accordingly, instructors who are unfamiliar with BL may encounter significant challenges due to varied interpretations and design approaches resulting from the ongoing debates about its meaning (Alammary et al., 2014). Similarly, the lack of an institutional definition and limited instructors' capacity to effectively engage with BL raises the possibility of misinterpreting its tenets and procedures (Mirriahi et al., 2015). Besides, the lack of clear policies, insufficient staff training, and limited access to computer laboratories significantly hindered the effective implementation of BL initiatives **(**Tshabalala et al., 2014**)**.

Four major challenges in the design of a BL environment have been identified by the researchers (Boelens et al., 2017): a) *the need for flexibility*: emphasizing providing students with a certain degree of control over the time and space of learning, as well as the organization of the curriculum, including the sequence of contents and pace of learning. It also involves choosing the most appropriate learning modality (F2F or online) for specific learning activities. b)

Interaction stimulation: developing face-to-face and online communication between teachers and students, which enables the effective integration of these modalities, maximizing the benefits of each within the educational relationship. c) *Support for students' learning processes***:** in BL environment, self-regulated learning impacts positively on academic success, thus educators necessarily employ learning approaches to design learning (difficulty of the task, expectations and goals, prior knowledge, time required) control of the process (continual feedback), adaptation based on results obtained (change in the development of the process) and self-evaluation of the learning. and d) *the creation of a positive learning environment:* creating a conducive learning environment that offers the student security, positive attitudes, and the feeling of belonging to the group to favor intrinsic motivation, creativity, and subjective well-being. The challenges encountered in designing and implementing BL may vary based on the specific context in which the learning is applied. This means that the challenges of BL design and implementation faced in developed countries may differ from those encountered in developing nations.

In the Ethiopian context, the researcher (Aweke, 2019) identified challenges, such as integrating BL into traditional universities, limited students' exposure to computers, frequent power outages, and the need for strict punctuality in BL, which are likely the main barriers for prospective students enrolling in BL courses. The findings of a mixed research approach conducted in Haromaya University demonstrated several challenges in the implementation of instructional technologies, including limited awareness of their importance, low motivation among both teachers and students, a shortage of technical staff and human resources, insufficient administrative support, weak collaboration among teachers and between the school and parents, improper use of available resources, time constraints faced by teachers, inadequate infrastructure, and a lack of consistent follow-up. Furthermore, the findings of the phenomenological design highlighted new challenges of implementing BL, including distractions from social media and leisure technologies, which negatively affect their concentration and study planning in HEIs (Lobos et al., 2024). Therefore, the challenges of BL arise not only from the learning facilities but also due to difficulties in designing the learning environment.

Although BL has gained attention as an effective instructional approach, its successful implementation remains challenged by technological, pedagogical, institutional, and learner-related factors. Existing studies have identified various BL challenges; however, most have focused on general educational contexts, with limited attention to how these challenges influence BL implementation in specific disciplines such as chemistry. Moreover, evidence from developing higher education contexts, particularly Ethiopia, remains scarce. Therefore, further context-specific research is needed to identify and address the challenges affecting BL implementation in chemistry education.

2.12. Moodle Learning Management System as a Learning Platform

BL can be implemented by using various open-source platforms, such as a free Learning Management System (LMS). An LMS is software used for administration, recording, monitoring, reporting, and distribution of online training courses. It serves as an institutional digital space with the potential to function as a learning, social, and communication environment (Ng'ambi, 2011). LMS can contain a variety of content such as syllabi, videos, lessons, tasks, quizzes, tests, forums, important schedules, collaboration spaces, and assessment tools. Moreover, LMS enables students to work cooperatively through the discussion forum, where questions are asked and shared ideas are discussed. There are several open-source LMS platforms such as Moodle, Coursework, Eliademy, Integrated Learning, Information and Work Cooperation System (ILIAS), Atutor, and Interact (Zakaria & Daud, 2013). Moodle (Modular Object-Oriented Dynamic Learning Environment) is widely utilized due to its convenience and nature. Moodle is an educational web platform designed based on the social constructionist approach, which emphasizes that students can contribute to the educational process in a variety of ways (Lin et al., 2017). This approach is grounded in the premise that individuals learn most effectively when they actively engage in creating and sharing knowledge with others. Furthermore, Moodle is a highly advanced LMS that offers numerous modules and applications within the educational context, allowing for the development of an online component to enhance classroom lessons (Vitošević et al., 2014). Moodle was utilized in the presented teaching model, enhanced student interest, improved attendance at F2F lectures, and positively impacted both formative and summative scores (Popovic et al., 2018).

Moodle, an LMS that serves as the primary learning platform for delivering the e-learning component of BL (Lin et al., 2017). It is a popular, user-friendly, and adaptable LMS that supports hybrid learning, enabling students to engage in personalized and collaborative experiences with their classmates and teachers, particularly in classroom activities (Zainuddin & Keumala, 2018). Unlike many LMS that are tool-centered, Moodle is learning-centered, emphasizing the sharing of ideas and collaborative knowledge construction (Cole & Foster, 2007). Additionally, an advantage of this type of LMS is its familiarity with students and the inclusion of many e-learning tools, such as quizzes, journals, blogs, and discussion forums. Moodle LMS is used to upload assignments and upload lecture or lesson learning materials, which are used during lectures (Sandanayake, 2019). Moreover, students download these learning materials, read instructions, and interact with professors and classmates through discussion forums to grasp the learning concepts. Then, students are expected to upload their tasks and assignments after completing them, allowing the professor to check them using the same platform. Finally, the instructors or professors provide feedback on the activities and assignments either through the online platform or in the conventional F2F learning environment. Although Learning Management Systems (LMS), particularly Moodle, are widely used to support BL, existing research has mainly focused on their technical features and general educational benefits. Limited attention has been given to how Moodle-supported BL facilitates students' CU, SE, and learning processes in specific disciplines such as chemistry. Therefore, further investigation is needed to examine the role of Moodle-based BL in enhancing undergraduate chemistry learning, particularly for complex concepts such as CBMG.

2.13. Students' Learning in Science and Chemistry Education: Conceptual Understanding, Student Engagement, and Epistemological Beliefs

Students develop an understanding of chemical phenomena and form mental models when using a variety of visualization tools in the teaching and learning of science, particularly chemistry (Herga et al., 2014). Models play a crucial role in advancing scientific literacy as they are fundamental components of both scientific methods and scientific knowledge (Develaki, 2019). Science topics require good and modern learning strategies for students to gain more understanding for academic achievement (Alsalhi et al., 2021). Research indicates that teaching science concepts alone using computer technology is insufficient for students to acquire science process skills. Computer technologies are more successful in teaching science than CTM (Çelik, 2022). To address these challenges, integrating multiple learning approaches can enhance students' conceptual understanding and skills. The modernization of the pedagogical approach and the implementation of BL significantly increase students' learning outcomes in general chemistry (Bernard et al., 2017). Furthermore, the findings of a systematic review study showed that BL has increased students' understanding, achievements, motivation, metacognitive, and critical thinking skills in chemistry (Stanley, 2022).

The effectiveness of BL has been observed in studies in other science disciplines. For instance, BL enhances students' learning and teachers' instruction in mathematics, improving learning attitudes, self-study techniques, and academic performance (Tong et al., 2022). Similarly, BL has the potential to improve students' learning performance in health science courses (Kiviniemi, 2014). In contrast, the preservice teachers in the BL format had significantly better attitudes than in the conventional F2F format, but no differences in mathematics achievement were found (Yudt et al., 2024). However, much of the existing literature evaluates BL effectiveness in terms of learning outcomes rather than examining the processes that lead to those outcomes, such as SE that resulted in those differential learning outcomes (Chamberlain et al., 2014). This suggests that most studies emphasize learning products rather than the learning processes. Although BL has demonstrated potential to enhance students' learning outcomes and CU in science education, most studies have focused primarily on achievement outcomes rather than the learning processes that contribute to these outcomes. Limited attention has been given to how BL promotes SE and active knowledge construction, particularly in chemistry education. Therefore, further research is needed to examine the processes through which BL influences students' learning in chemistry contexts.

2.13.1. The Students' Conceptual Understanding in Science and Chemistry Education

The primary goal of science education is to develop a deeper understanding of scientific concepts (Zou et al., 2024). Additionally, promoting students' CU and addressing persistent MCs remain fundamental aims of science education, particularly in chemistry, where students frequently encounter difficulties in connecting macroscopic observations, submicroscopic processes, and symbolic representations (Luxford & Bretz, 2014). In 21st-century science learning, the key learning outcomes include CU, thinking abilities, and problem-solving abilities (Resbiantoro & Setiani, 2022). CU refers to students' ability to apply scientific knowledge to real-world phenomena (Fatacharmita et al., 2024). In the same vein, CU refers to students' ability to explain, differentiate, provide examples, and connect what they know to new knowledge (Susilaningsih et al., 2019). In chemistry education, conceptual understanding requires the ability to interpret and analyze chemical phenomena across three modes of representation: macroscopic, submicroscopic, and symbolic (Enero Upahi & Ramnarain, 2019). Developing a deep understanding of chemistry concepts depends on the student's ability to move flexibly between these levels of representation (Gabel, 1999). Accordingly, CU in chemistry is achieved when students engage higher-order cognitive processes to construct internal representations or mental models that integrate these levels of chemical phenomena (Johnstone, 1991; Langitasari et al., 2024).

The three-level representations of chemical phenomena are essential for an understanding of abstract concepts in chemistry. These include (a) Macroscopic representations, which involve observable characteristics of matter, such as color changes, gas evolution, and precipitate formation; (b) Submicroscopic representations, which refer to phenomena that cannot be directly observed, such as particle interactions during dissolution; (c) Symbolic representations, which include symbols, formulas, or graphical representations such as solubility diagrams and periodic table symbols. In practice, CTMs in chemistry primarily focus on symbolic domains, whereas laboratory courses have emphasized the macroscopic level (Verangel & Prudente, 2023). As a result, the submicroscopic level, being abstract and difficult to visualize, receives comparatively less attention, leading to challenges in students' understanding of the particulate nature of matter. A mental model of the three levels of chemical knowledge and their interconnections is essential for students to develop a CU of any given chemical topic (Suits, 2015). Consequently, helping students develop a CU of the submicroscopic, as well as their ability to interpret and construct representations, remains a significant challenge in chemistry education (Herga et al., 2016).

Students' interests in science, their attitudes and beliefs about their own abilities, significantly influence their understanding of scientific concepts (Nieswandt, 2007). These factors enable students to move beyond rote memorization and to explain everyday phenomena using scientific knowledge. The use of computer visualizations in inquiry-based activities has been shown to enhance students' understanding of molecular interactions and support effective knowledge integration(Niroj & Srisawasdi, 2014). Moreover, dynamic visualizations could enhance chemistry learning by making invisible submicroscopic processes more accessible and by helping students establish connections across macroscopic, submicroscopic, and symbolic levels of representation (Herga et al., 2016; Lin & Wu, 2021; Suits & Sanger, 2013). Despite these advancements, many studies report that students are unable to understand the concepts of chemistry, particularly chemical bonding (Bergqvist & Chang Rundgren, 2017; Yayon et al., 2012; Yip et al., 2019). These difficulties lead students to hold MCs, which affect their learning outcomes. These challenges attributed to the practice of inappropriate instruction and limited opportunities for hands-on experience (Boachie et al., 2023). In particular, CMT has been challenging in developing the CU of chemical concepts (Yip et al., 2019). However, difficulties in visualizing the chemical phenomena at the molecular level can be addressed through an innovative instructional approach that integrates all three levels of representation (Herga et al., 2016). Therefore, promoting meaningful understanding of abstract concepts in science and chemistry requires the adoption of appropriate instructional strategies that effectively incorporate visualization tools and representational integration.

The key concern in science education, particularly chemistry, is helping students understand scientific concepts through the practice of effective instructional approaches in the learning environment (Zou et al., 2024). Several empirical studies reported that the use of diverse instructional approaches can enhance students' CU in science, particularly in chemistry. For instance, the results of a mixed-methods research study showed that secondary school students' CU of chemistry enhanced from 37% to 71% by using multi-representation teaching materials (Susilaningsih et al., 2019). Similarly, the adaptation of modeling instruction in secondary school chemistry enhances students' CU (Dukerich, 2015). Furthermore, the students who were taught through the conceptual change text with the analogies model better understand chemical bonding concepts than those who were trained through the conventional textbook and analogies model (Pabuçcu & Geban, 2012). Similarly, the study also reported that the students’ CU of chemistry increased using the SiMaYang learning environment in the medium category (Langitasari et al., 2024).

In contrast, the findings of a quasi-experimental design study have reported inconsistent results regarding the effectiveness of instructional approaches on students' CU. For instance, no statistically significant difference in undergraduate students' CU of pH between those who received a collaborative computer PhET simulation and those who used CTM (Watson et al., 2020). Similarly, the study found that grade 12 students who participated in an inquiry-based intervention did not experience significant improvement in their understanding of the biological concepts (Baytelman et al., 2023). Conversely, other studies study has found that undergraduate students who learned chemical equilibrium through argumentation and hands-on laboratory work outperformed their peers who received CTM guidance on concept-based assessments. However, students taught through direct instruction performed significantly better on the comprehensive final examinations (Aydeniz & Dogan, 2016). These findings suggest that the effectiveness of instructional approaches may vary depending on the type of assessment and learning context. Although promoting students' CU is a central goal of chemistry education, many students continue to experience difficulties in integrating macroscopic, submicroscopic, and symbolic representations of chemical concepts. Existing studies have examined various instructional approaches to improve CU, but findings remain inconsistent across contexts. Moreover, limited research has investigated the effectiveness of BL in enhancing undergraduate students' CU of complex chemistry concepts, particularly CBMG, in the Ethiopian higher education context.

2.13.2. Students' Conceptual Understanding in Chemistry Education

The capacity to integrate information into coherent concepts is known as conceptual comprehension (Boachie et al., 2023). Better CU more important objective of educational interventions and policy modifications (Bisson et al., 2016). In terms of knowledge competencies, CU is linked to science concepts since it is one of the core competencies in studying science (Widiyatmoko & Shimizu, 2018). Therefore, understanding science concepts, particularly chemistry, is critical for students. Chemical bonding is a fundamental concepts studied fully conceptualized, and understands the other chemistry topics (Gumonan & Bug-os, 2021). However, students frequently experience difficulty in understanding chemical concepts, which often leads to the development of MCs (Inayah et al., 2020). Besides, memorizing procedures without comprehension aligns with curricular approaches that prioritize content coverage over CU (Mills, 2016). CBMG is a complex concept and difficult for the majority of students to understand because it requires visualization of abstract phenomena, as well as advanced reasoning skills (Tsaparlis et al., 2018). This is because the concepts of CBMG are difficult to understand, and the abstract and submicroscopic nature of chemical materials (Eymur & Geban, 2017; Fitriyah et al., 2021). Therefore, the student's understanding of CBMG is dependent on their ability to understand and use multiple representations of chemical phenomena (Hilton & Nichols, 2011).

The presence of MCs impedes student learning because students are unable to make meaningful connections between their existing conceptions and the new ones they have learned (Cetin-Dindar & Geban, 2016). Moreover, CTM does not take into account students' conceptions and is ineffective in overcoming MCs (Awraris & Geletu, 2023; Karsli & Ayas, 2014). Thus, meaningful learning strategies are required to enhance students' CU (Mills, 2016). With the growing interest in integrating technology into education, the use of computer technology to enhance students' CU of scientific concepts has been accepted by educators worldwide (Almasri, 2022). More specifically, BL provides students with a more comprehensive approach to learning and education (Kennelly & SaVonnah, 2015). The adoption of BL can encourage students to become creative, independent, and actively involved in finding the necessary information to understand the concept (Novita, 2022). Students must therefore possess the CU to successfully learn science/ chemistry, particularly CBMG, through the practice of the BL approach.

The abstract concepts taught in chemistry might make it difficult for students to fully understand the lesson being taught (Salame & Makki, 2021). To support the development of students in CU in science, several interventional studies have been conducted on the use of BL across different educational levels. For instance, middle school students demonstrated improved CU using computer-supported cooperative BL in earth science (Dunn & Ramnarain, 2020). Similarly, secondary school students' CU of hydrocarbons was significantly enhanced through the BL approach (Inayah et al., 2020). Comparably, students' conceptual grasp of the state of matter and phase shift was enhanced in a mixed learning environment that combines web-based inquiry science with computer-based interactive lecture presentation (Niroj & Srisawasdi, 2014). Empirical findings revealed that BL improves both CU and learning independence among secondary school students in physics (Novita, 2022). At the tertiary level, the students who were taught using the BL model had better CU than their counterparts in basic computer network courses (Hawi & Sudira, 2019). Additionally, the application of BL improves undergraduate students' understanding of mathematics concepts (Ulfa & Puspaningtyas, 2020).

Adoption of computer-based simulated instruction improves the CU of students in chemical kinetics (Sweeder et al., 2019), PH in acid-base solutions (Watson et al., 2020), and general chemistry (Penn & Ramnarain, 2019; Salame & Makki, 2021). Similarly, an action research study asserted that computer simulation improves pre-service chemistry teachers' conceptual understanding of chemical bonding (Boachie et al., 2023). These findings demonstrated the impact of BL on students' CU in a global context. Although BL has demonstrated potential for improving students' CU across various disciplines, limited studies have examined its effectiveness in chemistry education, particularly for complex topics such as CBMG. Moreover, evidence regarding the impact of BL on undergraduate students' CU remains insufficient, especially in the Ethiopian higher education context. Therefore, further empirical investigation is needed to determine the effectiveness of BL in enhancing CU of CBMG concepts.

2.13.3. Student Engagement in Science and Chemistry Education

Student engagement (SE) is essential to foster meaningful learning throughout the educational journey. It refers to the student's active involvement with the learning environment, which includes interactions with the instructor and peers within the system (Al-Sakkaf et al., 2019). In recent years, SE has become a focal point in education as instructional approaches increasingly shift towards student-centered learning and constructivist pedagogies. Research indicates that a higher level of SE is associated with improved academic outcomes for students (Schindler et al., 2017). Hence, learning is understood as an active process in which individuals construct new knowledge by integrating existing knowledge with new experiences, thereby shaping their understanding of the world (Mcleod, 2023). Engaged students are more likely to participate actively in learning activities, leading to better retention rates and greater satisfaction with their educational experience (Gray & DiLoreto, 2016). Furthermore, SE plays a critical role in linking students' motivation to valued learning outcomes (Schnitzler et al., 2021) and it has been associated with positive learning outcomes (May et al., 2022). Therefore, SE is considered a fundamental prerequisite for effective learning (Werang et al., 2022).

Many researchers conceptualize SE as comprising three interrelated dimensions, namely cognitive, emotional, and behavioral (Fredricks et al., 2004; Reschly & Christenson, 2012). Cognitive engagement refers to the active involvement and willingness of students to invest effort to understand complex concepts and master challenging skills, which is essential for meaningful learning experiences (Maroco et al., 2016). It emphasizes the mental processes involved in learning, particularly the application of deep and shallow strategies during learning activities. Emotional engagement encompasses students' feelings, interests, perceptions, and attitudes toward their learning environment(Pham & Vu, 2024). It encompasses both positive and negative emotions that can significantly influence their engagement and motivation in the classroom. Besides, behavioral engagement relates to observable student actions that contribute to academic success and psychosocial adjustment. It includes effort, persistence, attention, and concentration for effective engagement in educational activities. Additionally, researchers (Fredricks et al., 2016; Xie et al., 2020) proposed social engagement as an important extension. SE represents the quality of students' interactions with their peers and instructors, as well as their willingness to invest in initiating and sustaining meaningful relationships within the learning context.

Enhancing SE in science and math is critical for academic and professional success in STEM education (Wang et al., 2016). Thus, SE is crucial for fostering academic success and encourages active participation and investment in the learning process across all educational settings. SE is a critical factor for assessing the quality of higher education (Loots et al., 2023; Tadesse et al., 2018). An improved level of SE holds the potential to positively influence the overall learning experience and plays a significant role in enhancing students' learning outcomes(James et al., 2025). SE is essential to enhance their educational experiences, overall well-being, and investment (Bresó et al., 2011; Kahu, 2013). Furthermore, SE provides instructors with immediate feedback on their instructional methods, allowing them to assess how effectively they are motivating students (Reschly & Christenson, 2012). Moreover, SE is a crucial indicator of the quality of instructional activities in the teaching and learning process (Sarıtepeci & Çakır, 2015). Consequently, the practice of CTM often lacks active SE in the classroom, which negatively impacts their learning performance (Satam et al., 2019). Hence, the practice of an appropriate teaching method is vital for promoting effective learning, as it directly shapes how students engage with the material and interact with one another.

Despite the critical importance of SE in the learning process, the growing evidence suggests that many students are not actively engaged, and that engagement tends to decline as they progress through their schooling (Goldspink & Foster, 2013). Engagement is fundamental to learning. And meaningful learning cannot occur without the active engagement of students (Nakulla & Toshalis, 2012). Without SE, the learning process becomes less effective, limiting active involvement and students' learning outcomes to fostering a deeper connection to the material (Hadzigeorgiou & Schulz, 2019) This issue, particularly in STEM subjects, can lead to broader global challenges, as disengaged students may hinder the development of essential skills and knowledge necessary for future innovation and problem-solving in an increasingly complex world (Urias, 2022). Moreover, there is alarming evidence that many students are not engaged and that engagement declines throughout their educational journey (Goldspink & Foster, 2013).

The major challenge for science educators is developing interesting activities in science learning to foster SE in science while advancing their scientific literacy (Woods-McConney et al., 2014). In the context of chemistry education, low student involvement is undesirable for effective learning, as it is often associated with low SE (Ross et al., 2020). Understanding SE in science, along with the various factors that influence it, is crucial for effectively addressing the challenges related to students' decisions to pursue science in their post-compulsory education (Hampden-Thompson & Bennett, 2013). Research further indicates that teaching and learning activities have a profound effect on SE in science. Despite SE is recognized as a key determinant of meaningful learning and academic success, many students, particularly in STEM education, continue to experience low levels of engagement. Existing research has mainly examined SE as a general educational outcome, with limited attention to how innovative instructional approaches influence its multiple dimensions in chemistry learning. Therefore, further investigation is needed to understand factors that enhance SE, particularly in undergraduate chemistry education contexts.

2.13.4. Blended Learning and Student Engagement in Science and Chemistry Education

The primary goal of BL is to maximize the benefits of both F2F and online learning and serve students with lower expenses and higher quality (Akinbobola, 2015; Šlechtová et al., 2015). SE in BL is defined as the process by which students invest time and effort into completing, participating in, or interacting with the learning (Chamberlain et al., 2021). BL is an innovative instructional approach that increases SE and learning performance and keeps students engaged (Shoukat et al., 2024). BL with a deliberate focus on integrating technology as a means of achieving meaningful SE contributes to the enrichment of learning environments (Shinde, 2020). When technology-enhanced learning is implemented, the chances of learning becoming interesting and SE are increasingly high (Abeka & Bosire, 2020). For instance, students are easily engaged in activities when using BL, which leads them to a better understanding of educational content (Eom, 2021). The connection between the learner and the learning environment is thought to be critical to understanding how technology-enabled learning environments engage students, especially given the ability of technology-enabled learning environments to provide individualized experiences (Abeka & Bosire, 2020). The rise of learning technologies presents educators and institutions with enormous opportunities to engage students in novel ways (Bouilheres et al., 2020). Furthermore, to encourage students to participate actively in learning experiences, structured BL models have been developed as an alternative to CTM (McGowan et al., 2014). In light of this, SE in BL leads to better student learning outcomes, including improved cognitive engagement (knowledge and skills), emotional engagement (motivation and enjoyment), and behavioral engagement (attitude) (Adams et al., 2020). Moreover, BL has the potential to improve SE in learning (Neumann et al., 2011; Sahni, 2019).

Science learning requires an engaging environment to understand abstract concepts through an innovative instructional approach. Science education and BL are linked, providing a more flexible and effective learning experience (Hendrowati et al., 2025). Thus, students can access learning materials from the online platform, learn independently, and engage in meaningful educational experiences. On the other side, SE in constructivist-based learning emphasizes the importance of personal experiences and social interactions, allowing learners to actively construct knowledge in meaningful ways that reflect their real-world contexts (Machumu et al., 2018). Additionally, BL could also enhance higher-order abilities such as communication, problem-solving, and reasoning skills (Cao, 2023; Hasanah & Malik, 2020). In a BL environment, SE is very different from CTM settings (Chiu, 2021). Compared to CTM or online courses alone, BL provides students with more opportunities for collaboration and learning from peers (Liao et al., 2023). They also stated that self-regulated and co-regulated learning are predictors of SE in a BL environment. Thus, teachers play a pivotal role in fostering SE, particularly through their ability to implement active learning effectively in HEIs (Almarghani & Mijatovic, 2017).

Various studies were carried out to examine the effectiveness of BL in enhancing SE across various disciplines in higher education. For instance, BL improves SE by visualizing molecular structure in organic chemistry (Hall & Allman, 2020), in mathematics and computer science courses (Baragash & Al-Samarraie, 2018), in health education (Adams et al., 2020), in the computer science course (Pellas, 2013), and in the business course (Beckem & Watkins, 2012). On the other hand, the findings of an action research study demonstrated that BL improves SE, concentration, and retention in higher education (Holbrey, 2020). Similarly, BL improves SE and learning outcomes in accounting courses (James et al., 2025) and in science courses (Loveys & Riggs, 2019). Other studies were carried out in middle schools and stated the effectiveness of BL to improve SE in social science courses (Sarıtepeci & Çakır, 2015), in English language courses (Li, 2021). Conversely, the study also investigated and validated the efficacy of BL in terms of advancing secondary school SE in a mathematics course (Chiu, 2021). In contrast, the results of the meta-analysis study across the USA and China stated that BL could not significantly improve SE in academic activities (Cao, 2023). Besides, the findings of the quasi-experimental study stated that no statistically significant differences were found for SE between the groups who received BL and CTM in the social science course (Saritepeci & Cakir, 2015).

However, the challenge of engaging students in science learning has consistently been significant and pressing (Hadzigeorgiou & Schulz, 2019). Similarly, the use of a passive instructional approach in the classroom is the primary factor affecting SE in HEIs, particularly in developing countries (Almarghani & Mijatovic, 2017). They also suggested that factors such as the availability and use of technology, teachers' motivational skills, and the ability to implement active learning are strong predictors of SE in HEIs. On the other hand, the conventional laboratory practices led to cognitive disengagement among students, as they concentrated solely on carrying out procedures without understanding the underlying material because they perceived a lack of control in the structure of their laboratory course (Galloway et al., 2015). This passive role of students in their learning, along with the lack of SE in HEIs, is a common issue in many HEIs in developing countries (Almarghani & Mijatovic, 2017).

In the Ethiopian context, instructional quality affects SE more in research Universities than in applied or comprehensive ones (Moges et al., 2024). The challenges, such as declining motivation, ineffective teaching practices, and resource limitations, persist, particularly in developing countries like Ethiopia, where CTM pedagogies dominate, and digital technology integration affects SE in HEIs (Faro et al., 2025). Moreover, the unique experience of SE in the Ethiopian HEIs context remains largely unknown (Tadesse et al., 2018). Therefore, addressing the issue of scientific uptake after compulsory schooling requires understanding SE and the factors that affect it in science education (Hampden-Thompson & Bennett, 2013). Although BL has been widely reported to enhance SE, existing findings remain inconsistent across disciplines and learning contexts. Moreover, most studies have focused on general academic courses, with limited attention to chemistry education, particularly complex topics such as CBMG. The influence of BL on undergraduate students' SE in chemistry remains insufficiently explored, especially in the Ethiopian higher education context.

2.13.5. Students' Epistemological Beliefs in Science and Chemistry Education

Knowledge is the main resource for people, being socially constructed and integrated into practice (Vygotsky, 1978). Understanding the nature of knowledge generally can provide valuable insights into the nature of scientific knowledge (Ardourel, 2017). Scientific knowledge is frequently highly valued, particularly in today's context, where knowledge is constantly expanding, and individuals rely on it to structure their thinking and intellectual growth (Önen, 2011). Consequently, students in science education must develop a thorough understanding of the nature of scientific knowledge and how science is constructed to achieve meaningful learning outcomes (Ongowo, 2022). Science literacy requires the acquisition of knowledge, science practices, and sophisticated epistemological beliefs (EBs) regarding the nature of science and science knowledge (Peffer & Ramezani, 2019). Students' science EBs are important in determining their learning orientations toward science(Guo et al., 2022) . Achieving science literacy is an important part of science education because it requires an understanding of scientific practices and how those practices are used to generate scientific knowledge (Peffer et al., 2018). EBs reflect an individual's views on the nature of science and the process by which scientific knowledge is obtained and are crucial for effective learning (Kaymak & Bekiroğlu, 2017). Moreover, students' EBs significantly influence how and why they participate in learning activities (Schafer et al., 2023).

Science EBs, in particular, are important in learning and the development of unique science goals that are linked to students' abilities and achievements, and students' characteristics and background (Kampa et al., 2016). They also stated that assessing EBs about science through authentic inquiry practices, as well as their relationship to affective factors, may provide novel insight into how students understand science and enhance overall science learning. Similarly, with the widespread adoption of curriculum innovations and alternative teaching methods in chemistry education, it is important to examine the effects of various changes on students' beliefs about chemistry and learning chemistry (Barbera et al., 2008). Although sophisticated EBs about science are necessary for achieving science literacy, examining students' beliefs is difficult (Peffer & Ramezani, 2019). Consequently, EBs influence the teaching-learning process, which makes chemistry learning difficult and is the main challenge of science in general (Yıldıran et al., 2011). Accordingly, examining the students' EBs about the knowledge they acquire is important in an instructional strategy (Peffer et al., 2018). Thus, understanding the students' EBs is essential for grasping how they perceive knowledge, the learning process, and their roles within this process.

Several studies have been carried out to examine the effect of instructional approaches on students' EBs in science/chemistry learning in learning environments. For example, the case study stated that secondary school students who were exposed to case-based learning instruction have more sophisticated EBs than those who were exposed to CTM in chemistry (Çam & Geban, 2011). Additionally, the study was conducted to examine the EBs of non-science students who were taught a science classroom inquiry simulation module that presents biological phenomena involved in either simple or complex investigations in HEIs (Peffer et al., 2018). As a result, students who are involved in complex investigations, despite not pursuing degrees in the sciences, have more expert-like investigations and potentially more sophisticated EBs in authentic science inquiry. An experimental study also affirmed that students with inquiry-based learning achieved better conceptions and sophisticated EBs in science as compared to those in CTM (Zhao et al., 2021). Another study asserted that preservice teachers' sophisticated EBs were promoted by constructivist conceptions of teaching and learning in science (Bahcivan, 2014). Similarly, a study indicates that during CTM in support of laboratory work in biology courses, college students majoring in science shifted toward novice-like EBs, while non-science-majoring students shifted toward expert-like EBs (Ding & Mollohan, 2015). Therefore, understanding the students' EBs requires deeper exploration to reveal and validate the differing perspectives that exist within the field of science. Although students' EBs are recognized as essential for meaningful science learning and scientific literacy, existing research has mainly focused on traditional instructional approaches, with limited attention to innovative approaches such as BL. Moreover, the development of students' chemistry-specific EBs, particularly when learning complex concepts such as CBMG, remains insufficiently explored. Therefore, further research is needed to examine how BL influences students' EBs in chemistry education.

2.13.6. Blended Learning and Students' Epistemological Beliefs in Science Education

As a foundational philosophical concept in the field of education, epistemology can play an important role in BL in HEIs (Ahmadian et al., 2022). The achievement of scientific literacy requires disciplinary knowledge, science practices, and the development of sophisticated EBs about the nature of science and scientific knowledge (Peffer & Ramezani, 2019). On the other hand, personal EBs represent an individual's development, encompassing their experiences in acquiring knowledge about the world, prior learning experiences, concepts of knowledge and cognition, cognitive processes, learning strategies, and methods of knowledge acquisition (Smyrnova-Trybulska, 2012). EBs influence science teaching and learning activities and approaches to learning (Shah & Choudhary, 2022). Moreover, the study has suggested that there is a link between students' epistemic beliefs, epistemic emotions, learning strategies, and learning outcomes (Muis et al., 2015). This suggests that students' beliefs about knowledge and their feelings when grappling with conflicting information about the issue are closely linked, with these emotions influencing the learning strategies they adopt to tackle the issue. Hence, students' EBs are interconnected with the learning strategies employed to foster meaningful learning. Empirical evidence further supports these relationships. The findings of this study indicate a significant correlation between students' EBs and their learning approaches in biology (Lin et al., 2012). Additionally, another study demonstrated a significant difference in the students' EBs as developed under the conditions of traditional study and e-learning (Bråten & Strømsø, 2006). In contrast, the results of a quasi-experimental study indicate that students who were taught biology through an active method approach did not influence university students' beliefs, as both methods (Beumer, 2019).

Technology-integrated learning strategies (such as BL) have the potential to promote meaningful learning for knowledge construction. However, students from diverse cultures and varying levels of prior knowledge might possess conflicting understandings of the scientific knowledge they acquire from formal classroom learning (Sahin, 2010a). This diversity highlights the importance of examining not only the learning outcomes but also students' EBs about the knowledge they acquired and the process of knowing. The literature shows that most BL studies primarily improve students' academic achievement rather than examining their EBs in HEIs. Consequently, only a limited number of studies have explored the effect of BL on students' EBs in higher education institutions. Existing literature presents mixed findings. For instance, the findings of a qualitative research design asserted that the BL approach, as opposed to fully contact or fully online methods, can support students' epistemological access and inclusivity in HEIs (Karassellos, 2024). This suggests that no universally applicable or optimal learning practices that address the diverse needs of learners with varying characteristics. Similarly, prospective teachers who taught using BL noted significant development in EBs concerning the notion that learning is based on effort in computer teaching practice at the tertiary level (Erdem, 2008).

Furthermore, a longitudinal study examining the effect of two BL models on the students' epistemic views in the engineering course found that 57% of successful students developed epistemic views over the modules, while 43% were only partially successful in the conventional BL model (Oshima et al., 2024). In contrast, only 36% of students were partially successful, and

64% were not successful in the hybrid BL model. These findings suggested that conventional BL can potentially improve university students' EBs. In contrast, other studies reported limited or no impact. For instance, a study on computer simulations and the constructivist approach demonstrated that although computer technology instruction enhances students' CU of physics, it didn't significantly change their EBs (Mirana, 2016). In sum up, these inconsistent findings indicate the need for further investigation. Although BL has been shown to influence students' learning outcomes, limited research has examined its effects on students' EBs, particularly in higher education science contexts. Existing studies report inconsistent findings regarding whether BL promotes changes in students' beliefs about knowledge and learning. Moreover, the influence of BL on chemistry students' EBs, especially when learning complex concepts such as CBMG, remains underexplored, particularly in the Ethiopian higher education context.

2.13.7. Conceptualization of CLASS-Chem Dimensions for Students' Beliefs in Chemistry

The Colorado Learning Attitudes about Science Survey (CLASS) is a widely used instrument in science education designed to measure students' beliefs about learning science (Douglas et al., 2014). These instruments have been validated across different science disciplines, including chemistry, biology, and physics, with constructs organized into distinct conceptual dimensions. Accordingly, the CLASS-Chem has been validated in the discipline of chemistry with nine distinct dimensions for measuring students' beliefs. Each dimension of the instrument, along with its specific items, has been conceptualized in accordance with its disciplinary context. The Colorado Learning Attitude about Science Survey in Chemistry (CLASS-Chem) consists of 50 validated items organized into nine dimensions. These dimensions are identified as real-world connections, personal interest, problem solving-General, problem-solving-confidence, problem solving-sophistication, sense-making/Effort, conceptual connection, conceptual learning, and atomic-molecular perspective of chemistry.

The conceptualization of Real-World Connection, Personal Interest, Problem-Solving dimensions, Sense-Making/Effort, and Conceptual Learning dimensions was demonstrated by the researchers (Adams et al., 2006; Perkins et al., 2005) as:

Real-world connection: Students' beliefs about the relevance and applicability of chemistry concepts to everyday life and real-world connections. Students with strong real-world connections see chemistry as meaningful beyond the classroom and are more likely to be engaged in learning.

Personal Interest refers to capturing students' intrinsic curiosity and enjoyment in learning chemistry. High personal interest reflects motivation to explore concepts for their own sake and is linked to persistence and deeper learning.

Problem Solving- General: This refers to the students' overall beliefs toward solving chemistry problems, including willingness to engage with challenges and confidence in approaching unfamiliar problems.

Problem Solving-Confidence refers to students' beliefs in their own ability to successfully approach, reason through, and solve scientific or chemistry-related problems. It reflects the student's self-efficacy when facing unfamiliar or challenging tasks. Students with higher problem-solving confidence are more likely to engage actively in problem-solving activities, apply conceptual understanding, and explore multiple solution strategies.

Problem Solving- Sophisticated: This reflects students' recognition of multiple solution strategies and deeper reasoning in chemistry problem solving. Sophisticated problem solvers value thoughtful reasoning and application of concepts across contexts.

Sense Making/Effort: This reflects the student's beliefs that understanding concepts deeply and making sense of the learned material are more important than rote memorization. It also encompasses the willingness to invest effort in challenging tasks.

Conceptual Connections/ Conceptual learning: These variables capture students' ability to relate new chemistry concepts to prior knowledge, integrating concepts into a coherent understanding. Strong conceptual learning supports problem solving, transfer, and meaningful engagement. The conceptualization of chemistry from an atomic and molecular perspective has been advanced through the influential contributions of (Gilbert, 2009; Johnstone, 1991; Nakhleh, 1992).

Atomic-Molecular perspective of Chemistry: Refers to the understanding of chemistry at the submicroscopic level, including atoms, molecules, chemical bonding, and interactions. The atomic-molecular perspective of chemistry emphasizes connecting macroscopic observations to microscopic explanations, which is critical for meaningful conceptual understanding. Although the CLASS-Chem instrument has been widely validated for assessing students' epistemological beliefs in chemistry, limited research has examined how these dimensions change within BL environments. Moreover, the influence of BL on students' chemistry-specific EBs remains underexplored in higher education contexts. Therefore, further investigation is needed to understand how BL affects students' EBs in chemistry learning.

2.14. The Relationship Between Conceptual Understanding, Student Engagement, and Epistemological Beliefs

Student engagement (SE) is the primary factor in how well students understand the concepts taught in classroom learning environments. It refers to the psychological investment and effort that individuals put into learning, CU, or mastering knowledge and skills, as well as enhancing their academic performance (Lamborn et al., 1992). Empirical evidences support the importance of SE in the learning environment. For instance, a quasi-experimental study found that a significant relationship exists between the level of SE and students' CU in secondary school mathematics (Hidayat et al., 2024). Similarly, highly engaged students tended to perform significantly better than those who were less engaged (Chen et al., 2019), suggesting that engagement plays a vital role in facilitating meaningful understanding of learning materials. Moreover, student academic self-concept has been identified as a key determinant of engagement patterns, and higher engagement is associated with higher achievement (Schnitzler et al., 2021). In the context of instructional approaches, research further indicates that BL can enhance both SE and CU. For example, an empirical study demonstrated that elementary school students who were taught via BL significantly enhanced their CU and increased their SE compared to those who received CTM in science learning (Chandola, 2023). This finding indicates a positive relationship between CU and SE. Overall, these findings highlight a strong and positive relationship between SE and CU, emphasizing the importance of fostering engagement to improve learning outcomes.

Emphasizing scientific practices in education aims to shift the focus from acquiring knowledge to an understanding of the methods and epistemic foundations of science (Evagorou et al., 2015). In this context, students' EBs have a crucial role in students' learning performance. For example, students who believe knowledge is certain and unchanging tend to use surface learning strategies and exhibit surface motivation(Guo et al., 2022) . Additionally, EBs are important predictors of reflective thinking, and reflective thinking is positively correlated with aspects of scientific identity, including beliefs about competence, performance, and interest. Moreover, higher degrees of self-efficacy or advanced conceptions of learning may be positively correlated with students' sophisticated EBs (Sadi & Dağyar, 2015). Research indicates that students with fixed views of knowledge tend to use memorization and surface learning, whereas those who view learning as an evolving process are more likely to pursue understanding through deeper learning approaches.(Chan & Elliott, 2004). These findings suggested that EBs significantly influence how students conceptualize learning, which subsequently impacts their choice of study approaches. Similarly, research revealed that EBs are associated with students' motivation, higher levels of self-concept and self-efficacy, perceptions of science, and selection of science-related careers. They also impact academic performance, comprehension, conceptual change, and CU (Chen, 2012; Mason et al., 2012). Collectively, the studies highlight that students' EBs are central to their cognitive, motivational, and academic development in science learning.

In conceptual change learning, the depth of text processing is correlated with EBs as well as motivating goals like self-efficacy and interest levels (Qian & Alvermann, 2000). Empirical studies further support the relationship between students' EBs and learning outcomes. For instance, an empirical study revealed that a significant positive correlation was found between EBs and CU (Sahin, 2010). Similarly, another study shows that students' EBs improved after engagement, as well as a significant positive relationship between EBs and the nature of knowledge and CU of the biology course through inquiry-based instruction (Baytelman et al., 2023). In addition to CU, an analysis of the study revealed a significant relationship between scientific EBs and SE in STEM education(Ondap & Hornejas, 2022). Furthermore, survey results from higher education institutions show that students' EBs are significantly related to their study engagement in philosophy courses at HEIs (Heiskanen & Lonka, 2012). Furthermore, Pearson correlation indicated that student EBs and academic self-efficacy are significantly associated with students’ academic engagement in secondary school (Abdi Zarrin & Soleimani, 2021). Although previous studies have established relationships among CU, SE, and EBs, most research has examined these variables separately or in general science contexts. Limited empirical evidence exists regarding their interrelationship within chemistry education, particularly in BL environments and higher education contexts. Therefore, further research is needed to examine how SE, CU, and EBs interact in BL-based chemistry learning, especially in the Ethiopian context.

2.15. Gender Differences in Science and Chemistry Education

Addressing gender balance remains a critical issue in science education. Gender equity in education and career development remains a significant social and political concern for scholars, educators, and politicians worldwide (Mau et al., 2020). In response, government and institutional stakeholders have implemented policies to execute various affirmative actions aimed at reducing gender disparities. However, evidence suggests that even when girls and boys are enrolled in the same class, they don’t have equal access to science-related experiences (Greenfield, 1996). Despite the many outstanding career options, only a small percentage of women are interested in science education in numerous nations (Thomas, 2017). Researchers reported contradictory findings on the gender gap in science education. For instance, the findings of a quasi-experimental study carried out through conceptually oriented instruction for the intervention group (IG) and textbook and analogy instruction for the comparison group(CG) demonstrate that there is no effect of gender differences in students' attitudes and understanding of chemical bonding (Pabuçcu & Geban, 2012). Similarly, the findings of the descriptive model research design asserted that there was no gender difference in secondary school students’ CU, self-efficacy, and scientific creativity in science learning (Panergayo, 2023). In contrast, other studies reported gender-based differences in academic performance. For example, a quasi-experimental study indicated that male students demonstrated a higher level of CU in mathematics (Azizah et al., 2021) and physics (Nisrina et al., 2018). These mixed findings highlight the need for further investigation into gender differences in science education, particularly in relation to the BL approach and its effect on students' learning performance.

An analysis of a quantitative research study indicates that SE in science across science teaching and learning activities varied by gender, with males reporting higher levels of SE than females (Hampden-Thompson & Bennett, 2013). Similarly, female students are less engaged cognitively within the learning environment than males in the Ethiopian HEIs context (Moges et al., 2025). However, the findings of a quasi-experimental study demonstrated that preservice teachers who taught through BL and conventional F2F instruction showed no significant maturation in males, while meaningful maturation was observed in females in the technology teaching practice course in HEIs (Erdem, 2008). Additionally, some studies have examined the gender effect on students' EBs in learning environments. For instance, the study's findings confirmed that there was no significant gender difference between elementary student EBs who were taught chemistry through hands-on science instruction (Conley et al., 2004). Similarly, the study's findings indicated that the effect of gender is not significant in either science courses using a person-centered approach among student EBs in HEIs (Korom et al., 2023). Despite these contributions, the overall evidence remains inconclusive. Although previous studies have investigated gender differences in science learning, findings remain inconsistent regarding students' CU, SE, and EBs. Moreover, the influence of gender on undergraduate students' learning outcomes within BL environments, particularly in chemistry education, remains insufficiently explored. Therefore, further empirical investigation is needed to clarify gender-related effects in BL-based chemistry learning.

2.16. Challenges of Blended Learning Implementation

The design and implementation of the BL approach aim to enhance instructional delivery by providing learners with expanded opportunities for engagement within classroom settings(Graham & Halverson, 2023). However, numerous studies highlight that the development and implementation of BL models present several challenges in educational environments(A. Amiruddin et al., 2022). Therefore, effective BL adoption and implementation require thorough preparation and adequately trained personnel, particularly teacher educators and instructors who possess the necessary pedagogical and technological competencies (Anthony et al., 2022). Among the most frequently reported challenges are students' limited self-regulation skills and teachers' insufficient proficiency in using instructional technologies (Rasheed et al., 2020). In addition, the literature identifies four key areas that complicate the successful delivery of BL: the need to incorporate flexibility, stimulate meaningful interaction, facilitate students' learning processes, and foster an affective learning climate (Boelens et al., 2017). Collectively, these challenges underscore the complexity of implementing BL effectively in classroom contexts. Despite these insights, gaps remain in the literature. Most studies address BL challenges in general contexts, with limited focus on subject-specific areas such as CBMG. Moreover, there is insufficient empirical evidence on how these challenges interact within classroom-based BL environments, particularly in developing country contexts. Therefore, this study examines the challenges influencing the implementation of BL in learning CBMG concepts.

2.16.1. Technological Challenges in Implementing BL for CBMG

The successful implementation of BL depends heavily on technology. The researchers (Sanders & Altman, 2023) identified challenges related to technology in BL environments. Given the challenges faced in implementing BL, it is understandable that BL might not be universally effective because of inconsistent access to technology (Song & Lai, 2025). This challenge involves students becoming overly stimulated and distracted by the technologies used in online learning environments, which may divert their attention away from learning tasks (Martin et al., 2025). Such distraction can result from the complexity of the technology or from the use of tools that students do not have access to at home, potentially encouraging non-educational use (Aagaard, 2015). Thus, educational institutions should achieve a balance between meeting students' technological needs and steering clear of overly complex or unnecessary technologies, thus minimizing the risk of misuse or abuse of technological resources(Wang, 2022). Furthermore, limited access to devices and reliable internet constitutes a major challenge for both students in developing contexts (Philip et al., 2023). Many educational settings may lack consistent access to computers, tablets, or high-speed connectivity required for active participation in the online components of BL(Zou et al., 2025). While teachers may also experience difficulties in effectively using Learning Management Systems (LMS) and digital tools due to insufficient training or technical support (Wong et al., 2019). Despite extensive evidence on technological challenges in BL, gaps remain in understanding how these issues specifically influence learning processes and outcomes in resource-constrained contexts. In particular, limited attention has been given to how unequal access to devices, unreliable internet, and varying levels of digital competence among students and teachers interact within classroom-based BL environments. Furthermore, the combined effects of technological distraction and insufficient instructor preparedness on students’ engagement and learning remain underexplored. Therefore, there is a need for context-specific empirical studies that examine how technological challenges affect the effective implementation of BL.

2.16.2. Pedagogical Challenges in BL for CBMG Instruction

BL is closely linked to the pedagogical framework, pedagogical practices, and institutional systems within educational institutions (Ashraf et al., 2022). Consequently, BL requires the careful integration of face-to-face instruction with online learning activities and relies heavily on assistive technologies that necessitate substantial changes in teaching methods (Ashraf et al., 2022). However, the lack of sound pedagogical and instructional design remains one of the most frequently encountered challenges in BL environments(Nagaraja & Davidson, 2024). Pedagogical challenges are particularly evident when instructors lack sufficient experience or training in designing and delivering BL courses, especially for complex subject areas. Furthermore, the researcher (Hofmann, 2014) found that the instructional design challenges associated with the implementation of BL include: i)Looking at how to teach, not just what to teach ii) Matching the best delivery medium to the performance objectives iii) Keeping online offerings interactive rather than just "talking at" participants iv) Ensuring participant commitment and follow-through with "non-live" elements v) Ensuring all the elements of the blend are coordinated.

Aligning online and face-to-face components with learning objectives can be difficult, and assessment strategies must be adapted to ensure fair evaluation of students across both modalities. Therefore, BL cannot be successful unless teachers upgrade their skills and effectively integrate technological, pedagogical, and content knowledge (TPCK) (Hungwe & Dagada, 2013). In this regard, two essential components for effective BL design are a reliable information technology (IT) infrastructure and adequate training in student-centered pedagogies, as well as the effective use of technology (Nagaraja & Davidson, 2024). Addressing these pedagogical and instructional design challenges is therefore crucial to ensure the effective and sustainable implementation of BL, especially for abstract scientific concepts like CBMG. Despite the recognized importance of pedagogical and instructional design in BL, significant gaps remain in the literature. Most studies emphasize general pedagogical challenges without adequately examining how these issues manifest in discipline-specific contexts, particularly in teaching complex concepts such as CBMG. Moreover, limited empirical evidence exists on how deficiencies in instructional design, teacher preparedness, and TPCK integration collectively influence the effectiveness of BL in classroom settings. Additionally, the alignment of online and face-to-face components, interactive design, and assessment strategies in BL remains underexplored, especially in resource-constrained environments. Therefore, there is a need for context-specific studies that investigate how pedagogical and instructional design challenges affect the implementation of BL in CBMG learning.

2.16.3. Learner- and Institution-Related Challenges in BL for CBMG

Teaching students through the BL model enables them to acquire the specific skills and competencies necessary for workforce development (Song & Lai, 2025). Students' readiness for BL depends on their digital literacy, self-regulation skills, and motivation (Geng et al., 2019). Students who are less familiar with technology or lack confidence in managing online tasks might find it harder to engage fully with the BL model. Motivation and time management issues can also decrease participation in online components (Song & Lai, 2025). From an institutional standpoint, inadequate administrative support, unclear policies, and limited professional development opportunities can worsen these challenges. Although BL is the correct direction for training initiatives, it fails to recognize that this is a complex process that requires thinking beyond an individual program. The researcher (Hofmann, 2014) identified the following factors as institutional challenges in the implementation of BL: i) overcoming the idea that BL is not as effective as CTM, ii) redefining the role of the facilitator, iii) managing and monitoring participant progress. Institutions that do not provide sufficient infrastructure, training, or guidance may unintentionally hinder both instructors and students, reducing the overall effectiveness of BL. Consequently, BL requires teachers to invest additional time in supporting learners and maintaining consistent follow-up throughout the instructional process. Despite acknowledging the importance of student readiness and institutional support in BL, limited research has examined how these factors interact to influence BL effectiveness in classroom settings, particularly in resource-constrained contexts and complex subject areas. Therefore, context-specific empirical studies are needed to address this gap.

2.17. Theoretical and Conceptual Framework of the Study

2.17.1. Theoretical Framework

A learning model refers to a systematically designed framework grounded in learning theories and assumptions about how students learn, aimed at achieving specific educational goals through structured learning environments and interaction processes (Dakhi et al., 2020). Within this perspective, BL can be understood as a pedagogical model that integrates face-to-face (F2F) and online learning environments to support knowledge construction. BL represents a contemporary paradigm in education that combines the strengths of both F2F and online instructional approaches to overcome their individual limitations and enhance student learning (Lu, 2021). As a result, BL provides a supportive learning environment to improve students' learning (Kok, 2008; Miyazoe & Anderson, 2010). From the theoretical perspective, learning is considered as the process of active construction of knowledge, while instruction is a process of supporting knowledge construction rather than communicating knowledge. In this regard, the constructivist approach to learning, which acknowledges the role of the student in constructing knowledge rather than merely receiving it, is aligned with BL (Lee et al., 2016). Consequently, BL has emerged as one of the most popular strategies in education to encourage active learning and enhance student learning outcomes (Ashraf et al., 2021).

The effectiveness of BL depends on how well its components are aligned with appropriate instructional design and contextual learning needs (Zhou et al., 2024). In this study, the theoretical framework is grounded in constructivist, connectivism, cognitive load, and self-determination theories. Furthermore, the implementation of BL contributes to the professional development of teacher educators and instructors by enhancing their capacity to design technology-integrated lessons(Tuan et al., 2022). However, limited integration of classroom instruction with technology underscores the need for skilled professionals and poses a challenge to the effective design and implementation of BL(Owston et al., 2008), particularly in developing countries where this approach is still emerging. Therefore, instructors are required to develop competencies in integrating instructional strategies with technology to create meaningful learning experiences that foster scientifically literate citizens. In this context, teacher educators are expected to possess strong subject knowledge, effective pedagogical skills, and professional expertise(Koehler et al., 2013). Accordingly, evaluating appropriate instructional frameworks for integrating technology in higher education is essential, as technology should support and enhance pedagogical goals (Vásquez, 2020).

2.17.1.1. Constructivism Learning Theory

Technology improvements are helping new learning paradigms like constructivism, student-centered learning, just-in-time learning, and collaborative approaches take hold. The focus of the educational system has shifted from merely transmitting knowledge to active learning, which entails focusing on its quality and is directly associated with the goals of constructivist theory in the teaching and learning process (Alsalhi et al., 2021). According to constructivist learning theory, the learner constructs his/her knowledge as a result of social interaction with others and the environment, and new information is built on the foundation of prior knowledge and experience (Fernando & Marikar, 2017). They also suggested that the constructivist theory of learning emphasizes the active construction of knowledge that has social and cultural roots. Similarly, the social and cultural diversity that students bring to the classroom can be used to produce an extremely productive learning experience. The potential of BL is highly effective. BL has the potential to be very effective if centered on cooperative learning activities (Moore et al., 2017). The BL environment can be carried out in consideration of the learning principles that address student-teacher, student-student, and student-to-subject matter interaction (Loots et al., 2023)

Social-constructivist learning theory recognizes the process of meaning-making through interaction between peers, which is essential to the learning process (Saleem et al., 2021). The social dimension of Constructivist Learning Theory often referred to as Social Constructivism or Sociocultural Theory emphasizes that learners develop their understanding and thinking through meaningful interactions with others, highlighting the essential role of social engagement in the learning process (Vygotsky, 1978). This theory posits that learning involves the active construction of knowledge, whereby students interpret their experiences by linking new information to prior knowledge, reflecting on new experiences, and integrating this understanding into their existing cognitive frameworks. Additionally, sociocultural theory is a theoretical perspective that connects social interaction with cognitive development (Vygotsky, 1978; Wheaton et al., 2024). A central idea in this theory is the Zone of Proximal Development (ZPD), which explains how interaction between more knowledgeable individuals and learners enables the development of new mental frameworks, allowing learners to accomplish tasks they could not perform independently (Tzuriel, 2021). Moreover, this theory highlights the crucial interplay of social, cultural, and biological factors in learning, emphasizing that the socio-cultural context is fundamental to human cognitive development.

BL environments facilitate social interaction and teamwork, which are often absent in fully online systems (Edem & Anari, 2021). BL effectively combines various delivery methods, pedagogical frameworks, and learning philosophies within a socially engaging learning environment(M. Kaur, 2013) . Moreover, it promotes peer-to-peer cooperation via discussion forums and group projects. Grounded in social constructivist theory, meaningful learning occurs when students actively collaborate to accomplish shared tasks. Therefore, this study adopts the social constructivist perspective, as BL functions as an active learning approach that fosters interaction not only among students but also between students and instructors.

2.17.1.2. Connectivism Learning Theory

Technology has influenced all theoretical points of view through the provision of new methodologies and innovative teaching methods (Duke et al., 2013). In this regard, connectivism learning theory provides a relevant framework for understanding how digital technology promotes learning through interactive environments. According to this theory, students now have more opportunities than ever to learn from and exchange knowledge with one another across the World Wide Web by using internet technologies (Goldie, 2016). Furthermore, in connectivism, learning occurs through collaborative connections across networks where knowledge is distributed among individuals, organizations, and technologies (Corbett & Spinello, 2020). In line with this, teaching and learning, particularly in HEIs, increasingly involve the use of various information and communication technologies both within and outside the classroom (Rajkoomar, 2015). As a result, students can access a variety of online information resources, including online databases, open-access academic communication publications, community-based and collaborative knowledge systems, and other library resources.

2.17.1.3. Cognitive Load Theory

Cognitive load theory (CLT) is an internationally recognized and widely accepted theory that provides guidelines to assist in presenting information in a way that encourages learner activities to optimize intellectual performance (Bannert, 2002; Kirschner, 2002). Instructional methods are likely to be unproductive if they fail to achieve the goal of enhancing knowledge in long-term memory while reducing any unnecessary load on working memory (Sweller, 2011). CLT emphasizes that learning is most effective when cognitive overload is reduced, enabling students to concentrate on key information and assimilate it in a meaningful way. Additionally, CLT balances the information presented between F2F and online sessions, ensuring that students are not overwhelmed (Plass et al., 2010; Sweller, 2020). Integrated technological instruction has the potential to justify the abstract concepts simply and provide students with the opportunity to understand the learned material. CLT plays a crucial role in educational technology and instructional design, and in minimizing extraneous cognitive load to maximize learning (Clark & Kimmons, 2023). Understanding of human cognition, CLT specifies which types of knowledge are most likely to be susceptible to manipulation during teaching and which are likely to be resistant. Importantly, CLT is directly applicable to technology-assisted learning and reduces extraneous loads via multimedia tools(Sweller, 1988, 2020). Accordingly, CLT can provide a guide to appropriate uses of technology-assisted learning. Consequently, the BL approach can be guided by the CLT to comprehend how learning happens and how to design successful learning experiences.

2.17.1.4. Conceptual Change Theory

Conceptual change refers to significant changes in cognitive structure resulting from inconsistencies with previous experiences, which is highly valued as a crucial process in students' active knowledge construction(Yao & Qiyum, 2024). The conceptual change theory is one of the modern theories of learning that has helped to expand our understanding of constructivism (Denis et al., 2015). The theory was introduced to education as an analogy drawn from the history and philosophy of science as a result of the difficulties students experienced in changing from one explanatory framework to another. It posits that learning involves the restructuring of prior knowledge, whereby learners replace incorrect or naïve conceptions with scientifically accurate understandings (Posner et al.,1982). For such a change to occur, learners must first experience dissatisfaction with their existing conceptions, creating the conditions necessary to adopt more plausible and scientifically valid alternatives. Furthermore, the epistemological assumptions underlying Conceptual Change Theory extend beyond the mere correction of misconceptions. They emphasize that cognitive development depends fundamentally on how individuals construct, refine, and reorganize their CU through interaction with experience (Ozdemir & Clark, 2007). According to these epistemological presumptions, comprehending how an individual conceptualizes the environment and how it develops and interacts with experience is the fundamental challenge in understanding cognitive development. Within this perspective, instructional approaches grounded in conceptual change are particularly effective in helping students overcome persistent MCs and develop a deep understanding of complex concepts across disciplines (Belachew et al., 2021).

2.17.1.5. Self-Determination Theory

Self-determination theory is a psychological framework that emphasizes the importance of autonomy, competence, and relatedness as fundamental psychological needs in determining intrinsic motivation and individual well-being (Manninen et al., 2022). Additionally, engagement in SDT is motivated by the fulfillment of three psychological needs: autonomy, competence, and relatedness, highlighting their essential role in fostering self-determined motivation, well-being, and personal growth (Deci & Rayan, 1985; Legault, 2017). Autonomy is fueled by the satisfaction of these three needs, which are essential for fostering self-determined motivation, personal growth, and overall. According to SDT, students who see their learning as a self-determined or autonomous experience view their studying as a self-chosen, voluntary action that aligns with their personal goals and values (Willems & Lewalter, 2012). In BL environments, the online learning components provide students with pace and resource selection, which enhances intrinsic motivation. Accordingly, SDT suggests that providing feedback that strengthens perceived competence, along with promoting social interaction through collaborative tasks, fosters relatedness and engagement in the BL context.

2.17.2. Khan's Octagonal BL Framework

The effectiveness of BL depends on the optimal integration of learning environments to enhance the learning experience (Gu, 2017). Khan's Octagonal framework provides a structured guide for planning, developing, delivering, managing, and evaluating BL programs (Singh, 2003). When designing learning and performance strategies, organizations must consider several interrelated and dependent factors to ensure effective learning delivery and high return on investment. A relevant learning environment requires systematic attention to these factors, which can be organized into an octagonal framework. Each dimension of the framework corresponds to a category of problems that must be addressed, helping in structuring ideas and ensuring that the final BL program offers an engaging and effective educational experience (Singh, 2003). All eight dimensions play a crucial role in the development of the BL environment.

Institutional dimension: This dimension addresses issues concerning organizational, administrative, academic affairs, and student services. In designing and implementing a BL environment, instructors and educational designers can assess the university's readiness, the infrastructure, and content, and the specific demands of the experience (Singh, 2003). Higher education institutions should prioritize building a strong institutional framework and investing continuously in staff training and professional development to effectively implement and manage BL programs (Gu, 2017). Consequently, HEIs may need to revise their policies and guidelines to facilitate the effectiveness of BL.

Pedagogical dimension: Pedagogical dimension presents the combination of content that has to be delivered (content analysis), the learner's needs (audience analysis), and learning objectives (goal analysis). This dimension also encompasses the design and strategy aspect of the BL environment (Joseph, 2015; Singh, 2003). Additionally, in this dimension, the most appropriate instructional approaches are chosen to address scenarios where all learning goals in a given program are listed. Thus, BL supports the pedagogical needs that align with the institution's mission to empower teaching staff and students through the adoption of different styles, learning environments, and tools to improve the learning experience (Gu, 2017).

Technological dimension: This dimension concerns the technological infrastructure that is needed to address and create the BL learning environment and the tools to deliver the learning program. This dimension covers the requirement for a learning content management system (LCMS) that catalogs the actual content (online content modules) for the learning program, as well as the best learning management system (LMS). Moreover, this dimension addresses technical requirement issues, such as the server that supports the learning program, access to the server, bandwidth, accessibility, security, and other hardware, software, and infrastructure (Singh, 2003).

Interface Design dimension: This dimension addresses factors related to the user interface of each element in the BL environment. The user interface supports all the elements and integrates the different elements, which will enable the learner to use each delivery type and switch between the different delivery types. This dimension can address issues related to content structure, navigation, graphics, and assistance (Joseph, 2015; Singh, 2003).

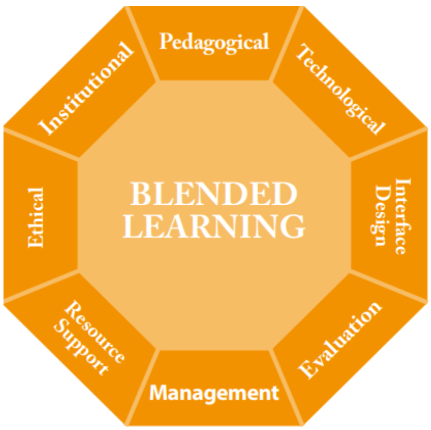
Evaluation dimension: This dimension concerns examining the students' learning performance and evaluating how the BL instructional approach is implemented in the learning environment. Appropriate evaluation methods (both formative and summative) should be employed in each lesson delivery, particularly formative assessment, which contributes to SE and understanding of the topic under discussion (Joseph, 2015; Singh, 2003).

Management dimension: The management dimension deals with issues related to the management of a BL program, such as infrastructure, to manage multiple delivery types. The BL delivering program is more work than delivering the entire course in one delivery type. It also addresses maintenance of learning environments and distribution of issues like information, registration, notification, and scheduling of the different elements (Singh, 2003).

Resource supporting dimension: The resource support dimension is concerned with making the offline and online resources available for learners to employ the BL environment, as well as organizing them. This dimension could also concern teacher educators/professors always available in person, via e-mail, or on a chat system (Joseph, 2015; Singh, 2003).

Ethics dimension: This dimension identifies the ethical issues that need to be addressed when developing a BL program, such as equal opportunity, cultural diversity, and nationality. BL programs should be developed to enable all learners to have a similar learning experience and ensure students can access all the components of the BL *(*Joseph, 2015*;* Singh, 2003*)*.

(a)



(b)

Figure 2. 3: (a) Khan's Octagonal Framework, 2003 (b) Adapted Khan's Octagonal BL Framework (Singh, 2003)

2.18. Conceptual Framework

The conceptual framework of this study, presented in Figure 2.4, is grounded in social constructivist learning theory, which emphasizes that students actively construct knowledge through interaction with peers and their learning environment (Pritchard, 2017). From this perspective, learning is both an active and socially mediated process influenced by contextual factors. Within this framework, BL is treated as the independent variable, integrating face-to-face and online instructional approaches to enhance students' learning experiences. It is expected to influence key dependent variables, namely CU, SE, and EBs. In addition, gender is incorporated into the framework as a moderating variable to examine whether differences exist in students' learning outcomes across male and female groups. While gender is not part of the causal pathway, it provides important insight into potential variations in the effectiveness of BL. Furthermore, challenges associated with the implementation of BL, such as technological limitations, instructional design issues, and limited instructor support, are considered as contextual factors. These challenges may influence the effectiveness of BL in achieving the intended learning outcomes.

In this study, BL is treated as the independent variable, while CU, SE, and EBs are considered dependent variables. The independent variable is deliberately manipulated to examine its effects on these learning outcomes. The choice of an appropriate instructional approach plays a critical role in shaping students' learning, engagement, and academic performance; therefore, adaptive learning strategies are essential for improving the teaching–learning process.(Rincon-Flores et al., 2024).

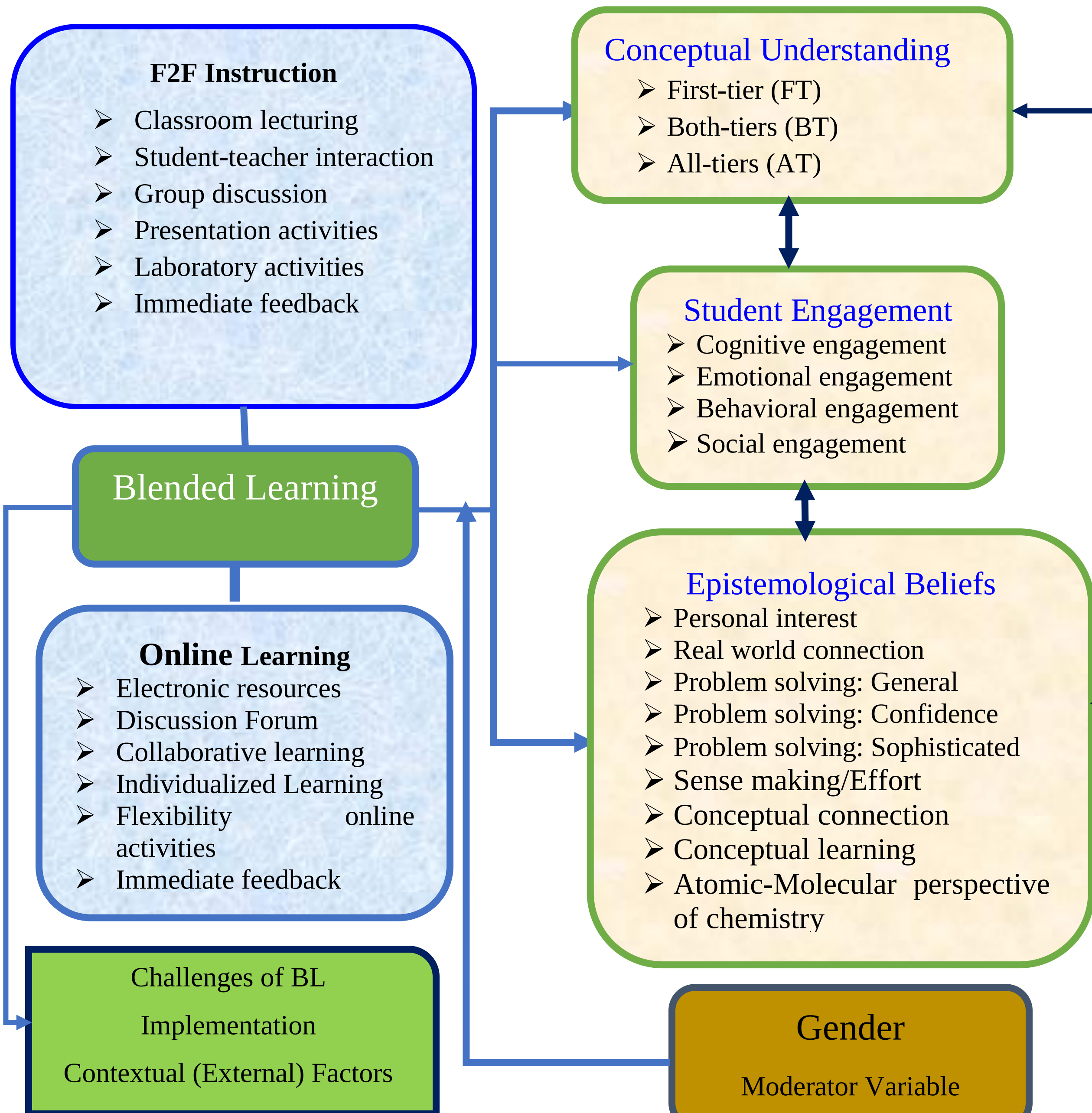


Figure 2. 4: Conceptual framework of the study

CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1. Introduction

This chapter presents the methodological framework of the study, encompassing the research paradigm, approach, and design, followed by a detailed account of the population, sample, and sampling techniques employed. It outlines the study variables and treatments, describes the data collection instruments, and discusses their validity, trustworthiness, and reliability. The chapter also reports on the pilot study, explains the data collection procedures, and elaborates on the data analysis methods. Finally, it addresses the ethical considerations that guided the study.

3.2. Research Paradigm

In this study, pragmatism was adopted as a guiding research paradigm. Pragmatism emphasizes action-oriented inquiry and recognizes the interconnection between experience, knowing, and practice, viewing research as an iterative experiential process (Kelly & Cordeiro, 2020). This philosophy looks for the practical implications of any new ideas or theories before making a judgment on their value (Pritchard, 2017). Within this context, pragmatism supports the integration of diverse paradigms, assumptions, and methods to address research problems effectively(Creswell, 2014). Accordingly, a pragmatic approach was employed to evaluate the effectiveness of blended learning (BL) in enhancing undergraduate students' CU, SE, and EBs.

3.3. Research Approach and Design

3.3.1. Research Approach

The study utilized both quantitative and qualitative data. The method employed was a concurrent embedded mixed-methods approach. A mixed-methods approach provides a better understanding of the research problem and questions than either method by itself (Cresswell, 2012). This approach is particularly effective as it combines the strengths of both methods while addressing their individual limitations. In this study, a mixed-methods approach with an emphasis on quantitative (QUAN) data and less on qualitative (qual) data was employed to answer the research questions. Accordingly, a concurrent embedded mixed-methods research approach was adopted in which both data strands were collected simultaneously at the post level, only represented by the notation "QUAN" + "qual". The concurrent embedded mixed-methods approach is familiar in the basic and advanced mixed-methods approaches (Creswell, 2014). This approach allows the researcher to give priority to quantitative types of data while addressing the research questions. For this study, both quantitative and qualitative data were collected concurrently, but qualitative data were embedded into quantitative data, analyzed separately, and then compared and integrated to determine the extent to which the results converged or diverged, thereby enabling triangulation. Accordingly, the current study employs a concurrent embedded mixed research approach, ensuring the integration of both data sets to provide a comprehensive understanding of students' CU, SE, and EBs. Figure 3.1 illustrates the procedural actions of the concurrent embedded mixed research approach.

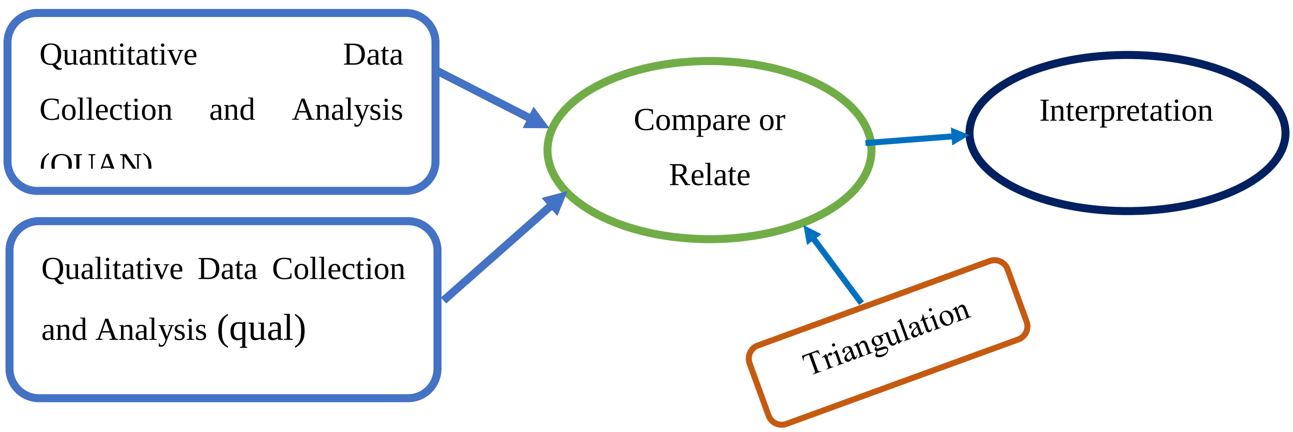


Figure 3.1: Concurrent embedded mixed research design (adapted from Creswell, 2014)

In this mixed-methods approach, both quantitative and qualitative data were collected to assess respondents' levels of CU, SE, and EBs while learning CBMG concepts during instruction.

3.3.2. Research Design

3.3.2.1. Pretest-Posttest Nonequivalent-Groups Quasi-Experimental Design

Research design refers to the overall framework and procedures for conducting a study, encompassing elements from broad hypotheses to specific methods of data collection and analysis (Creswell, 2009). In this study, a quantitative approach was adopted using a pretest-posttest quasi-experimental design with a nonequivalent control group, a design commonly employed in educational research when random assignment is not feasible (Johnson & Christensen, 2016). The research was carried out in a natural classroom setting with intact groups, as university classes follow fixed schedules; thus, forming new groups randomly was impractical and could disrupt the normal teaching and learning process. Accordingly, two intact classes were selected and randomly assigned to intervention and comparison conditions to implement the quasi-experimental design. The primary aim of this study was to examine the impact of BL on undergraduate students' CU, SE, and EBs, and to compare these outcomes with those of students in intact groups taught through a non-BL approach. The pretest-posttest non-equivalent quasi-experimental design consists of one IG and one CG, as described in Table 3.1. The nonequivalent control group design with pretest and posttest is represented as follows:

Table 3.1: The nonequivalent control group quasi-experimental design

Group	Measurement (Pretest)	Treatment	Measurement (Posttest)
IG	O_1	X	O_2
CG	O_1	_ _ _	O_2

IG = Intervention Group, CG = Comparison Group, O1 = pretest, O2 = Posttest, X= treatment

As shown in Table 3.1, the researcher selected two intact groups and assigned them to the intervention (IG) and comparison (CG) conditions. Both groups were administered a pretest (O1) for CU and EBs, after which the intervention group received the treatment (X) activities, while the comparison group did not. Only the post-test was administered to measure SE, as it is a context-dependent and dynamic construct that develops through instructional experiences rather than existing as a stable baseline characteristic. Prior research indicates that SE is most appropriately assessed within specific learning environments during or after exposure to instructional interventions (Henrie et al., 2015). Finally, a posttest (O2) was conducted to evaluate differences in CU, SE, and EBs between the two groups.

3.3.2.2. The Case Study

To obtain an in-depth portrayal of undergraduate students' understanding of chemical bonding and molecular geometry (CBMG) concepts, a case study approach was employed. These concepts constitute a central focus of General Chemistry course material, and case studies have been widely recognized as an effective qualitative research method in educational contexts. For instance, it has been used to illuminate the alignment or inconsistencies between espoused theories of learning and classroom practices (Lyons et al., 1997), to explore the role of reflection in teacher development and instructional practice (Sweeney et al., 2001), and to examine the use of models in understanding chemistry concepts (Harrison & Treagust, 2000). In line with this tradition, the present study adopted a case study design to gain a deeper grasp of undergraduate students' CU, SE, and EBs in General Chemistry. The case was defined as freshman undergraduate students enrolled in General Chemistry, consistent with the literature that views case study as focusing on a single unit such as an individual, group, organization, or program (Ary et al., 2010). As (Creswell, 2007) notes, case study research involves the exploration of an issue through one or more cases within a bounded system, providing comprehensive accounts of phenomena. Similarly, the researcher(Simons, 2014) emphasizes that case studies document particular situations or events in detail to arrive at a rich description and understanding of the case. Accordingly, this dissertation employed an instrumental case study program (Ary et al., 2010) with a small group of participants (nine participants) to examine patterns of behavior related to CU, SE, and EBs. In an instrumental case study, the case is selected because it represents a broader issue under investigation and is expected to provide insights into that issue (Ary et al., 2010). The unit of analysis for the qualitative data was the meaningful textual segments obtained from students' interview responses, including words, phrases, sentences, and statements, which were coded into categories and themes related to CU, SE, and EBs of those who received BL and those in the comparison group who did not (Ryan, 2012). To strengthen the findings, diagnostic tests and questionnaires were also administered, providing corroborative evidence to support the case study analysis.

3.4. Population, Sample, and Sampling Techniques

The population for this research consisted of freshman undergraduate students enrolled in general chemistry (Chem1012) courses covering CBMG topics at Bahir Dar University, Ethiopia, with a total undergraduate student population of 1142 in the regular program. The study was conducted on first-year undergraduate students. Two intact classes were selected and randomly assigned to the IG and CG. The study was carried out on a total sample of 86 participants, with 42 students in the IG (BL approach group) and 44 students in the CG (conventional approach group). For the qualitative component, twelve participants were initially selected from both groups (six from each group), with representation across high, medium, and low achievement levels based on their post-Three-Tier Conceptual Understanding Diagnostic Test (post-TTCUDT) results. However, only nine participants ultimately participated in the interviews, comprising six students from the IG group and three from the CG, as three participants from the comparison group withdrew from the semi-structured interviews due to personal reasons.

3.5. Variables of the Study

Research variables are characteristics or attributes of individuals or organizations that researchers can measure or observe. These variables differ among the individuals or organizations being examined (Cresswell, 2012). These include independent and dependent variables, where changes in the independent variable are likely to result in changes in the dependent variable, indicating a cause-and-effect relationship between these two variables (Johnson & Christensen, 2016). In this study, the IG and CG were exposed to the variables of BL and the CTM, respectively.

3.5.1. Independent Variable

The independent variable is the manipulated variable intended to cause changes in other variables, the dependent variables. In this study, BL is treated as an independent variable considered in this study.

3.5.2. Dependent Variables

According to the researchers (Ary et al., 2010), when a variable represents the consequence of another, it is considered a dependent variable. Dependent variables are the outcome variables of the research that are expected to be influenced by one or more independent variables. In this study, the dependent variables are CU, SE, and EBs.

3.6. Treatments

3.6.1. Blended Learning Instruction

In this study, the internation group (IG) was exposed to the BL approach integrating face-to-face and online instructional modalities. This learning approach is structured to provide a comprehensive learning experience by combining active, cooperative, and technology-supported strategies. In the face-to-face sessions, instruction emphasized active SE through brief clarifications, group activities, and peer discussions. Students actively construct and refine conceptual models (e.g., Lewis structures, Valence Shell Electron Pair Repulsion theory (VSEPR) -based molecular shapes, and bonding representations through guided tasks that require them to explain, justify, and apply their reasoning to CBMG concepts. These model-based activities are paired with immediate formative feedback, which helps reinforce accurate understanding and correct misconceptions in real time. Complementing this, the online learning offered flexible, self-paced learning opportunities. Students accessed instructional videos, interactive simulations, and online animations to enhance conceptual visualization of the chemical phenomena. Additional learning support was provided through structured CBMG learning activities, assignments, and online discussion forums, facilitating continuous interaction and reflection beyond scheduled face-to-face class time.

The intervention procedures were designed to ensure the effective implementation of the BL approach for the IG. Before the intervention, necessary arrangements were made in collaboration with the university's e-learning coordinator and computer lab technician to ensure the functionality of computers, internet access, and digital learning resources. Following these preparations, students were oriented to the purpose and procedures of the study, including their roles and rights as participants. The instructor assigned to the IG received training on the use of Moodle, a learning management system (LMS) employed to support the online component of the BL approach. The training focused on uploading, organizing, and managing course materials, as well as facilitating online learning activities. In addition, user accounts (usernames, passwords, and email access) were created for all students in the IG. Subsequently, students in the IG participated in a structured training session by the university's Teaching and Learning Technology Head (E-learning) on how to access and use the online learning materials effectively (see Figure 3.2). Following these preparatory activities, the BL intervention was implemented through the intentional integration of online and face-to-face instructional components, where both modalities were systematically combined to support students' learning of CBMG concepts. In line with these instructional procedures, the BL approach was designed to enhance not only students' CU and SE but also the development of their EBs about learning chemistry, particularly CBMG concepts.

Figure 3.2: E-learning training for students who received the blended learning approach.

A structured training manual incorporating CBMG topics, along with supplementary activities beyond the standard course module, was developed to guide instruction in both groups under the CTM and BL approach. Before each lesson, a variety of instructional materials, including videos, animations, simulations, and reading resources (e.g., textbooks, PowerPoint presentations, and PDFs), as well as assignments and activities related to CBMG topics, were uploaded to the online learning platform. During the intervention period, the IG received instruction through the BL approach as the treatment condition, integrating online and face-to-face components, whereas the CG was taught using the CTM. Technical support was made available through an ICT technician to assist students during online sessions conducted in the digital library. The instructional program was implemented over a period of nine weeks, including two weeks allocated for the administration of pre- and post-tests. Throughout the intervention, students engaged with online assignments and activities via the e-learning platform. Interactive features, such as discussion forums, enabled students to submit responses, ask questions, and exchange ideas, while instructors provided feedback through the same platform.

3.6.2. Moodle Learning Platform

Moodle (Modular Object-Oriented Dynamic Learning Environment) is a free, open-source LMS widely used to support BL, online learning, and distance education in higher education(Costa et al., 2012; Kumari, 2016). Due to its flexible and customizable features, Moodle enables instructors to organize course materials, provide multimedia resources, administer assessments, facilitate discussions, and monitor students' learning activities. In this study, Moodle was selected as the online learning platform for implementing the online component of the BL intervention because its features supported the integration of digital learning activities with face-to-face (F2F) instruction. The researcher used Moodle to provide students with access to course materials, learning resources, and online activities designed to complement classroom instruction and support students' understanding of CBMG concepts. Before the intervention, student accounts were created to facilitate access to the platform. Since most students did not have existing email accounts, the university's Teaching and Learning Technology Head (E-learning) obtained students' voluntary consent, email addresses, usernames, and passwords for the participants. Figure 3.3 presents the Moodle homepage interface accessed by students at Bahir Dar University, where the study was conducted.

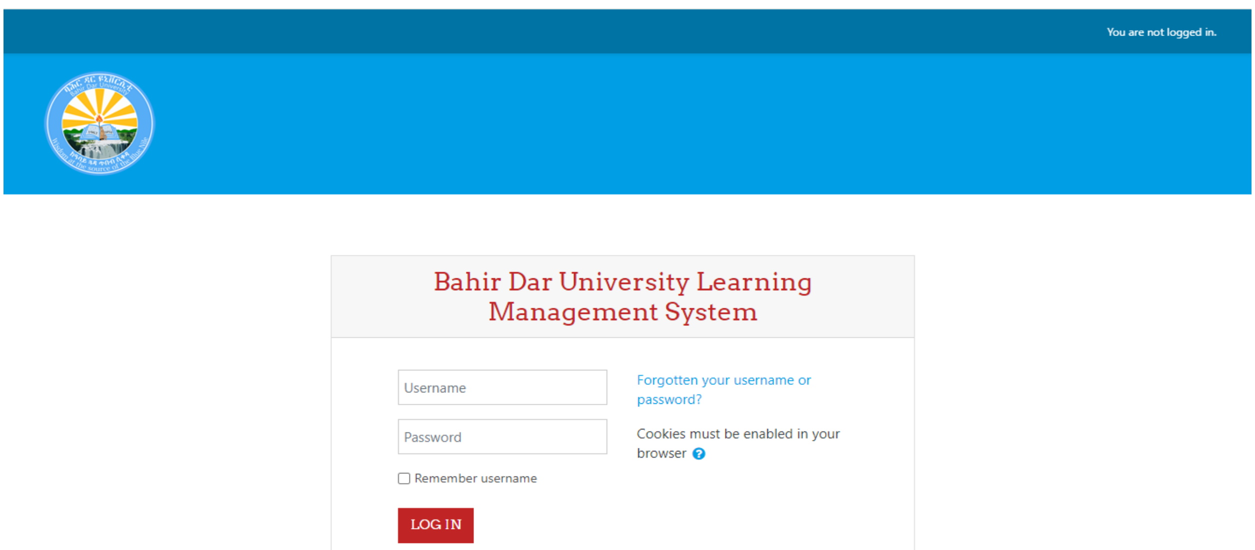


Figure 3. 3. Moodle-based online learning platform utilized in the study

3.6.3. Analysis of the BL Environment of the Study

An effective BL environment requires careful integration of F2F instruction and online learning components, supported by appropriate instructional design and technological infrastructure. In this study, the university's computer laboratory was equipped with the Moodle LMS, which provided the technological platform for implementing the online component of the BL intervention. The online activities were designed to complement F2F instruction and support undergraduate students' learning of CBMG concepts. Before the intervention began, the researcher, in collaboration with a computer laboratory technician, assessed the readiness of the university's digital learning facilities. This assessment involved verifying the functionality of available computers and ensuring their compatibility with the Moodle LMS for delivering, managing, and documenting course materials for the intended class size. Figure 3.4 demonstrates the students learning in an online learning format.

Figure 3. 4. Students learning in an online learning platform

In this study, the BL approach was implemented by integrating face-to-face instruction with structured online learning activities. Before the intervention, the researcher, in collaboration with the computer laboratory technician, prepared the computer laboratory and verified that all available computers were functional and compatible with the LMS. Four incompatible and unused computers were removed and replaced with operational units to ensure adequate access to the online learning environment. Following this preparation, the director of the university's digital library assigned a specific computer laboratory and arranged a schedule that allocated 110 minutes per week exclusively for the study. Although the laboratory was also used by students enrolled in computer courses and digital library users, additional instructional groups could not be accommodated due to existing facility constraints. Therefore, the IG accessed the computer laboratory according to the allocated schedule. During the intervention, the instructor implemented the BL activities by uploading learning materials to the Moodle platform, assigning online supplementary tasks, and providing feedback through the system. These online activities were designed to complement face-to-face instruction, promote continuous learning, and reinforce students' understanding of CBMG concepts. The researcher monitored the instructional sessions throughout the intervention period to ensure the fidelity of BL implementation. As planned, students completed online learning activities in the computer laboratory under the guidance of the instructor (see Figure 3.5).

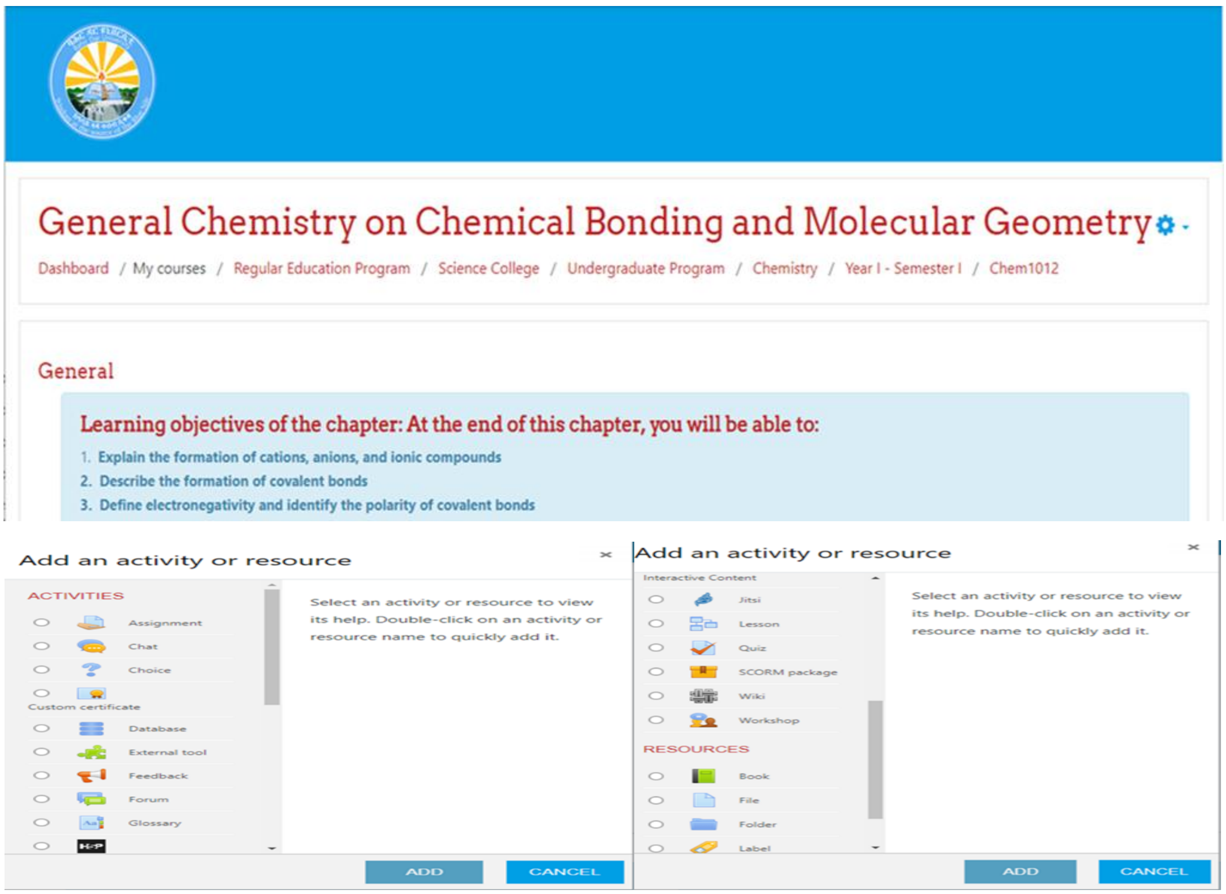


Figure 3. 5. The Moodle course interface for CBMG at Bahir Dar University.

3.6.4. Conventional Instruction

Students in the CG followed the same curriculum over the same period using the CTM, which was characterized by a teacher-centered, instructor-led approach. Instruction was delivered through structured face-to-face sessions, primarily using lectures supported by chalkboard demonstrations and PowerPoint presentations. During these sessions, the instructor explained CBMG concepts, highlighted key points, solved problems, and summarized the main ideas at the end of each lesson. Learning activities included worked examples, individual exercises, and end-of-lesson question-and-answer sessions to clarify students' understanding. Students also completed paper-based exercises, which were reviewed during class. In addition, tutorial sessions were conducted as a supplementary component to reinforce learning. These sessions focused on revisiting abstract concepts, addressing students' questions, and providing further explanations. Students engaged in additional practice exercises and received feedback to strengthen their CU.

3.7. Data Collection Instruments

In this study, data were typically gathered using the researcher-developed and adapted instruments to address the research questions. Quantitative data were collected using the Three-tier Conceptual Understanding Diagnostic Test (TTCUDT), the Student Engagement Scale (SES), and the Colorado Learning Attitudes about Science Survey for Chemistry (CLASS-Chem) to assess epistemological beliefs (EBs). The TTCUDT instrument of CU consists of three dimensions categorized into the first-tier, reason tier, and confidence tier. Each tier comprises 26 items; the first and second tiers consist of multiple-choice questions with two to four options and one correct answer, whereas the third-tier measures students' confidence using a rating scale rather than a correct or incorrect response. The Student Engagement Scale (SES) variable included four dimensions: cognitive engagement (CogSE), emotional engagement (EmSE), behavioral engagement (BehSE), and social engagement (SocSE). SE with these dimensions was measured using 31 five-point Likert scale items. On the other hand, the students' EBs were measured using 36 CLASS-Chem five-point Likert scale items across nine dimensions: personal interest, real-world connection, problem-solving: general, problem-solving: confidence, problem-solving: sophisticated, sense-making/effort, conceptual connection, conceptual learning, and the atomic-molecular perspective of chemistry. Qualitative data were collected using semi-structured interview questions focused on CU, SE, and EBs. Details of each instrument are discussed below.

The selected instruments were intended to provide a complementary and multidimensional assessment of the study variables. In particular, the TTCUDT enables a deeper examination of students' CU by integrating correctness, reasoning, and confidence, thereby allowing the identification of both scientifically accurate conceptions and persistent MCs. This approach goes beyond traditional assessment by capturing not only students' answers but also the quality of their explanations and their level of certainty. The SES offers a comprehensive view of SE by addressing cognitive, emotional, behavioral, and social aspects of learning. These dimensions collectively reflect how students invest effort in understanding the content, respond affectively to the learning environment, participate in instructional activities, and interact with peers during the learning process. Similarly, the EBs provide insight into students' beliefs about the nature of knowledge and learning in chemistry. It captures how students perceive the relevance of chemistry to real-life contexts, approach problem-solving tasks, and engage in sense-making and conceptual connections. By encompassing these dimensions, the instrument helps to explain variations in how students learn and apply chemical concepts. Taken together, these instruments allow for a holistic analysis of students' learning by linking CU with engagement patterns and underlying EBs

3.7.1. Three-Tier Conceptual Understanding Diagnostic Tests

Three-Tier Conceptual Understanding Diagnostic Tests (TTCUDTs) were employed to assess students' understanding of CBMG concepts in this study. These diagnostic tests are considered more effective than two-tier and conventional multiple-choice tests because they identify MCs with higher reliability and distinguish them from a lack of knowledge(Milenković et al., 2016). This tool/instrument comprised 26 multiple-choice diagnostic items across each of the three tiers, specifically designed to examine students' CU of CBMG topics. Nine items were adapted from the literature, and the remaining 17 items were developed by the researchers based on the development procedures. For example, items 1, 7, and 9 were adapted from the existing literature (Tan & Treagust, 1999); items 5, 21, and 24 from (Mellyzar, 2021); item 6 from (Rohmah et al., 2022); and Items 10 and 12 from (Ballester et al., 2017). In the present study, the instrument was adapted by incorporating a third-tier confidence measure with two response options ("sure" and "not sure") to assess students' confidence in learning CBMG topics. Additionally, the items were refined by integrating supplementary distractors derived from interview data and informed by relevant literature, consistent with the development of three-tier diagnostic instruments as an extension of two-tier formats. The development procedures of items developed by the researcher are discussed here.

3.7.1.1. Development of the TTCUDT Instrument

The TTCUDTs were developed by researchers based on the reported literature (Chandrasegaran et al., 2007; Treagust, 1988). The development process of the TTCUDT instrument was guided by the stepwise procedures shown in Table 3.2 (below). The procedure was organized into three stages comprising a total of ten steps: the first stage included four steps, the second stage three steps, and the third stage three steps.

Table 3. 2: Tabular Presentation of all ten steps organized under three stages of the diagnostic test process instrument development

Stages	Title	Steps	Implemented Activities
I	Determining the concept boundaries	1	Identify propositional knowledge statements on CBMG
		2	Developing a concept map
		3	Relating propositional knowledge statements to the concept map
		4	Validating the content
II	Obtaining information about the students' alternative conceptions	5	Examining related literature and identifying misconceptions
		6	Conducting semi-structured student interviews
		7	Developing multiple-choice content items with accompanying free-response options
III	Development of the diagnostic test (TTCUDT)	8	Developing the three-tier diagnostic test (TTCUDT)
		9	Designing a specification grid (equivalent to a table of specifications)
		10	Refining the Three-tier diagnostic test (TTCUDT)

Stage 1. Determining the content

Identifying the Propositional Knowledge Statement

The standardized general chemistry course (Chem 1012) module, developed in 2019 by the Ministry of Science and Higher Education for freshman undergraduate students, was used to define the content scope of this study. The module covers fundamental topics of the CBMG, as well as selected laboratory activities and other chemistry topics. Accordingly, the content boundaries and learning objectives were determined in accordance with the purpose of the present study. This stage comprised four steps to determine the concept boundaries. In the first step, relevant CBMG subtopics were identified from the module, including ionic bonding, covalent bonding, metallic bonding, Lewis structures, formal charge and resonance, bond strength, molecular structure and polarity, and atomic and molecular orbital theory. Based on these subtopics, a total of 146 propositional knowledge statements were developed to represent the target contents and sub-contents. The course goals and objectives are clearly stated in the module; thus, this study focused specifically on CBMG topics aligned with those objectives (see Appendix A). The corresponding propositional knowledge statements for the contents are presented in Appendix B.

Developing Concept Maps

Concept maps serve as powerful tools for enhancing understanding of key topics. Concept mapping involves the integration of concepts through graphical representations that organize and depict an individual’s understanding (Novak & Cañas, 2006). They facilitate the integration of new ideas with prior knowledge, supporting meaningful learning and the development of coherent cognitive structures(Dosanjh, 2011; Tseng et al., 2012). In the second step, the concept map was developed based on the standardized module, following the identification of propositional knowledge statements. Each concept map consists of three essential components: concept terms, linking arrows, and linking phrases. Concept terms are typically enclosed in boxes, arrows indicate the direction of relationships, and linking phrases describe the nature of these relationships, forming meaningful propositions that reflect students’ CU of CBMG. In this study, two concept maps were constructed to represent the core CBMG contents. The first concept map (see Appendix C) illustrates the overall concepts of chemical bonding. It begins with the classification of chemical bonds and includes intermolecular forces that exist in compounds formed through interactions between charged particles. It further explains the formation of major bond types: ionic, covalent, and metallic bonds, highlighting that ionic bonds arise from electrostatic attraction between cations and anions, covalent bonds from the sharing of electrons between nonmetal atoms, and metallic bonds from the delocalization of electrons within a metal lattice. The second concept map (see Appendix D) focuses on molecular geometry. It illustrates how molecular shape is determined based on the valence shell electron pair repulsion (VSEPR) theory and the quantum mechanical model, providing an overall representation of the relationships among key concepts within molecular geometry.

Relating Propositional Knowledge Statements to the Concept Map

The third step in the concept demarcation of the content is relating the propositional knowledge statements to the concept map. Primarily, the contents of the learned material were determined. This was followed by identifying the relationship among key concepts and representing them through the concept map. Validation of the propositional knowledge statements and concept maps is the fourth step in the content determination stage of TTCUDT development. The relationship between the propositional knowledge statement and concept map was validated through alignment analysis and supervisors' evaluation. The knowledge statements were mapped onto the corresponding concept map to ensure consistency between conceptual propositions and their graphical representation.

Validating the Content

The fourth step in Stage I of the diagnostic test development involved validating the propositional knowledge statements and the concept map. Validation of the content was accomplished in collaboration with senior two chemistry instructors at the university, and their valuable comments were incorporated accordingly. Their feedback was used to verify the scientific accuracy, clarity of relationships, and completeness of the conceptual structure, and necessary revisions were made accordingly to strengthen the foundation for subsequent item construction.

Stage 2. Obtaining Information About Students' Misconceptions

Examining Related Literature and Identifying Misconceptions

The literature indicates that concepts of chemical bonding and molecular geometry (CBMG) are abstract and difficult to understand across all educational levels. Accordingly, the fifth step of the entire process, or the first step of phase 2, focused on examining relevant literature that discussed the students' misconceptions (MCs). The existing literature on students' alternative conceptions (ACs) related to ionic and covalent bonds (Luxford & Bretz, 2014; Müller et al., 2024; Tsaparlis et al., 2018; Vrabec & Prokša, 2016; Widarti et al., 2024), and metallic bonding (Candra, 2022; Özmen, 2004). Formal charge, Lewis structure, and resonance(Karonen et al., 2021; Mellyzar, 2021; Santos et al., 2024; Suidan et al., 1995), strength of ionic and covalent bonds (Ballester et al., 2017; Hunter et al., 2022; Tan & Treagust, 1999), molecular structure and polarity (Ballester et al., 2017; Erman, 2017; Mahmudah et al., 2020; Özmen, 2004) was consulted to identify and incorporate ACs as distractors in the diagnostic test developed.

Conducting a Semi-structured Interview

The sixth step of the entire process, or the second step of phase 2, was focused on identifying the students' MCs through conducting a semi-structured interview. The students' MCs were identified using the academic matter interview on CBMG topics. Five students participated in the interview, consisting of open-ended questions aligned with the proposed TTCUDT instrument and designed to elicit students' MCs regarding CBMG concepts. The identified MCs derived from both the interviews and the literature review were used to develop items of the proposed TTCUDT.

Developing Multiple-Choice Content Items with Accompanying Free-Response Options

The seventh step of the overall process, or the third step of Phase 2, involved developing multiple-choice items with accompanying free-response parts. These items were administered to undergraduate students and used as the second tier of the diagnostic test. The identified MCs derived from both the interviews, the literature review, and responses from students on multiple-choice items with accompanying free-response parts were used to develop items of the proposed TTCUDT.

Stage 3. Development of the Three‑ Tier Diagnostic Test

The eighth step of the entire process, or the first step of phase 3, was developing the three-tier diagnostic test. At the seventh step, the TTCUDT items were developed in alignment with the objectives of the General Chemistry I (Chem 1012) module. The development process was informed by a review of relevant literature and responses obtained from interviews with undergraduate students. Open-ended questions were designed to elicit explanations underlying students' choices, thereby informing the construction of appropriate distractors.

Designing a Specification Grid

The ninth step of the entire process, or the second step of phase 3, was designing a specification grid (equivalent to a table of specifications). In the ninth step of this stage, using a table of specifications, both adapted and newly developed TTCUDT items incorporated distractors derived from students' alternative conceptions identified through interviews, the literature review, and open-ended items were put in a summary table. The specification grid summarizing the content areas is presented in Table 3.3. An initial pool of 37 TTCUDT items was adapted and subsequently reviewed by supervisors and chemistry instructors at Bahir Dar University to ensure content validity, particularly the alignment with propositional knowledge statements related to CBMG topics. Based on their feedback, the instrument was revised, resulting in the retention of 30 items after seven items were removed

The distribution of items across the different concepts was determined based on curriculum emphasis, content complexity, and expert judgment. Greater weight was assigned to core and frequently misunderstood concepts in CBMG, while ensuring balanced representation of all key subtopics identified in the course syllabus. This approach ensured content validity and adequate coverage of the instructional objectives.

Table 3. 3: Specification grid for TTCUDT development

Main Topic	Sub-contents	No. of items	Propositional knowledge statements
Chemical Bonding and Molecular Geometry	Ionic bonding	7	1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13
	Covalent bonding	2	1, 3, 4, 5, 6, 7
	Metallic bonding	2	2, 3, 4, 5, 6
	Lewis's structure	1	1, 5, 6, 7, 8, 9, 10
	Formal Charge and Resonance	3	2, 3, 4, 5,6, 8, 9, 10, 11
	Strengths of ionic bonds and covalent bonds	3	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 14, 15
	Molecular structure and polarity	7	2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 16, 17,18, 19, 20, 24, 25, 26, 27
	Valence bond and molecular orbital theory	1	25, 26, 27, 29, 30

Refining the Three-tier Diagnostic Test

The tenth step of the entire process, or the third step of phase 3, was refining the three-tier diagnostic test. The researcher refined the tool by administering the developed TTCUDT. The finalized TTCUDT instrument was developed to assess undergraduate students' conceptual understanding (CU). The first tier consists of content questions, mostly with four options (except one item with two choices). The second tier provides reasoning options, including one correct explanation and three distractors representing common MCs. The third-tier diagnostic test measures students' confidence levels, offering two options to indicate whether they are certain about their responses to the first and second tiers. Each item contains one correct answer per tier, with distractors reflecting probable MCs. The instrument was refined through successive drafts based on the supervisor's feedback and finalized for administration. The final version of the TTCUDT, consisting of 26 items, was administered after the pilot testing phase (see Appendix E).

3.7.2. Student Engagement Scale

Thirty-one survey questionnaire items on student engagement (SE) were adapted from relevant literature (Heilporn et al., 2020); (Wang et al., 2016). These items were used to measure overall SE among undergraduate students in both groups. The questionnaire items encompass four domains of SE, including Cognitive Engagement (CogSE = 8 items), Emotional Engagement (EmSE = 7 items), Behavioral Engagement (BehSE = 7 items), and Social Engagement (SocSE = 9 items), which describe undergraduate students' involvement during the teaching and learning process. All items were represented using five-point Likert scales, ranging from strongly disagree to strongly agree. The questionnaire was administered in an English version that was familiar to the undergraduate students' level of understanding. Among the 31 SES, eight were reverse-coded items to minimize response bias. The responses to the reverse-coded items were transformed into positive values based on the established scale. Five-point Likert scales were used to assess students' level of engagement with chemistry (See Appendix F).

3.7.3. Epistemological Belief Survey (CLASS-Chem)

The epistemological beliefs survey (CLASS-Chem) was aimed at determining how undergraduate students' views about the acquisition of knowledge in the learning process and how educational practices affect their beliefs in chemistry instruction. A five-point Likert scale ranging from strongly disagree to strongly agree was used to assess undergraduate students' epistemological beliefs (EBs) about knowledge and the process of knowing chemistry. The student EBs assessment with 36 CLASS-Chem items was adapted from the Colorado Learning Attitudes about Science Survey, particularly chemistry (CLASS-Chem) (see Appendix G)

3.7.4. Semi-Structured Interviews

Qualitative data collection instruments are designed to capture individuals' feelings, perceptions, and opinions about issues or organizations. Among these, semi-structured interviews are particularly valuable because of their flexibility. They allow researchers to probe deeper, explore new areas of inquiry, and generate richer data. They also tend to encourage participants to express their own opinions and descriptions, and help uncover concerns that the researcher had not anticipated (Trigueros et al., 2017). In this study, semi-structured interviews were employed to collect the undergraduate students' CU, SE, and EBs.

3.7.4.1. Semi-structured CU Interview Items

Semi-structured interviews are widely recognized as suitable for in-depth exploration of participants' perspectives(Adams, 2015). In this study, semi-structured interview protocols were employed to examine undergraduate students' CU of CBMG. Four interview items were developed in English by the researcher, informed by a review of relevant literature and students' responses to diagnostic assessments, to guide the data collection process. The interviews also aimed to capture students' views on their understanding of CBMG concepts across both groups (see Appendix H). Each interview lasted approximately 25–30 minutes. In addition, open-ended questions on CBMG were administered to a separate group of students to further identify alternative conceptions and to refine the development of interview questions and diagnostic distractors.

3.7.4.2. Semi-Structured SE Interview Items

Assessing learners' engagement in classroom lesson delivery and creating a participatory instructional strategy underlying an effective learning experience. In this study, five semi-structured interview items were developed by the researcher based on the review of relevant literature to measure the undergraduate students' level of engagement during the delivery of CBMG concepts. These instrument items were used to capture information about undergraduate SE in both classroom instructional deliveries, i.e., BL and CTM (see Appendix I).

3.7.4.3. Semi-Structured EBs Interview Items

The consideration of undergraduate students' EBs is an important construct to attain the intended learning outcomes in learning environments. In this study, semi-structured interviews were employed to obtain in-depth information about respondents' EBs on the status of knowledge and knowing in the learning of chemistry, particularly CBMG concepts. To this end, four semi-structured interview questions about EBs were developed by the researcher through consultation of relevant literature. These items were designed to assess the undergraduate students' beliefs about knowledge and knowing CBMG concepts in the process of learning in both groups (Appendix J).

3.7.5. Classroom Observation Checklist

Classroom observation is a primary mode of research that has the potential to yield valid or authentic data, as compared to using mediated or inferential approaches (Cohen et al., 2017). In this study, classroom observation checklists were used to monitor the implementation of BL and identify problems that arise during the learning delivery. These checklists covered domains such as instructional design, time management, learning environment, student engagement, and assessment and feedback. The classroom observation checklist was used weekly during lesson delivery throughout the intervention to monitor the implementation of instructional activities. In addition, the classroom observation checklist was used as part of the qualitative data analysis to identify challenges in BL implementation (see Appendix K).

3.7.6. Validity of the Instruments

Validity refers to the extent to which an instrument measures what it is intended to measure(Wu et al., 2016). Before data collection, the content and face validity of all instruments- Three-Tier Diagnostic Test (TTCUDT), Student Engagement Scale (SES), Epistemological Beliefs survey (CLASS-Chem), and the semi-structured interview items- were examined and verified. These instruments were reviewed by researchers, supervisors, and senior instructors in curriculum, psychology, and language at the study site. Curriculum, psychology, and language instructors were involved to ensure content alignment, construct validity, and clarity of the instruments. In addition, the alignment between the study objectives and the items in TTCUDT, SES, and CLASS-Chem was carefully evaluated and refined based on their feedback. Following these revisions, a pilot study was conducted to further validate the instruments before their use in the main study.

The SES was adapted from existing literature. The wording of the items was revised to fit the context of this study, and some items were further modified in consultation with supervisors to ensure relevance. The SES was administered as both a pre-test and a post-test to all participant groups. To minimize memorization effects, the post-test items were reshuffled before administration. The inclusion of SES at the course level was based on the premise that instructional approaches and teaching activities influence undergraduate students' engagement in learning CBMG concepts.

Similarly, the CLASS-Chem was adapted from previously validated instruments and had also been used with a different group of students at Bahir Dar University. The CLASS-Chem items were reviewed by supervisors and senior instructors before piloting, and their wording was revised to align with the objectives of this study. Some items were further modified in consultation with supervisors to ensure contextual relevance. The instrument was administered in English, which was appropriate for the participants' level of understanding. Following the pilot study and subsequent revisions, the instrument was refined to 36 items and administered as both a pre-test and a post-test. As with the SES, the post-test items were reshuffled to minimize memorization effects.

3.7.7. Trustworthiness and Reliability of the Instruments

For the qualitative interview component of the study, trustworthiness was ensured by employing well-established research methods, providing sufficient contextual information, maintaining early communication with participants, and applying triangulation. Additional measures included selecting participants who were genuinely willing to take part, using iterative questioning during interviews, engaging in regular debriefing with supervisors, and consulting previous research findings (Shenton, 2004). For the quantitative components, internal consistency reliability was assessed in line with established literature (DeVellis, 2017; Nunnally & Bernstein, 1994)

3.8. Pilot Study

In the present study, a pilot study was conducted to check the item difficulty, the discrimination indices of test items, and the reliability of the instruments. The validation process involved three instruments: TTCUDT, SES, and CLASS-Chem, and the semi-structured interview questions. The pilot study was conducted before the commencement of the actual study to validate the appropriateness and effectiveness of the instruments, generating reliable findings.

3.8.1. Piloting the Instrument

In a pilot study, the researcher modified the instrument based on the feedback from a limited group of participants who completed and evaluated the instrument (Cresswell, 2012). After the approval of TTCUDT, SES, and CLASS-Chem, a pilot study was conducted to verify their reliability. All instruments were piloted, then modified and revised based on the findings of the pilot study. The instruments were piloted with 30-second-year undergraduate students enrolled in the CBMG course at Bahir Dar University, but not part of the study before the main intervention. The primary reason for selecting second-year students for the pilot study was that first-year students were planned to participate in the intervention, and administering the instrument to the same cohort multiple times could have introduced information contamination and affected the variability of responses. The pilot study was conducted over two days. The TTCUDT was piloted on the first day, lasting an average of 60 minutes, while the SES and CLASS-Chem were piloted on the second day, each lasting approximately 35 minutes. The semi-structured interview was also piloted with a small group of students to ensure the clarity and appropriateness of the questions, and minor modifications were made based on the feedback. For the TTCUDT, item analysis was conducted to evaluate item difficulty, discrimination indices, and internal consistency reliability using the Kuder–Richardson-20 (KR-20) coefficient. For the SES and CLASS-Chem, internal consistency reliability was assessed using Cronbach's alpha coefficient. Details are discussed in the sections below.

3.8.2. Item Analysis

The analysis of the Three-Tier Test of Conceptual Understanding Diagnostic Test (TTCUDT) followed established procedures reported in the literature on its effectiveness (Arslan et al., 2012; I. Caleon & R. Subramaniam, 2010; Irmak et al., 2023; Milenković et al., 2016). Table 3.4 presents all possible response combinations. Responses were categorized based on the accuracy of the content (first tier), reasoning (second tier), and confidence (third tier). Scientific knowledge was identified when both the first and second tiers were correct with high confidence ("sure"). Responses were classified as false positives when the first tier was correct but the second tier was incorrect with high confidence, and as false negatives when the first tier was incorrect but the second tier was correct with high confidence. When both tiers were incorrect with high confidence, responses were categorized as pure MCs. If both tiers were correct but confidence was low ("not sure"), the response was considered a lucky guess. All other combinations involving incorrect responses with low confidence were categorized as a lack of knowledge.

Table 3.4: All possible responses for the TTCUDT instrument.

Type of tiers			
First tier	**Second tier**	**Third-tier**	**Categories**
Correct	Correct	Sure	Scientific knowledge
Correct	Incorrect	Sure	Misconception (False Positives: FPs)
Incorrect	Correct	Sure	Misconception (False negatives: FNs)
Incorrect	Incorrect	Sure	Misconception
Correct	Correct	Not sure	Lucky guess (Lack of confidence)
Correct	Incorrect	Not sure	Lack of knowledge
Incorrect	Correct	Not sure	Lack of knowledge
Incorrect	Incorrect	Not sure	Lack of knowledge

Source: *Arslan et al., 2012*

To analyze the TTCUDT instrument, appropriate scoring procedures were applied. The scoring approach presented in Table 3.5 is supported by the literature, which highlights its effectiveness (Arslan et al., 2012; Irmak et al., 2023; Milenković et al., 2016). Accordingly, TTCUDT items were scored and categorized based on students' responses into three levels: First-tier (FT), Both Tiers (first and second tiers, BT), and All Tiers (first, second, and third tiers, AT), as presented in Table 3.5. Moreover, the analysis considered students' confidence levels by focusing solely on third-tier responses.

Table 3. 5*:* The criteria used to score the TTCUDT items

TTCUDT item category	Abbreviations	Scoring Criteria
First-tier (Content-concept multiple-choice item)	FT	If the FT item is answered correctly, score 1; otherwise, 0.
Both tiers (first and second tiers)	BT	If both the first and second tiers are answered correctly, score 1; otherwise, 0
All tiers (first-tier, second-tier, and confidence tier)	AT	If all tiers (first, second, and third tiers) are answered correctly, scoring 1; otherwise, 0

After piloting, the item difficulty and discrimination indices of the 30 TTCUDT instruments were analyzed to identify reliable items for pre-posttest use. These indices of the TTCUDT were evaluated based on the acceptable ranges described in the literature (Mahjabeen et al., 2017; Pande et al., 2013). The analysis presented in Table 3.6 shows that several items required revisions to improve the overall quality of the instrument. Specifically, four items (3, 5, 19, and

26) were revised and modified, while the other four items 2, 7, 11, and 25) did not meet the acceptable criteria and were therefore rejected. According to established guidelines, items with very high or very low difficulty indices (e.g., $p < 0.30$ or $p > 0.80$) and low discrimination indices (e.g., $D < 0.20$) are considered unsuitable for inclusion, as they do not effectively differentiate between high- and low-performing students (Arslan et al., 2012; Ebel & Frisbie, 1991). Therefore, these items were excluded to improve the overall quality and reliability of the instrument. The mean item difficulty index of TTCUDT was 0.46, with values ranging from 0.2 to 0.90. Similarly, the mean discrimination index was 0.39, with values ranging from 0.2 to 0.90. Overall, the results indicated that the remaining items demonstrated acceptable levels of reliability and discrimination according to established guidelines. Consequently, the final version of the TTCUDT, consisting of 26 items, was administered as both the pretest and posttest.

Table 3. 6: Item difficulty and discrimination indices of TTCBCUTs

Difficulty index (p)	**No. of items**	**Discrimination index(D)**	**No. of Items**
$0.70 < p < 0.9$	6	$0.8 < D < 0.9$	3
$0.6 < p < 0.7$	13	$0.6 < D < 0.8$	10
$0.5 < p < 0.6$	9	$0.4 < D < 0.6$	7
$0.2 < p < 0.5$	1	$0.2 < D < 0.4$	7
$P < 0.2$	1	$D < 0.2$	3
Mean = 0.46	Total = 30	: Mean = 0.39	Total =30
SD = 0.15		SD = 0.22	

Additionally, the TTCUDT instrument's item difficulty and discrimination indices were analyzed for each tier (FT, BT, and AT) to assess the quality of the test items. The results show that the means of both indices decreased as the number of tiers increased (item discrimination index for FT: 0.52; BT: 0.45; AT: 0.39, and item difficulty index for FT: 0.61; BT: 0.30; AT: 0.27). The decline in mean item difficulty indicated that answering the FT test is easier than finding the reasons for the selected answer and being certain of it. (Arslan et al., 2012). Similarly, the decrease in the mean item discrimination index across tiers shows that higher-tier TTCUDT items may not adequately discriminate against CBMG concepts. Accordingly, the final version of TTCUDT consisted of 26 items for the pre-post-test for all groups (see Appendix E).

3.8.3. Reliability Results

Reliability is one of the psychometric features to consider when using a test or assessment method (Johnson & Christensen, 2016). Reliability refers to the degree of consistency with which the instrument measures a construct. The examination of the reliability and validity of instruments through a pilot study significantly supports the acceptability of the research findings. The internal consistency /reliability/ of items was checked based on the relevant literature. This means the reliability results obtained from the pilot study were compared with the acceptable levels in the appropriate literature. As presented in Table 3.7, the reliability of TTCUDT, SES, and CLASS-Chem (EBs) was evaluated. The reliability of the TTCUDTs was determined using the Kuder-Richardson formula-20 (KR-20). The overall Kuder-Richardson-20 (KR-20) value of the test for correct answers, considering correct answers for each tier of all items, was found to be 0.84. Furthermore, the Kuder-Richardson-20 (KR-20) values were analyzed for each category of TTCUDT and showed that the first tier (FT), both tiers (BT), and all tiers (AT) were found to be 0.87, 0.85, and 0.81, respectively. This implies that the instrument is highly reliable (Taber, 2018).

The reliability of the SES and CLASS-Chem scales was assessed using Cronbach's alpha in a pilot study. The overall SE Cronbach's alpha was found to be 0.89, indicating acceptable internal consistency across all items. Furthermore, the reliability of the SE items across the four dimensions showed that CogSE scored 0.75, EmSE 0.72, BehSE 0.65, and SocSE 0.71. This result suggests that the SES is reliable for measuring SE. Similarly, we examined the reliability of CASS-Chem (EBs) using Cronbach's alpha. The Overall reliability for CLASS-Chem was 0.89, indicating an acceptable range of internal consistency across all items. In addition, the reliability for the dimensional categories of CLASS-Chem ranged from 0.68 to 0.73. These values are comparable to those reported for the original EBs instrument, which range from 0.55 to 0.79 (Heredia & Lewis, 2012), and fall within the acceptable range of 0.54 to 0.76 for CLASS-Chem items (Schommer-Aikins, 2004). Accordingly, the final versions of the SES and CLASS-Chem instruments were administered for the pretest and post-test for all respondent groups. Besides, the post-test was administered after the completion of learning by reshuffling the items to reduce memorization effects.

Table 3.7: Cronbach’s alpha and Kuder-Richardson reliability coefficients of the instruments

Instrument	No. Items	Reliability	Reliability Across the Dimensions of Three Instruments									
TTCUDT	26		**Overall**	**FT**	**BT**	**AT**						
		KR-20	0.84	0.87	0.85	0.81						
SES	31	**Cronbach alpha**	**Overall, SE**	**CogSE**	**EmE**	**BehSE**	**SocSE**					
			0.89	0.75	0.72	0.65	0.72					
CLASS-Chem	36	Cronbach alpha	**Overall CLASS-Chem**	**PI**	**RWC**	**PSG**	**PSC**	**PSS**	**SME**	**CC**	**CL**	**AMPC**
			0.89	0.72	0.73	0.73	0.71	0.71	0.73	0.68	0.70	0.70

3.8.4. Piloting and validating the BL Model

The same groups of freshman undergraduate students who were taking CBMG topics were recruited to validate the effectiveness and appropriateness of the implementation of the BL instructional approach. The pilot study was conducted with these students who were excluded from the main study and aimed to assess the implementation of the BL model, identify challenges in its design and delivery, determine the appropriate duration of instructional intervention, and detect limitations in the approach in the initial draft before the main study. The BL model pilot was conducted by the researcher over ten consecutive days (1 hour per day) with 15 volunteer first-year undergraduate students in a computer laboratory, using an online platform with pre-uploaded learning materials. During the pilot, the researcher facilitated the implementation by organizing the learning activities, providing guidance on the use of the online platform, monitoring students’ participation, and offering technical and instructional support throughout the pilot. Additionally, the researcher conducted observational follow-ups to evaluate the students’ learning activities. Students were encouraged to explore the learning materials, including interactive videos, animations, and simulations that illustrate the chemical phenomena related to the course topics.

Furthermore, the researcher held 30-minute discussion sessions with the participants after five days to provide feedback on the overall learning activities. The feedback shows that the implemented BL approach, particularly the online learning platform, was an attractive and interesting learning environment with clearer concepts than the CTM. However, students reported challenges, including limited computer lab time, slow internet speed, a lack of computer skills to access resources using their username and password, and the problem of power outages. Based on this feedback, adjustments were made for the main study. Students were allocated sufficient computer lab time, and detailed ICT training was provided to implement the BL model. Furthermore, internet interruptions highlighted the need for computer lab assistants to manage these interruptions during the BL implementation. Overall, the implementation of the BL approach was employed in consideration of the feedback provided by the pilot group throughout the finalization of the study sessions.

3.9. Data Collection Procedures

Planning what data to acquire is the first stage in the data collection process (Wu et al., 2016). After obtaining permission from Bahir Dar University, the researcher introduced the voluntary participants, chemistry instructors, the university's ICT director, the head of e-learning under the teaching and learning unit, and computer lab assistants to the study. The researcher also provided an overview of the purpose and significance of the BL approach to students in the IG. A pilot study was conducted with 30 first-year undergraduate students to confirm the validity and reliability of the instruments before the intervention. Pretests were administered for both groups to establish the participants' baseline status before the commencement of the intervention. The pretest was conducted over two days to avoid boredom while completing the tools used. Pretest data were collected using TTCUDT, SES, and CLASS-Chem (EBs). Next, the IG and CG were exposed to the BL approach and the CTM, respectively. During lesson delivery, the researcher documented the respondents' involvement in the process of implementing BL and CTMs using the classroom observation checklist. After the completion of the intervention, posttests were administered to both groups to measure the students' CU, SE, and EBs. The posttests were administered using the same instruments. At the posttest stage, qualitative data were collected through semi-structured interviews addressing CU, SE, and EBs. All interviews were conducted in English, audio-recorded, and transcribed verbatim, and the transcripts were coded manually following established qualitative analysis procedures.

3.10. Methods of Data Analysis

3.10.1. Quantitative Data Analysis

The analysis of the current study data was conducted in alignment with a concurrent embedded mixed-methods design, integrating quantitative and qualitative data. Data analysis and interpretation involve making sense of information obtained from respondents during or immediately after data collection (Cresswell, 2012). Assumption tests were performed on the pretest and posttest data to ensure the validity of subsequent statistical analyses. Specifically, the assumptions of normality and homogeneity of variance (Levene's test) were examined. Based on the assumption tests, the quantitative data from the pretest and posttest were analyzed using parametric and non-parametric statistical techniques. IBM SPSS version 26 was used for all analyses. Specifically, the independent-samples t-test was used to compare mean differences between the experimental and control groups, the paired-samples t-test was employed to examine within-group pretest–posttest changes, and Pearson correlation was used to assess relationships among the study variables. When normality assumptions were violated, the Mann–Whitney U-test and Wilcoxon signed-rank test were applied as non-parametric alternatives for between-group and within-group comparisons, respectively. Welch-adjusted tests were used where the assumption of homogeneity of variances was violated, and this was reported to ensure robust statistical comparison between groups.

3.10.2. Qualitative Data Analysis

Qualitative data from the semi-structured interviews were analyzed thematically to complement the quantitative results. Although initial coding involved identifying relevant words and phrases, the analysis was conducted at the level of meaningful segments (phrases and statements) to preserve participants' intended meanings. This approach ensured that codes and themes were derived from contextually meaningful units rather than isolated words. First, transcripts were read repeatedly to ensure familiarity with the data. Second, initial codes were developed by identifying meaningful segments related to students' experiences, perceptions, and reflections on CU, SE, and EBs within the BL environment. These codes were then grouped and refined into themes through an iterative process of comparison and refinement. Themes were developed by continuously moving between the data, codes, and emerging interpretations to ensure alignment with participants' responses. The responses from the CU interviews were categorized into four themes: accuracy of CU, depth of reasoning and application, MCs and their persistence, and conceptualization of electron pair geometry, molecular geometry, and polarity. Similarly, the responses from SE interviews were categorized into five themes, including CU and retention, engagement and motivation, participation and learning agency, social interaction and collaboration, and real-life relevance and application. Likewise, EBs interview responses were analyzed inductively, resulting in four emergent themes, including conceptual knowledge and learning aspects, sources of chemistry knowledge, problem-solving aspects, and conceptual connection aspects.

The classroom observation data were analyzed using qualitative descriptive (narrative) analysis. Specifically, the structured checklist was first reviewed to identify and code observed indicators related to students' learning behaviors and implementation processes in the BL environment. The coded data were then grouped into categories reflecting student-related challenges (e.g., engagement and access to online learning resources) and institution-related challenges (e.g., technological and infrastructural limitations). These categories were subsequently synthesized and presented in narrative form to support interpretation and triangulation with the interview and quantitative findings.

3.11. Ethical Considerations of the Study

Research requires careful ethical consideration to ensure the reliability of information and to minimize biases. A sound research problem must comply with moral, ethical, and legal standards that guide scientific inquiry. Accordingly, the researcher addressed ethical considerations before, during, and after the research process.

3.11.1. Ethical Clearance

At the beginning of the study, ethical clearance was obtained from Bahir Dar University, College of Education, specifically the School of Teacher Education, Department of Science and Mathematics Education, Ethiopia. The study was approved by Bahir Dar University in Ethiopia before commencing it. This approval was granted after the research proposal was reviewed. It enabled the researcher to seek permission from university stakeholders and administrators. Ethical approval (Ref. No. STE196/42/17) was granted on December 11, 2023.

3.11.2. Informed Consent

The researcher obtained permission and informed consent from all participants before the study. Participants were clearly informed about the purpose of the research, the confidentiality measures in place, and their right to withdraw at any time if they encountered unsafe conditions during the intervention. They were thoroughly briefed on the study's objectives, methods, potential risks, and anticipated benefits before agreeing to participate. Instructors were specifically assured that classroom observations were not intended to evaluate their individual performance but rather to monitor the implementation of the intervention. Throughout the data collection process, the researcher adhered to established ethical principles by ensuring voluntary participation, securing informed consent, and safeguarding participants' privacy and confidentiality. Careful attention was consistently given to protecting the welfare and rights of all individuals involved in the study.

3.11.3. Guaranteeing Confidentiality and Anonymity

Confidentiality and anonymity are ethical practices designed to protect the privacy of human subjects while collecting, analyzing, and reporting data (Coffelt, 2017). These ethical practices were strictly followed throughout the study involving first-year undergraduate students at Bahir Dar University. Before data collection, participants were informed that all data would be used solely for academic research purposes. They were assured that participation was voluntary and that they could refuse or withdraw at any time without any academic or personal consequences. Participation involved no cost or harm, and the BL approach was expected to enhance their chemistry learning. No personal identifiers, such as names, were included; instead, participants were assigned unique codes used consistently during data processing and analysis. Confidentiality and anonymity were ensured by keeping all data securely, reporting results in a collective form, and anonymizing interviews by removing identifying details. Participants were also informed that findings would not be published in any way that could reveal their identities.

CHAPTER FOUR

4. RESULTS OF THE STUDY

4.1. Introduction

This chapter presents the findings of the dissertation entitled: Effect of BL on Students' CU, SE, and EBs in CBMG Concepts: The Case of Bahir Dar University. Both quantitative and qualitative data analysis techniques were employed to address the research questions outlined in Section 1.4. For clarity and coherence, the results are organized and presented separately according to the respective methodological approaches. The results of the analysis are presented in three parts: the assumption test analysis, followed by the descriptive statistics, and then the inferential statistics. The inferential statistics include both parametric and non -parametric tests used to compare differences in learning gains between the intervention and comparison groups. Finally, the qualitative findings were analyzed thematically based on the interview questions for each variable of the study and triangulated with the quantitative results.

4.2. Biographical Characteristics of the Study Participants

The biographical (demographic) characteristics of participants are now presented first to provide context for interpretation, followed by the main outcome variables, namely CU, SE, and EBs, which are reported in separate sections. This revision improves clarity and coherence in presenting the study findings. Table 4.1 shows the demographic characteristics of respondents of the study.

Table 4.1**:** Demographic Profile of the Study Participants

Variable	Category	IG (n = 42)	CG (n =44)	Total (N = 86)
Gender	Male	25 (59.52%)	34 (77.27%)	59 (68.60%)
	Female	17 (40.48%)	10 (23.73%)	27 (31.40%)
Age	18-20	30 (71.43%)	35 (79.55%)	65 (75.58%)
	> 20	12 (28.57%)	9 (20.45%)	21(24.42%)
Year of study	First year	✓	✓	✓

4.3 Effect of Blended Learning on Students' Conceptual Understanding

In this section, the results and discussions of quantitative and qualitative data are presented. The data are presented using descriptive statistics, inferential statistics (mean, standard deviation, parametric tests, non-parametric tests), and thematically, wherever appropriate.

4.2.1. Comparison of Mean Scores of IG and CG in CU

Research Question One: What is the effect of BL on undergraduate students' conceptual understanding of CBMG concepts, and in what ways does their understanding change?

4.2.1.1. Comparison of Pretest Mean Scores of IG and CG in CU

Descriptive statistics

Before the intervention, students' prior knowledge regarding the concepts of CBMG were assessed in both groups using a pretest. The assumptions of the pretest instrument, TTCUDT, were examined before the main data analysis. Descriptive statistics for the pretests were then analyzed for both the IG and CG respondents across categories. In relation to prior understanding, key descriptive measures, including the mean, standard deviation, and the number of respondents in each group, were computed to provide a clear overview of the initial data. After testing the assumption, Table 4.1 demonstrates the descriptive statistics for the pretest scores. The pre-TTCUDT for each tier category was scored out of 26 points. The descriptive statistics for the pre-TTCUDT scores were analyzed in percentages. The pre-TTCUDT scores for each tier category were calculated out of a maximum of 26 points and subsequently converted into percentages. For students in the intervention group (IG), the pre-test scores ranged from 30.77% to 73.08% in the first tier (FT), from 19.23% to 50.00% in both tiers (BT), and from 11.54% to 38.46% in all tiers (AT). The descriptive statistics presented in Table 4.1 indicate that the mean pre-test score for the FT category in the CG (M = 51.1, SD = 15.9) was slightly higher than that of the IG (M = 50.1, SD = 10.9). However, the IG demonstrated slightly higher mean scores in the BT (M = 32.1, SD = 8.6) and AT (M = 23.9, SD = 7.4) categories compared to the CG (BT: M = 28.8, SD = 12.2; AT: M = 22.6, SD = 9.9). Overall, the mean pre-TTCUDT score of the IG (M = 35.4) was marginally higher than that of the CG (M = 34.2). Additionally, the mean pre-TTCUDT score decreased as the number of tiers increased from pre-FT to pre-AT in both groups. Thus, the descriptive statistics presented indicate variations in the pre-TTCUDT mean scores among the FT, BT, and AT categories. This finding supports the previous findings, indicating that the observed decrease in correct answers can be attributed to the lower probability of lucky guesses in three-tier tests compared to one- or two-tier tests, thereby enhancing the reliability of the assessment outcomes on the same topic (Şen & Yilmaz, 2017).

Table 4.2: Descriptive statistics for pre-TTCUDT score

Variable	Group	Category	N	Mean	SD
Pre-TTCUDT	IG	Pre-FT	42	50.1	10.9
		Pre-BT	42	32.1	8.6
		Pre-AT	42	23.9	7.4
	CG	Pre-FT	44	51.1	15.9
		Pre-BT	44	28.8	12.2
		Pre-AT	44	22.6	9.9

Assumption testing was conducted to examine whether the respondents had comparable prior knowledge of chemical bonding concepts and to assess the normality of the pretest data distribution. The analysis was performed for the TTCUDT across the FT, BT, and AT categories. The results indicated that the skewness and kurtosis values for all variables fell within the acceptable range (−1 to +1). In addition, the Shapiro–Wilk test showed that the pre-FT and pre-BT data were normally distributed. However, the normality assumption was not met for the pre-AT data, indicating a non-normal distribution. Accordingly, parametric tests were applied to the pre-FT and pre-BT data, whereas non-parametric analysis was used for the pre-AT data.

Inferential Statistics for Pre-TTCUDT

The results obtained from the independent t-test in Table 4.2 present the mean scores of pre-TTCUDT across the FT, BT, and AT categories between groups. Levene's test for equality of variance of pre-BT was insignificant, $F(1, 84) = 2.431$, $p > .05$, indicating that the assumption of homogeneity of variances was met. In contrast, Levene's test for equality of variance of pre-FT and pre-AT was significant at $F(1, 76.4) = 6.61$, $p < .05$, and $F(1,80) = 4.53$, $p < .05$, respectively, indicating that the assumption of homogeneity of variances was violated. An independent-samples t-test (for FT and BT scores) was carried out to assess whether there is a statistically significant mean difference in pre-TTCUDT related to understanding CBMG concepts between IG and CG or not. The results of the t-test analysis, shown in Table 4.2

asserted that there is no statistically significant mean difference between groups in pre-TTCUDT of pre-FT, t (76.4) = -.410, p > .05; pre-BT, t (84) = 1.301, p > .05. These findings indicated that the groups were assumed to have a similar level of CU regarding chemical bonding topics before the implementation of the intervention.

Table 4.3: Independent-samples t-test for pre-TTCUDT results

Observation				Levene's test for equality of variances		t-test for equality of means			
	Group	M	SD	F	Sig.	t	df	p	Cohen's d
Pre-TTCUDT-FT	IG	50.10	10.90	6.61	.012	-.410	76.4	.683	0.08
	CG	51.10	8.60						
Pre-TTCUDT-BT	IG	32.10	15.90	2.43	.123	1.301	84	.197	0.28
	CG	28.80	12.20						

As the data for the alternative-tier (AT) were not normally distributed, a Mann–Whitney U test was conducted on the pre-TTCUDT AT scores to determine whether there was a statistically significant difference between the IG and the CG in their baseline understanding of CBMG concepts. The results of the t-test analysis in Table 4.3 indicated that there was no statistically significant mean difference between groups in pre-TTCUDT of pre-AT, U =798, Z = -1.104, p > .05, r =.15. This suggests that the groups were comparable at baseline.

Table 4.4: Mann-Whitney U-test for pre-TCUDT results

	Group	N	Mean ranks	Sum of Ranks	U	Z	P-value	r
Pre-TCUDT-AT	IG	42	46.50	1953	798	-1.104	.270	.15
	CG	44	40.64	1788				

4.2.1.2. Comparison of Posttest Mean Scores of IG and CG in CG

Descriptive statistics for post-TTCUDT Scores across groups

The descriptive statistics of the post-TTCUDT scores reveal clear differences between the IG and the CG across all three tiers. The IG achieved higher mean scores in the first tier (FT) (M = 65.93, SD = 13.04), both tiers (BT) (M = 51.47, SD = 16.18), and all tiers (AT) (M = 49.26, SD = 18.18) compared to the CG, which recorded lower mean scores in FT (M = 53.39, SD =

10.70), BT (M = 32.97, SD = 11.74), and AT (M = 28.29, SD = 10.47). Across both groups, a decreasing trend in mean scores was observed from FT to BT and AT. Table 4.4 presents the descriptive statistics of post-TTCUDT scores for both groups across the FT, BT, and AT categories of the CU variable.

Table 4.5: Descriptive statistics for post-TTCBCUT scores across groups

	Groups	Category	N	Mean	SD
Post-TTCUDT	IG	Post-FT	42	65.93	13.04
		Post-BT	42	51.47	16.18
		Post-AT	42	49.26	18.18
	CG	Post-FT	44	53.39	10.7
		Post-BT	44	32.97	11.74
		Post-AT	44	28.29	10.47

To assess whether the observed descriptive statistics reflect meaningful differences, it is necessary to conduct further inferential analyses to determine the statistical significance of these patterns.

Inferential Statistics for post-TTCUDT

The post-TTCUDT scores in descriptive statistics demonstrated that there was a slight mean difference across groups. Inferential statistics for post-TTCUDT scores, presented in Table 4.6, were used to assess whether mean differences across groups and genders were statistically significant. Levene’s test was used to assess the homogeneity of variances for the post-TTCUDT scores across groups. The results indicated that the assumption of equal variances was met for the FT category, $F = 1.184$, $p > .05$, as the significance value exceeded .05. However, the assumption was violated for both the BT and AT categories, with $F = 6.534$, $p < .05$, and $F = 10.660$, $p < .05$, respectively, indicating unequal variances. Accordingly, equal variances were assumed for FT, whereas equal variances were not assumed for BT and AT in subsequent analyses.

Table 4.6: Independent t-test for post-TTCUDT scores at a 95% confidence interval

Observation	**Group**	**M**	**SD**	**Levene's test for equality of variances**		**t-test for equality of means**			
				F	**Sig.**	**t**	**df**	**p-value**	**Cohen's d**
Post-TTCUDT-FT	IG	65.93	13.04	1.184	.280	4.91	84	.000	1.1
	CG	51.47	16.18						
Post-TTCUDT-BT	IG	49.26	18.18	6.534	.012	5.92	74.32	.000	1.3
	CG	53.39	10.7						
Post-TTCUDT-AT	IG	32.97	11.74	10.660	.002	6.91	68.65	.000	1.4
	CG	28.29	10.47						

As the data were normally distributed, an independent-samples t-test was carried out to determine whether there was a statistically significant difference between groups after the implementation of interventions in BL and CTM. The results of Levene's test for equality of variances also demonstrated that the assumption of homogeneity of variances for post-FT scores was met ($p > .05$), indicating equal variability between groups. In contrast, the test for homogeneity of variances of post-BT and post-AT scores was violated ($p < .05$), showing there was a difference in variability across groups. Accordingly, the post-TTCUDT data were analyzed using a parametric test, such as an independent-samples t-test. The t-test result analysis asserted that there was a statistically significant difference between the groups on post-TTCUDT which mean scores for post-FT: $t(84) = 4.912$, $p < .05$, $d = 1.1$; post-BT: $t(74.3) = 5.917$, $p < .05$, $d = 1.3$ and post-AT: $t(68.6) = 6.91$, $p < .05$, $d = 1.4$. All data exhibited a large effect size (Cohen, 1988), which indicates a substantial mean difference between groups (see Table 4.5). The effect size increased as the number of tiers increased from post-FT across post-BT to post-AT across groups.

The large effect sizes observed in the post-TTCUDT scores may be attributed to the nature and intensity of the BL intervention implemented in this study. CBMG are highly abstract topics that require students to develop visual and conceptual representations of microscopic structures. The integration of online learning resources, including multimedia materials and interactive activities, with face-to-face instruction may have provided students with multiple opportunities to visualize, explore, and reflect on these complex concepts. Furthermore, the BL environment promoted active engagement and self-regulated learning, which may have facilitated deeper conceptual understanding. The relatively low initial levels of CU among students may have also provided greater potential for improvement, contributing to the large observed effect sizes.

4.2.1.3. Paired Samples Statistics Test Results

The paired sample test was performed to compare means in related samples, control for individual differences, and evaluate the impact of treatments or interventions. In this study, pretest and posttest scores within each group were analyzed as related measures to determine the mean differences under the BL and CTM conditions. The analysis of the paired-sample t-test aims to determine if there is strong evidence that the difference between paired observations is significant or not in the same group. The analysis aimed to evaluate how respondents' understanding of CBMG concepts was influenced by either the content tier or the reason tier, as well as the confidence they had in their responses regarding the first two tiers. The descriptive statistics of the paired-sample t-test for post-TTCUDT mean scores were analyzed across pretest and posttest TTCUDT scores within the same group, as indicated in Table 4.7.

Table 4. 7: Descriptive statistics of post-TTCUDT for paired-sample t-test

Intervention Group				Comparison Group			
Variable	**N**	**M**	**SD**	**Variable**	**N**	**M**	**SD**
Pre-FT	42	50.55	10.89	Pre-FT	44	51.75	15.58
Post-FT	42	65.93	13.04	Post-FT	44	53.32	10.70
Pre-BT	42	32.05	8.56	Pre-BT	44	29.11	12.03
Post-BT	42	51.46	16.18	Post- BT	44	33.39	11.67
Pre-AT	42	23.99	7.39	Pre-AT	44	22.64	9.72
Post-AT	42	49.27	18.18	Post-AT	44	28.41	10.37

The descriptive statistics presented in Table 4.7 indicate the pretest and posttest mean scores and standard deviations for the IG and CG across the three tiers of CU: First Tier (FT), Both Tiers (BT), and All Tiers (AT). At the pretest level, both groups demonstrated relatively comparable mean scores across all tiers. Specifically, the IG recorded mean scores of 50.55 (SD = 10.89), 32.05 (SD = 8.56), and 23.99 (SD = 7.39) for FT, BT, and AT, respectively, while the CG showed similar values of 51.75 (SD = 15.58), 29.11 (SD = 12.03), and 22.64 (SD = 9.72). This suggests that the two groups were approximately equivalent in their baseline CU before the intervention. Following the intervention, noticeable differences emerged between the two groups. The IG exhibited substantial improvements across all three tiers, with mean scores increasing to 65.93 (SD = 13.04) for FT, 51.46 (SD = 16.18) for BT, and 49.27 (SD = 18.18) for AT. These gains indicate substantial improvements not only in content–concept understanding (first tier, FT), which reflects factual knowledge, but also in content–concept–reasoning (both tiers, BT) and content–concept–reasoning–confidence (all tiers, AT).

In contrast, the CG showed only modest improvements. The posttest mean scores for the CG were 53.32 (SD = 10.70) for FT, 33.39 (SD = 11.67) for BT, and 28.41 (SD = 10.37) for AT. While slight increases are observed compared to pretest scores, the magnitude of improvement is considerably smaller than that of the IG. This limited gain may be attributed to the nature of CTM, which primarily emphasizes teacher-centered delivery and provides fewer opportunities for active engagement, conceptual visualization, and iterative learning. Although students in the CG were exposed to routine classroom instruction, the absence of structured blended learning components, such as online simulations, supplementary digital resources, and self-paced reinforcement activities, likely restricted deeper conceptual processing and correction of MCs. Consequently, learning gains in the CG remained incremental and largely dependent on classroom exposure alone, whereas the IG benefited from multiple learning pathways that reinforced understanding more effectively. Overall, the pattern of results demonstrates that the intervention group experienced a substantially greater improvement in CU across all tiers compared to the comparison group. Furthermore, in both groups, mean scores decreased progressively from FT to BT and then to AT in the posttest, indicating that higher-order understanding involving reasoning and confidence remains more challenging for students than basic factual knowledge.

Table 4. 8: Paired-samples t-test for pre-post-TTCUDT scores

Pre-TTCUDT	**Post-TTCUDT**	**Group**	**t**	**df**	**p-value**	**Cohen's d**
Pre-FT	Post-FT	IG	-5.91	41	.000	1.28
Pre-BT	Post-BT	IG	-7.94	41	.000	1.50
Pre-AT	Post-AT	IG	-9.09	41	.000	1.80
Pre-FT	Post-FT	CG	-.525	43	.603	0.12
Pre-BT	Post-BT	CG	-1.699	43	.096	0.36
Pre-AT	Post-AT	CG	-2.790	43	.008	0.57

Table 4.8 presents the paired-sample t-test results comparing the pretest and posttest mean scores of the IG and CG on the TTCUDT across the FT, BT, and AT dimensions. The analysis focused on the descriptive statistics of pre-post-TTCUDT for pre-post FT scores, pre-post BT scores, and pre-post AT scores for IG and CG. The post-test mean scores of each FT, BT, and AT in both IG and CG were slightly higher than their corresponding pre-test scores. An inferential paired-samples t-test was conducted to determine whether a statistically significant difference existed between the pretest and posttest scores of IG and CG. The results of the paired-samples t-test revealed statistically significant differences between pre- and post-test scores in the IG across all categories: FT, $t(41) = -5.91$, $p < .05$, $d = 1.28$; BT, $t(41) = -7.94$, $p < .05$, $d = 1.50$; and AT, $t(41) = -9.09$, $p < .001$, $d = 1.80$. All effect sizes were large according to the researcher (Cohen, 1988). In contrast, for the CG, no statistically significant differences were observed for FT, $t(43) = -0.53$, $p > .05$, $d = 0.12$, or BT, $t(43) = -1.70$, $p > .05$, $d = 0.36$. However, a statistically significant difference was found for AT, $t(43) = -2.79$, $p < .05$, $d = 0.57$, indicating a moderate effect size. These results indicated that the post-test scores of respondents in the IG, who were taught using the BL approach, showed significant improvements in their understanding of CBMG concepts compared to the CG, which utilized CTM. Moreover, the effect size of pre-post FT, BT, and AT scores within IG respondents was larger than that within CG respondents, and an increase was observed in each pre-post FT, BT, and AT score for both IG and CG. The BL approach profoundly enhances students' understanding of CBMG concepts regarding content knowledge, providing explanations for their answers, and developing self-confidence compared to CTM. Overall, the findings demonstrate that the intervention was highly effective in improving students’ conceptual grasp and reducing MCs related to CBMG as measured by the TTCUDT.

Table 4.9 shows the percentages of responses for the sample TTCUDT questions (Q6.1, Q6.2, and Q6.3) provided by both groups. The results show that the IG students scored higher percentages compared to the CG students in both FT, BT, and AT. However, the results indicate that the scores in the content concept tier are higher than those in the content-reason combination in both groups. This implies that the content tier questions were easier for students than the content-reason questions, as providing the reason explanations for the content concept tier questions is more difficult and requires critical thinking. Despite the challenges students faced in responding to the reasons for the content tiers, the IG students scored higher percentages (73.29) compared to the CG students (47.36). Additionally, responses in the confidence tiers were considered in conjunction with the combination of the content concept tier, reason tier, and confidence tier. The results show that IG students had higher confidence ratings than CG students. This suggests that students who received BL developed greater confidence than those who received CTM. Meanwhile, students in both groups responded incorrectly to questions, indicating persistent misunderstandings. These incorrect responses reflect challenges in students' conceptual understanding, such as a lack of knowledge, lucky guesses, and MCs in both groups.

Table 4. 9: Sample question for TTCUDT and its resulting post-data analysis

	Sample Question	IG	CG
Q6.1	The bromide ion (Br^-) is one of the anions readily absorbed by colloidal peat soils to increase the productivity of the plant. Some of the following compounds contain bromide nutrients.		
	I) $CaBr_2$ II) HCN III) NH_4Br IV) HBr		
	Which of the above compounds are ionic compounds?		
	A. I and II	4.79%	9.09%
	B. I and III*	80.95%	61.36%
	C. I, II, and III	4.76%	13.64%
	D. I, II, III, and IV	9.525%	15.915%
Q6.2	The reason for your answer is:		
	a. $CaBr_2$ and HCN are ionic compounds because they consist of metals and non-metals.	7.48%	17.59%
	b. $CaBr_2$, HCN, NH4Br, and HBr are covalent compounds because they consist of non-metals.	6.81%	11.25%
	c. $CaBr_2$ and NH_4Br are ionic compounds because they consist of cations and anions and have ionic bonds **	73.29%	47.36%
	d. All compounds are ionic compounds because they consist of cations and anions	12.51%	23.80%
Q6.3	Are you sure about your answers to the previous two questions?		

a. I am sure***	83.33%	61.36%
b. I am not sure	16.67%	38.64%

***Note**: The calculation of percentages for correct responses in the reason tier was performed based on the valid content-reason choices: * correct response for FT only; **Correct combination responses (BT); ***Correct combination responses with confidences (AT).*

4.2.1.4. Analysis of Students' CU in Post-TTCUDT Scores

In addition to analyzing students' CU of CBMG topics through post-TTCUDT responses categorized by tiers (FT, BT, and AT), the quality of learning was assessed in terms of the percentages of response scores for students with scientific knowledge (SK), those lack of knowledge (LK), misconceptions (MCs), and the proportion of students providing correct answers due to lucky guesses (LG) or lack of confidence (LC). Students' responses to the post-TTCUDT were categorized into SK, LK, MC, and LG and analyzed to evaluate differences in treatment effectiveness in their understanding of the CBMG concept across groups. The overall response patterns for the post-TTCUDT data, presented in Table 4.10, were described using percentages based on the theoretical scoring principles outlined in Table 3.5.

Table 4. 10: Analysis of the percentage of students' responses to post-TTCUDT scores per category

	Intervention Group (n =42)				**Comparison group (n = 44)**			
Question	**SK**	**LK**	**LG**	**MCs**	**SK**	**LK**	**LG**	**MCs**
1	78.57	4.76	2.38	9.52	65.91	9.10	0.00	9.09
2	38.10	11.9	0.00	23.81	40.91	11.36	0.00	15.91
3	21.43	38.09	0.00	35.71	6.82	54.55	4.55	15.91
4	78.57	4.76	4.76	0.00	61.36	20.45	2.27	9.09
5	83.33	4.76	4.76	0.00	**72.72**	9.10	0.00	4.55
6	73.81	4.76	7.14	11.9	61.36	18.18	0.00	11.36
7	76.19	11.9	4.76	4.76	54.55	20.45	0.00	15.91
8	38.10	16.67	0.00	2.38	25.00	13.64	0.00	6.82
9	61.9	16.67	0.00	4.76	9.10	22.27	11.36	2.27
10	42.86	14.29	0.00	9.52	20.45	20.45	2.27	9.09
11	45.24	23.8	2.38	7.14	20.45	18.18	2.77	20.45
12	50.00	14.29	0.00	16.67	22.73	15.91	4.55	20.45
13	28.57	21.43	7.14	16.67	29.55	27.27	4.55	25.00
14	57.14	9.52	0.00	33.33	22.73	22.73	0.00	47.73
15	47.62	16.67	16.67	11.9	22.73	25.00	13.64	25.00

16	26.19	14.29	2.38	28.57	18.18	36.36	2.27	31.82
17	35.71	21.43	0.00	11.9	**4.55**	29.55	4.55	31.82
18	45.24	14.29	16.67	16.67	31.82	38.64	6.82	15.91
19	**19.05**	40.48	16.67	7.14	13.64	54.55	2.27	11.36
20	40.48	35.71	0.00	4.76	22.73	38.64	2.27	20.45
21	69.05	16.67	0.00	14.29	31.82	36.36	6.82	23.73
22	66.67	9.52	7.14	4.76	36.36	29.55	11.36	11.36
23	40.48	21.43	0.00	11.9	6.82	36.36	2.72	27.27
24	35.71	38.1	0.00	11.9	11.36	54.55	2.27	15.91
25	35.71	42.86	0.00	21.43	11.36	50.00	6.82	31.82
26	35.71	40.48	0.00	2.38	27.27	54.55	0.00	6.82
Mean	**48.90**	**19.59**	**3.57**	**12.45**	**28.76**	**29.72**	**3.62**	**17.96**
SD	**18.95**	**12.22**	**5.44**	**9.65**	**19.51**	**14.78**	**3.86**	**10.51**

The scientific understanding of students was interpreted solely based on the scores derived from the AT of the post-TTCUDT (Peşman & Eryılmaz, 2010). The findings from the post-TTCUDT reveal a diverse spectrum of SK among students in both IG and CG. In the IG group, the percentage of students' response scores for scientific knowledge ranged from very low (19.05%) in Q19 to very high (83.33%) in Q5. Similarly, in the CG group, small percentages of students ranged from very low (4.55%) in Q17 to very high (72.2%) in Q5. Overall, the percentage of students' response scores for scientific knowledge (SK) was higher in the IG than in the CG across most items, with the exception of item Q13, where the CG slightly outperformed the IG. This implies that IG students have strong scientific knowledge and a full understanding of the electrical conductivity property of NaCl compounds. Similarly, for item Q19, a higher percentage of students in the IG demonstrated scientific knowledge (SK) responses compared with the CG when identifying the overall formal charge of the nitrate ion (NO_3^-), the high resonance contributors of nitroethene molecules, and the acceptable Lewis structure of nitrosyl chloride (NOCl). However, the average percentage of students classified as demonstrating scientific knowledge (SK) across the 26 items was 48.90% in the IG and 28.76% in the CG, indicating that a higher proportion of students in the IG demonstrated scientific knowledge responses compared with the CG. The results reveal that a larger percentage of IG students not only answered both tiers of questions correctly but also demonstrated greater confidence in their answers compared to CG students.

Across the 26 post-TTCUDT items, the average percentage of students demonstrating scientific knowledge (SK) responses was 48.90% in the IG and 28.76% in the CG (see Table 4.14). This indicates that, on average, a greater proportion of students in the IG selected the correct content-reason combinations and expressed high confidence in their answers compared with the CG. This implies that the students in IG responded to the post-TTCUDT more successfully for SK than those in CG. The difference in the mean percentage of students' response scores in post-TTCUDT for SK in IG and CG is approximately 20%. This shows that a relatively high rate of students in IG who were taught CBMG concepts through the BL approach solved all tiers of post-TTCUDT items and were more certain about their answers than the CG students taught in CTM. Thus, the IG students have a more acceptable SK in understanding CBMG concepts than the CG students. This finding aligns with previous research indicating that the questions answered correctly were associated with confidence ratings ranging from 40% to 81%, and it also highlights a notable correlation between increasing levels of overconfidence (Kapoor & Natarajan, 2012). For the remaining items, students (51.19%) who selected incorrect content-reason options demonstrated low confidence, which may indicate the presence of MCs, LK, LG, or a lack of confidence in their responses.

The graph in Figure 4.1 illustrates clear differences between the IG and the CG across the four diagnostic categories of post-TTCUDT. The IG shows a notably higher level of SK compared to the CG, indicating that the intervention effectively strengthened students' accurate CU. In contrast, the CG exhibits a higher level of LK, suggesting that more students in this group were unable to understand the required concepts. Both groups display very low LG scores, implying that responses were generally based on actual reasoning rather than random guessing, which enhances the reliability of the diagnostic outcomes. Regarding MCs, the CG again records higher values, meaning they held more incorrect alternative conceptions than the IG. Overall, the pattern shows that the intervention contributed to reducing students' knowledge gaps and MCs while simultaneously improving their scientific understanding, as reflected by the superior performance of the IG across most categories.

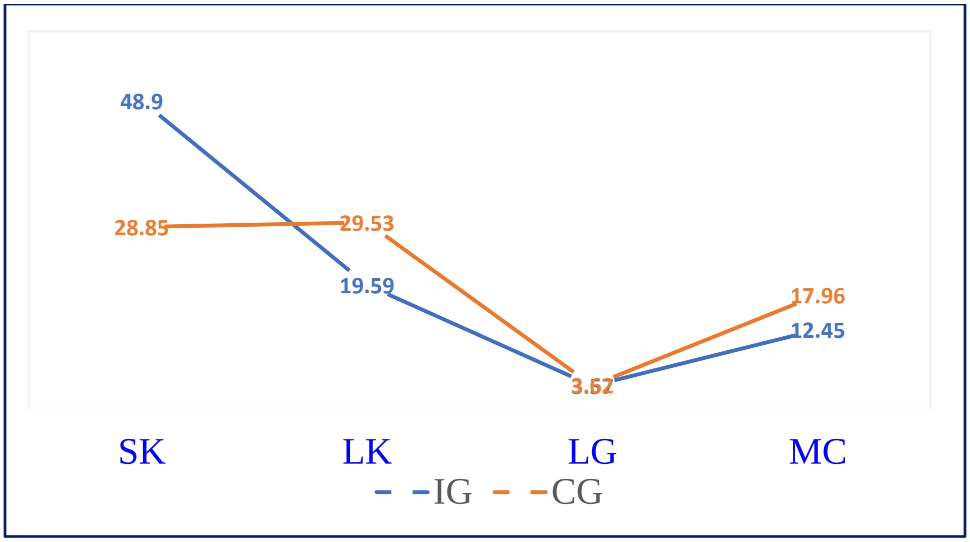


Figure 4.1: Comparison of students' scientific understanding and learning difficulties

Figure 4. 2 illustrates that, except for Q2 and Q13, the percentage of students who responded to the items in IG for SK was higher than that of CG students in all items. A relatively small percentage of students in Q3 and Q19 showed a weak understanding of the concepts of determining the formal charge of the nitrate ion (NO_3^-) and identifying the resonance contributors of the nitroethene ($CH_2 = CHNO_2$) molecule in both groups, respectively. This implies that students in both groups had difficulty in understanding the concepts of formal charge determination and the identification of resonance contributors of molecules and ions. Among IG students exposed to the BL approach, 50% and above demonstrated scientific knowledge on 42.31% of the items, whereas those who received the CTM achieved 19.23%. This indicates that students who were taught through the BL approach exhibited higher scientific knowledge and a deeper understanding of CBMG concepts compared to their peers taught via the CTM, despite both groups showing high confidence ratings. On the other hand, students in both groups demonstrated better scientific knowledge in Q1, Q4, Q5, Q6, and Q7. This indicates that most students had a stronger CU of bond formation, bond polarity, the electrical conductivity of ionic compounds, the identification of bond types in molecules, and the physical properties of ionic compounds.

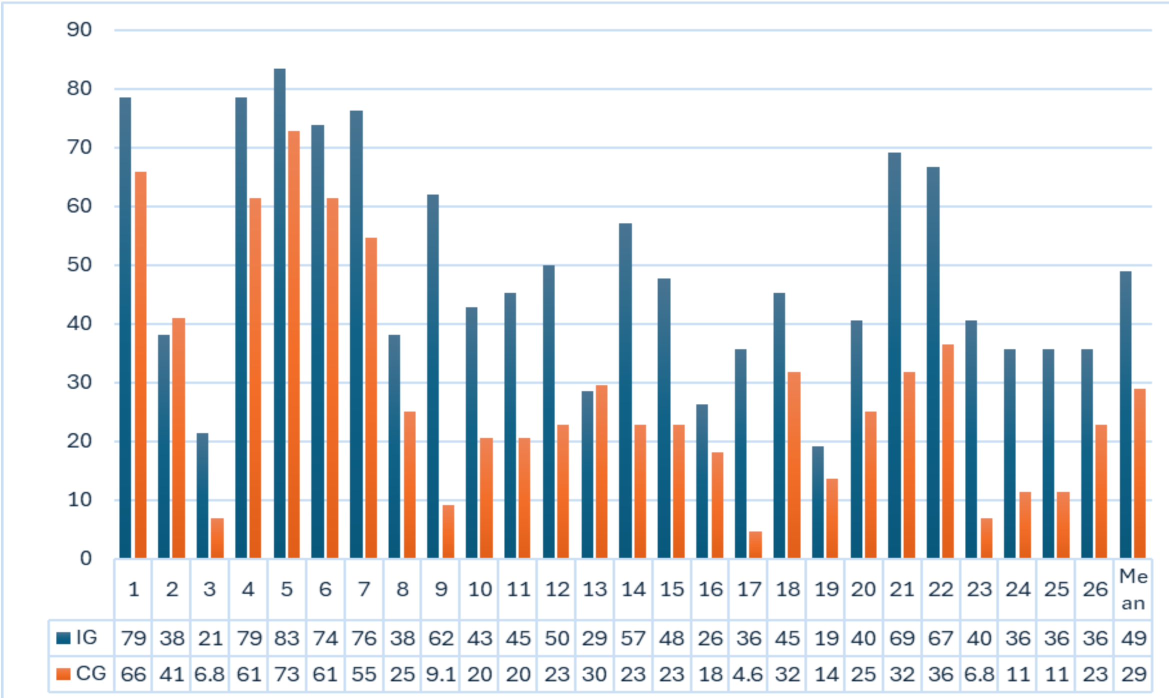


Figure 4. 2: A bar graph for the analysis of students' scientific knowledge between groups

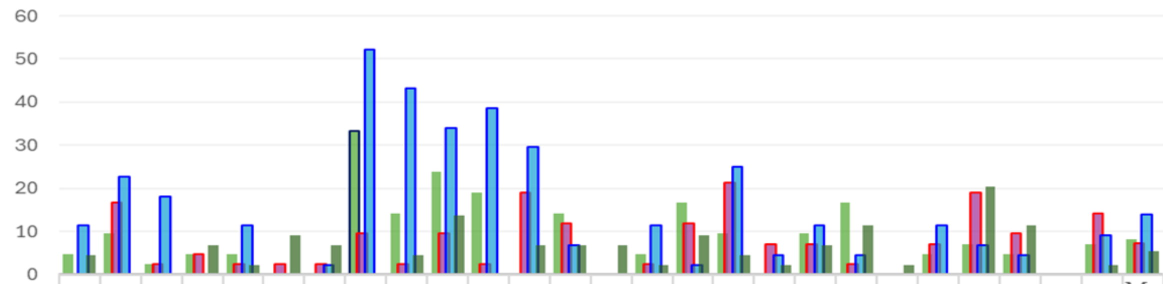
On the other hand, Table 4.14 shows different patterns of CU, such as LK, LG, and MCs, which serve as significant barriers to students' grasp of CBMG concepts in learning environments. For instance, 38.09% to 42.86% of students’ responses for LK were observed in the IG group across items Q3, Q19, Q24, Q25, and Q26. In contrast, a higher proportion, ranging from 50.00% to 54.55%, of students in the CG group demonstrated LK in the same items (Q3, Q19, Q24, Q25, and Q26), indicating that students in the CG group experienced relatively greater conceptual difficulties compared to those in the IG group. Comparatively, the mean percentage of CG students' responses for LK was higher than that of IG students in understanding the CBMG concepts. The mean percentage of students’ responses in TTCUDT for LK was approximately 10% higher in the CG (30.07) than in the IG (19.96). This indicates that the IG students who were taught the CBMG concept through BL have more accurate conceptual knowledge than the CG students who were taught this topic using CTM. In contrast, a relatively low mean percentage of students' responses was observed for LG with IG (16.67) for each of Q15, Q18, and Q19, and the CG (13.64) for Q15. However, the mean percentage of students' responses on TTCUDT for LG was small and almost similar in IG (3.29) and CG (3.32).

Additionally, the students' MCs (the consideration of incorrect content-reason with a certain confidence rating combination) were observed in post-TTCBCUT in both IG and CG students. Significant MCs, defined as those exceeding 10% of the sample, were observed in 14 items among IG students and in 19 items among CG students. The CG students had high MCs in Q14 (47.73%), and the IG students in Q3 (35.71%), which was higher than 10% of the students (Tan & Treagust, 1999). This indicated that both groups of students had difficulty understanding the concepts of CBMG. However, it was found that no MCs were identified among the IG students for Q4 and Q5, while very low levels of MCs were noted for Q8 in the IG and Q9 in the CG, suggesting that both groups had a better understanding of CBMG concepts. The mean percentage of MCs held by CG students who responded to the content reason wrongly was relatively higher at 18.01%, compared to 12.45% for IG students, indicating that CG students struggled more with understanding the concepts of CBMG.

4.2.1.5. Comparison of IG and CG in Misconceptions

False Positives and False Negatives

False positives and false negatives represent different learning disparities that arise when assessing students' understanding. This is especially relevant during evaluations of their knowledge or learning capabilities through tests or assignments. The students’ learning barriers to understanding the concepts of CBMG were analyzed in terms of false positives (FPs) and false negatives (FNs) responses. The scoring of post-TTCUDT for false positives (FPs) and false negatives (FNs) was conducted based on the possible response patterns for three-tier diagnostic tests, as outlined in Table 3.5, which defines these metrics in the evaluation context. FPs are the students' correct responses in the first tier, wrong answers in the second tier, and certainty of their answers, while FNs are the students' wrong responses in the first tier, the correct answers in the second tier, and certainty of their answers. The percentage of FPs and FNs was calculated by excluding incorrect content reasons and certain response scores of certain MCs. The percentage of students' FPs and FNs response scores for TTCUDT was determined using their responses in all three tiers and is presented in Figure 4.3. The mean percentage of students' response scores for FPs was higher than that of FNs in both groups. Moreover, the mean percentage of the FN value was lower than the threshold value of 10% in both groups. The result of this study also aligned with prior work, indicating that the percentages of FPs occurred more frequently than the percentages of FNs (Irmak et al., 2023). The probability of FNs being certain is less than 10% (Hestenes & Halloun, 1995). They also stated that the low rate of FNs shows the test items are clear, allowing students with correct conceptions to understand the questions without difficulty.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	Mean
FP-IG	4.8	9.5	2.4	4.8	4.8	0	0	33	14	24	19	0	14	0	4.8	17	9.5	0	9.5	17	0	4.8	7.1	4.8	0	7.1	8.2
FN_IG	0	17	2.4	4.8	2.4	2.4	2.4	9.5	2.4	9.5	2.4	19	12	0	2.4	12	21	7.1	7.1	2.4	0	7.1	19	9.5	0	14	7.2
FP-CG	11	23	18	0	11	0	2.3	52	43	34	39	30	6.8	0	11	2.3	25	4.5	11	4.5	0	11	6.8	4.5	0	9.1	14
FN-CG	4.5	0	0	6.8	2.3	9.1	6.8	0	4.5	14	0	6.8	6.8	6.8	2.3	9.1	4.5	2.3	6.8	11	2.3	0	20	11	0	2.3	5.4

Figure 4.3: Percentages of false negatives and false positives for post-TTCUDT Scores

In this research, the mean percentage of students' response scores for FP values in IG was lower than in CG. The lower mean percentage of FP scores in the IG compared to the CG implies that the intervention effectively reduced false positive errors. This suggests that the intervention improved students' understanding of CBMG concepts, reduced MCs, or enhanced their ability to evaluate their responses critically. It highlights the importance of targeted interventions in improving students' understanding of CBMG concepts and reducing learning barriers in classroom settings. In terms of items, the percentage of students' response scores for only seven items in IG and thirteen items in CG for FPs was greater than the threshold value of 10%. Additionally, the FP values of nineteen items in IG and nine items in CG were lower than 10%. This indicated that most students responded to the items with a meaningful understanding of the concepts in both groups. In contrast, the mean percentage of students' response scores for FNs in IG was relatively higher than in CG. This indicates that the higher mean percentage of FN responses in the IG compared to the CG suggests that the intervention may have caused students to doubt their correct responses or struggle with applying their knowledge. The percentage for FN values of seven items in IG and four items in CG was greater than 10%, which can be attributed to the careless answers of the respondents (Hestenes & Halloun, 1995). Meanwhile, the percentage for FN values was less than 10% in 19 items in IG and 22 items in CG, showing that these items were more valid, and the students could better understand how to respond correctly.

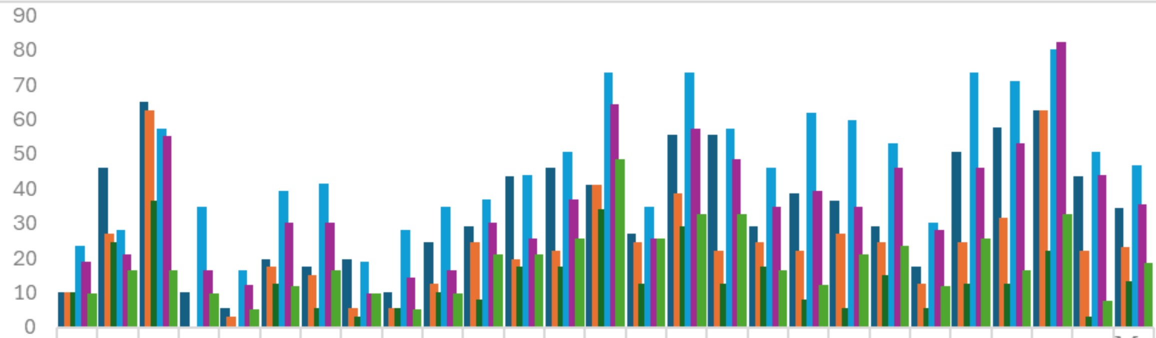
4.2.1.6. Misconceptions Across FT, BT, and AT

In addition to analyzing the learning barriers that students had when trying to understand the concepts of CBMG, the degree of students' misconceptions (MCs) was also investigated based on LK, LG, or LC. This is because students' CU and MCs are the two sides of the same coin in classroom learning. The students' MCs, identified from post-TTCUDT responses, were analyzed by examining frequently selected incorrect response patterns across the three tiers: incorrect content responses (FT), incorrect reasoning responses (BT), and the combined content–reasoning–confidence response patterns (AT). In other words, students' frequent selection of incorrect content tiers for FT-MC, incorrect content-reason combinations for BT-MC, and incorrect content-reason-certainty choices for AT-MC scores were analyzed to identify MCs (Arslan et al., 2012). The MC scores were calculated from students' incorrect combinations of content, reasoning, and certainty (referred to as AT-MCs). These scores reflect students' MCs after the post-TTCUDT assessment for each tier, as shown and further analyzed in Figure 4.4. The percentage of MCs presented in this analysis excluded FP, FN, and LK responses, similar to the MC-AT approach, thereby ensuring a more accurate evaluation of students' understanding and minimizing barriers in the post-TTCUDT.

The mean percentage of students' MCs decreased from FT to AT in both groups (see Figure 4.4). Similarly, the data indicate that, except for item 1 in IG, there is a notable decrease in the percentage of MCs with the increasing number of tiers, progressing from FT to AT in both groups of all items. These results are consistent and fully in agreement with previous research findings that utilized a three-tier diagnostic test to identify MCs in chemistry, including in the contexts of carbohydrates (Milenković et al., 2016) and environmental chemistry (Arslan et al., 2012) in higher education settings. Furthermore, the mean percentages of MCs for CG students in both FT, BT, and AT categories were higher than for IG students. Except for Q2 and Q3 in the IG, the percentage of students' MCs, regardless of FT, BT, and AT, in the CG is consistently higher than in the IG across all items. This finding agrees with the one that using FT or BT to identify MCs tends to overestimate the percentage of MCs, as these methods may not fully account for students' justifications (Bala, 2013; Peşman & Eryılmaz, 2010). Therefore, accounting for all tiers (AT) in three-tier diagnostic tests is best to identify prevalent MCs.

The students' MCs can be analyzed irrespective of the reason for incorrect content and the specific category of certain MCs associated with AT. The percentage of students' MCs in the AT was reduced compared to the FT and the BT scores; this might be due to a lack of confidence, regardless of their incorrect content-reasoning responses. The mean percentage of students' MCs for AT in CG is higher (approximately 6%) than that of IG students (see Figure 4.4). This result suggests that implementing the BL intervention demonstrated greater effectiveness, enabling students to address MCs and enhance their CU of CBMG in IG than in CTM in CG. The results of this study also demonstrated that the percentage of students' incorrect content-reason and certain (AT) response scores for both groups above 10% were observed in Figure 4.4 and taken as the prevalent MCs (Gurel et al., 2015; Tan & Treagust, 1999).

According to Figure 4.4, 14 items (53.85%) in the IG and 19 items (73.01%) in the CG exhibit a prevalent percentage of students' MCs (>10%) for AT compared to one another. This result indicated that students had difficulty understanding the concepts of CBMG in general. Specifically, the students held MCs commonly in Q14, Q16, and Q25 in both groups. Accordingly, students in both groups had wrong scientific conceptions about energy change during bond formation in a chemical reaction (in Q14). Students in both groups incorrectly believed that energy is absorbed during bond formation in a chemical reaction because they thought energy is required to form bonds in the products and is stored within those bonds. Similarly, the students in both groups (Q16) also had relatively high MCs in understanding the concept of molecular polarity, including the existence of non-polar molecules with polar bonds (e.g., CO_2). The CG students selected CH_3Cl, while those of IG selected CH_4 molecules as non-polar molecules with polar bonds, and they provided the same reasons for their FT response, as the electronegativity difference between bonded atoms shows that each of these bonds has a zero-dipole moment to develop polar bonds.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	Mean
FT-IG	9.5	45	64	9.5	4.8	19	17	19	9.5	24	29	43	45	40	26	55	55	29	38	36	29	17	50	57	62	43	34
BT-IG	9.5	26	62	0	2.4	17	14	4.8	4.8	12	24	19	21	40	24	38	21	24	21	26	24	12	24	31	62	21	23
AT-IG	9.5	24	36	0	0	12	4.8	2.4	4.8	9.5	7.1	17	17	33	12	29	12	17	7.1	4.8	14	4.8	12	12	21	2.4	12
FT-CG	23	27	57	34	16	39	41	18	27	34	36	43	50	73	34	73	57	45	61	59	52	30	73	70	80	50	46
BT-CG	18	20	55	16	11	30	30	9.1	14	16	30	25	36	64	25	57	48	34	39	34	45	27	45	52	82	43	35
AT-CG	9.1	16	16	9.1	4.5	11	16	9.1	4.5	9.1	20	20	25	48	25	32	32	16	11	20	23	11	25	16	32	6.8	18

Figure 4.4: A bar graph for the analysis of students' misconceptions per item across groups

Besides, the CG students had an adequate understanding of the electrical conductivity properties of ionic compounds, such as sodium chloride (NaCl), which are in both solution and molten states. They correctly identified that NaCl conducts electricity in these states because it dissociates into sodium ions (Na^+) and chloride ions (Cl^-), which are free-moving charged particles, in Q5. These ions facilitate the conduction of electricity by allowing the flow of electric charge. Similarly, these students exhibited a stronger understanding of the role of intermolecular forces in explaining the physical states of H_2O and H_2S at room temperature, despite their similar molecular formulae and shapes. They correctly reasoned that the difference arises from the polarity of the molecules. H_2O exhibits stronger hydrogen bonding due to its highly polar O-H bonds, which leads to a liquid state at room temperature. In contrast, H_2S has weaker dipole-dipole interactions and lacks significant hydrogen bonding, resulting in its gaseous state under the same conditions (in Q9).

In contrast, no MCs were observed in IG students in the BT and AT for Q4 and in the AT for Q5. This result demonstrates that IG students possessed adequate conceptual knowledge of reasoning through the responses they provided for content-tier questions. This means they selected HF as a more polar molecule than H_2O, NH_3, and H_2S molecules in the content tier, and also developed higher self-confidence in Q4 compared to CG students. On the other hand, the presence of low MCs (< 10%) in the FT and BT of Q5 but their absence in the AT suggests that students may initially select incorrect answers for this question when they are asked about the state in which NaCl conducts electricity in the FT and provide flawed reasoning for their response in BT. This shows that for the few students who do hold MCs in the FT and BT, the absence of MCs in the AT (incorrect content-reason-uncertain response) implies that these MCs are not deeply entrenched. In summary, this result is attributed to the effectiveness of the intervention employed through the BL approach, which facilitated a deeper understanding of CBMG concepts in IG students compared to the CTM used for CG students.

Thirty-three prevalent MCs were identified across all items regardless of the students' responses in all groups, with most originating from CG students. Out of the 33 MCs (>10%) found from the post-TTCUDT scores across both groups, Table 4.10 shows detailed information on 22 prevalent MCs associated with confidence ratings for BT, which were the most common ones (taken from Figure 4.4). In the context of the current study, analyzing MCs involves examining the percentages of respondents who were certain or uncertain about their responses for various content-reason combinations. Additionally, these MCs were obtained through interviews and literature during item development and adaptation. The MCs were identified through student interviews and a review of the literature. Interview data were analyzed to reveal common patterns of misunderstanding, while the literature provided established MCs reported in prior studies. This combined approach ensured that the identified MCs were both contextually relevant and theoretically grounded. The identified MCs were organized into key content areas of the CBMG topics, including ionic bonding, covalent bonding, metallic bonding, Lewis structures, formal charge and resonance, bond strength, molecular structure, and polarity. Additionally, terms associated with MCs and their confidence ratings were utilized to characterize these MCs. Significant MCs refer to answer choices in either the FT or BT that were selected by at least 10% of the sample more frequently than would be expected by chance (Caleon & Subramaniam, 2010). In the current study, 22 significant MCs were identified at the content–reason (MC-BT) level for both groups. Table 4.11 presents the prevalent MCs identified in the post-TTCUDT. Students' confidence associated with MCs was further examined in relation to their responses to the corresponding questions. These MCs were analyzed by considering incorrect content, reason, and certainty combinations. For instance, the expression Q2C(b) represents students exhibiting MCs for Question 2, where students selected option "C" in the first tier incorrectly and provided reason "b" in the second tier with certainty. Students' confidence associated with MCs (CMCs) was identified to assess their confidence in providing incorrect responses to the questions, using a confidence scale ranging from 1 = sure to 2 = not sure.

Table 4. 11: Prevalent misconceptions identified using post-TTCUDT (n = 42 for IG and n = 44)

			IG	CG
Misconceptions (MCs)				
		C-R	%MCs	%MCs
Ionic and covalent bonds				
MC1	Transition metals (e.g., Fe) lose electrons from the 3d orbital first, then from the 4s orbital to form bonds	Q2C(b)	23.81	15.91
MC2	$CaBr_2$, HCN, NH_4Br, and HBr are ionic compounds because they consist of cations and anions	Q6D(d)	11.36	11.36
MC3	H_2O_2, CO_2, and CaO contain ionic and covalent bonds because they are formed from the electrostatic forces of metal cations and delocalized electrons	Q12D(a)	10.00	
MC4	NaCl, Mg_3N_2, and KBr compounds contain both ionic and covalent bonds because they contain metal and nonmetal ions.	Q12B(a)		18.18
MC5	CH_4 is a polar molecule with polar bonds, and the bond moments cancel due to its linear molecular geometry	Q16A(b)	28.57	
MC6	CH_3Cl is a polar molecule with polar bonds because the electronegativity difference between bonded atoms shows that each of these bonds has a zero-dipole moment to develop polar bonds.	Q16D(b)		31.82
Metallic bonding concepts				
MC7	The melting points of Al < Mg < Na because the fewer electrons a metal can release, the lower the density of the electron cloud, and the weaker the metallic bond	Q13A(a)	14.29	

MC8	The melting points of Al < Mg < Na are because the more reactive metals can release electrons easily and hold tightly to their nuclei to form strong metallic bonds.	Q13A(c)		25.00
Lewis's structure of molecules				
MC9	Formaldehyde (CH_2O) has two central atoms, C and O, that share three pairs of electrons to accommodate their octet with consistent formal charges in its Lewis structure	Q15D(c)	11.90	20.45
MC10	The Lewis structure of the NOCl molecule with a large formal charge of atoms is the most stable and acceptable because all atoms of the NOCl molecule obey the octet rule and are stabilized by filling their outer shells	Q17B(b)	11.90	31.82
Formal charge and resonance concepts				
MC11	The single-bonded oxygen atom determines the overall charge of the ion.	Q3C(c)	35.71	
MC12	Nitrogen has a high electron density in its valence shell	Q3C(b)		15.91
Strength of ionic and covalent bonds				
MC13	Energy is absorbed during bond formation because it is required to form bonds in the products of a reaction and is stored in the bonds.	Q14B(d)	33.33	47.73
MC14	MgF_2 requires the highest energy to convert one mole of the solid into separate ions compared to MgO, KF, and SrO due to the small radius of the F^- ion	Q25B(d)	21.43	
MC15	KF requires the highest energy to convert one mole of the solid into separate ions compared to MgO, MgF_2, and SrO due to the small radius of the F^- ion.	Q25D(b)		31.82
Molecular structure and polarity				
MC16	BF_3 and NH_3 have the same electronic arrangement that determines their geometry and shape because they have the same number of bonding electrons	Q18B(a)	16.67	
MC17	BF_3 and NH_3 are polar molecules because they have the same number of bonding electrons	Q18D(a)		13.64

MC18	BF_3 has a dipole moment greater than CH_4, NH_3, and $BeCl_2$ because the BF_3 molecule is symmetrical, and the B-F bonds reinforce each other, resulting in a non-zero dipole moment	Q21D(a)	14.29	22.73
MC19	The H–N–H angle in NH_3 is larger than the H–C–H bond angle in CH_4, and NH_3 and CH_4 have different orbital hybridizations	Q23D(c)	11.90	
MC20	The molecules have different electron pair geometries and the same molecular shape.	Q23D(d)		25.00
MC21	NO_2^- has a trigonal planar shape because the ion contains three terminal atoms bonded to the central atom with lone-pair electrons	Q24C(b)	11.90	
MC22	SO_3^{2-} has a trigonal planar shape because the ion contains three terminal atoms bonded to the central atom with lone-pair electrons	Q24A(b)		15.91

Note: *% MCs = Percentage of the total sample who chose the content-reason combination wrongly*
Q2C(c) = Q2, the content response is "C" and the reason is "c"; the responses are described either commonly (if both groups select the same responses for content and reason tier), or separately (if both groups select different responses for the content and the reason tier).
MC1 is the first misconception in Table 4.17, and C-R = content-reason MCs.

Table 4.11 shows 22 significant MCs, of which 5 in IG and 6 in CG are genuine MCs according to the literature(I. Caleon & R. Subramaniam, 2010) , This indicates that they may recognize some uncertainty in their understanding of the concepts. The significant MCs were discussed for each relevant question, and the scientifically accepted correct answers were provided accordingly. The analysis of significant MCs and their associated confidence ratings was conducted by examining the incorrect content-reason responses (BT-MCs) alongside the corresponding confidence rating options for each item. For instance, Q2 assessed how students understand the electronic structure of transition metal ions (e.g., Fe^{3+}). Only 38% of IG and 41% of CG students responded with the correct answer for Q2 in both groups. These students demonstrated a good understanding that the electronic configuration of the Fe^{3+} ion is determined by the sequential removal of electrons from the 4s orbital first, and then the 3d orbital. Based on the BT responses of students for Q2, the majority of students, including 62% in the IG and 59% in the CG, responded to the content-reason incorrectly. Only 26.2% in the IG and 20.5% in the CG demonstrated the belief that the electronic configuration of the transition metal ion Fe^{3+} is determined by the loss of electrons first from the 3d orbital, followed by the 4s orbital (MC1). However, the students in IG demonstrated slightly greater confidence in their MCs in understanding the concepts of electronic configuration of transition metals than the CG.

The bromide ion (Br^-) is a versatile anion that can exist in various types of compounds, both ionic and covalent, depending on the chemical environment and the cations or molecules it interacts with. Understanding these theoretical possibilities helps students grasp the diverse chemical behavior of the ion (Br-). Q6 was used to measure the students' understanding of the compounds as being either ionic or covalent. A significant proportion of students, 81% in the IG and 61% in the CG, correctly identified $CaBr_2$ and NH_4Br as ionic compounds composed of cations and anions, selecting the appropriate correct content-reason. Despite the 19% in the IG and 39% in the CG students answering this question incorrectly, only the proportion of these students (21.34% in IG and 62.75% in CG) in their content-reason choices went with the wrong responses: $CaBr_2$, HCN, NH_4Br, and HBr are covalent compounds because they consist of non-metals (MC2). This indicates that IG students express complete certainty in their understanding of the concepts as compared to the CG students in this particular concept.

Only 31% of the IG and 20% of the CG students responded to the content-reason correctly (Q16) and believed that CO_2 is a polar molecule with polar bonds compared to (CH_4, SO_3, and CH_3Cl) because the bond moments cancel due to its linear molecular geometry. The vast majority of students, 69% in IG and 80% in CG, responded to this question incorrectly, and only 38.1% in IG and 56.8% in CG chose the content-reason response that CH_4 and CH_3Cl are polar molecules with polar bonds, respectively. The reason for their response was that the electronegativity difference between bonded atoms shows that each of these bonds has a zero-dipole moment, to develop polar bonds.

In the study, approximately 57% of students in the IG and 23% in the CG correctly answered Question 14, recognizing that energy is released during bond formation in a chemical reaction, leading to increased stability of the system. There was a clear difference between the groups in their understanding of the concept, with the IG demonstrating relatively better conceptual clarity than the CG. Despite this, 43% of students in the IG and 77% in the CG incorrectly responded that energy is absorbed during bond formation in a hypothetical chemical reaction. This substantial proportion of incorrect responses indicates a widespread misunderstanding of the fundamental principle that energy is released during bond formation, which is essential for explaining the stability of chemical systems. Furthermore, approximately 40.5% of students in the IG and 63.6% in the CG held MCs that energy is absorbed during bond formation because it is required to form bonds in the products of a reaction and is stored within those bonds (MC9). This finding suggests that a considerable number of students in both groups possess an alternative conception about energy changes in chemical reactions, with the MCs being more prevalent in the CG.

Understanding the shape of molecules is essential because it helps predict how they behave, interact, and function in various biological processes. Students' understanding of the molecular geometry of BF_3 and NH_3 was assessed, and the results showed that approximately 59% of respondents in the IG and 39% in the CG correctly identified that these molecules have different molecular geometries and shapes in response to item Q18. This indicates a comparatively better CU among students in the intervention group. However, a considerable proportion of students demonstrated misunderstandings. Approximately 41% of students in the IG and 61% in the CG provided incorrect responses, indicating that BF_3 and NH_3 have the same electron pair geometry (MC11). Among these, 23.8% of IG students and 34.1% of CG students consistently exhibited these MCs. These findings suggest that, although the IG performed better overall, a substantial number of students in both groups still struggled to accurately distinguish between electron pair geometry and molecular shape, with the MCs being more prevalent in the CG.

In the study, approximately 50% of IG students and 25% of CG students correctly identified that compounds such as NH_4Cl, KCN, and $NaNO_3$ exhibit both ionic and covalent bonding due to the presence of cations, anions, and covalently bonded atoms. This indicates a comparatively better understanding among students in the IG.

However, a substantial proportion of students demonstrated MCs. About 50% of IG students and 75% of CG students incorrectly answered item Q12, indicating that compounds such as H_2O_2, CO_2, and CaO_2, as well as NaCl, Mg_3N_2, and KBr, possess both ionic and covalent bonds. IG students commonly justified their responses by referring to electrostatic forces between metal cations and delocalized electrons (MC3), while CG students based their reasoning on the presence of both metal and nonmetal elements within the compounds. Among these incorrect responses (MC4), 19% of IG students and 25% of CG students consistently exhibited these MCs. These findings suggest that, although the IG demonstrated relatively better CU, MCs regarding the nature of CBMG remain prevalent in both groups, particularly in the CG.

Understanding the Lewis structure of molecules helps students grasp the chemical properties and reactivity patterns of different substances. Item Q15 was used to assess students' CU of identifying the central atom in formaldehyde (CH_2O). The results showed that approximately 64% of students in the IG and 36% in the CG correctly identified carbon as the central atom, indicating a relatively better understanding among students in the IG. In contrast, 36% of IG students and 64% of CG students incorrectly identified both carbon (C) and oxygen (O) as central atoms, assuming that they share three pairs of electrons to satisfy the octet rule with consistent formal charges in the Lewis structure. Among these incorrect responses, 23.8% of IG students and 21.4% of CG students consistently exhibited this misconception (MC6). These findings suggest that, although the IG demonstrated better performance overall, MCs regarding the identification of the central atom in Lewis structures remain evident in both groups, particularly among students in the CG.

On the other hand, students were assessed on their understanding of the correct Lewis structure of nitrosyl chloride (NOCl) in item Q17. Only 36% of students in the IG and 9% in the CG correctly identified the structure featuring a double bond between nitrogen and oxygen and a single bond with chlorine. This structure is considered the most appropriate representation due to its minimized formal charges and greater stability. In contrast, a larger proportion of students (64% in the IG and 91% in the CG) selected incorrect structures, typically those with larger formal charges on the atoms. Although these alternative structures may satisfy the octet rule, they are less stable and therefore less favorable. A notable proportion of students in both groups consistently exhibited this misconception, indicating a limited understanding of the role of formal charge in determining the most stable Lewis's structure. These findings suggest that many students rely primarily on the octet rule without adequately considering formal charge minimization when evaluating molecular structures.

However, very low percentages of students' MCs (< 10%) for AT were observed in 10 specific items in the IG (38.46% of items) and 7 items in the CG (26.92% of items), indicating that students in both groups possess a sufficient understanding of CBMG concepts. Among these items (items 8 and 26 for IG and Q5 and Q9 for CG), the students who showed the fewest MCs were identified and analyzed to evaluate their understanding and performance. The IG students demonstrated a solid understanding of covalent bond formation when two neutral atoms of different non-metallic elements react, explaining that the atoms approach each other and that electrons from each atom are attracted to the other's nucleus, resulting in molecule formation (for Q8). Furthermore, these groups of students showed an adequate understanding of estimating the approximate enthalpy change for the chemical reaction $H_2 + F_2 \rightarrow 2HF$ by using the provided dissociation bond energy values of all reactants and products (for Q26). They also explained that the bonds in the products are stronger than those in the reactants, leading to the reaction releasing more energy than it consumes. Overall, the comparison between IG and CG suggests that the BL intervention contributed to reducing MCs across several key concepts in chemical bonding and molecular geometry. Nevertheless, a considerable proportion of MCs persisted among students, indicating their resistance to change and highlighting the need for more targeted instructional strategies that explicitly address alternative conceptions and promote deeper conceptual restructuring.

4.2.1.7. Comparison of Gender Effect within Groups in Students' CU

Research question: Is there a statistically significant difference between male and female students in CBMG CU within the BL and CTM groups?

Descriptive Statistics of Posttest Scores of TTCUDT Across Gender

To address the above research question, the data were analyzed descriptively and inferentially after testing for normality. The descriptive statistics presented in Table 4.12 show variation in post-TTCUDT scores between male and female students across the FT, BT, and AT dimensions. Except for post-AT in the CG, the mean scores of male students were slightly higher than those of female students across FT, BT, and AT within both groups. Moreover, the analysis shows that mean scores decreased from post-FT to post-BT and post-AT for both male and female students within the groups.

Table 4. 12: Descriptive statistics of posttest TTCUDT scores by gender

Observation	Group	Gender	N	M	SD
Post-FT	IG	M	25	67.31	12.78
		F	17	64.10	13.52
	CG	M	34	53.74	11.33
		F	10	51.71	8.18
Post-BT	IG	M	25	53.53	16.67
		F	17	48.72	15.55
	CG	M	34	33.74	11.73
		F	10	32.05	12.01
Post-AT	IG	M	25	51.92	17.97
		F	17	45.73	18.37
	CG	M	34	28.79	11.40
		F	10	29.06	12.48

Inferential Statistics of Posttest Scores of TTCUDT Across Gender

Inferential statistics were used to determine whether the differences in mean scores between male and female students within each group were statistically significant. The results of Levene's test for equality of variances indicated that the assumption of homogeneity of variances was met for post-FT, post-BT, and post-AT scores ($p > .05$) in both groups, suggesting equal variances. Table 4.13 presents the results of the independent-samples t-test for post-TTCUDT scores, indicating that gender differences were not statistically significant ($p > .05$) for post-FT, post-BT, and post-AT, with small effect sizes (Cohen, 1988). These findings suggest that male and female students demonstrated similar levels of CU of CBMG topics under both BL and CTM approaches.

Table 4. 13: Independent t-test for post-TTCUDT scores across gender

			Levene's test for equality of variances			t-test for equality of means			
Observation	**Group**	**Gender**		**F**	**Sig.**	**t**	**df**	**p**	**Cohen's d**
Post-FT	IG	M F	EVA	.137	.713	.785	40	.437	0.244
	CG	M F	EVA	.636	.430	.502	42	.616	0.205
Post-BT	IG	M	EVA	.078	.782	.952	40	.347	0.298

		F							
	CG	M	EVA	.217	.644	.383	42	.704	0.144
		F							
Post-AT	IG	M	EVA	.164	.688	1.09	40	.280	0.341
		F							
	CG	M	EVA	.271	.606	-.06	42	.951	0.023
		F							

4.2.2. Qualitative Comparison of Groups in CU

Semi-structured interviews were used to examine students' CU of CBMG under two instructional approaches: BL and CTM. Guided by a structured protocol, the interviews included sample questions designed to generate comparable responses across both groups, focusing on students' experiences, levels of understanding, and views on instructional effectiveness. All responses were transcribed and organized into four emergent themes, enabling a systematic comparison of insights between the BL and CTM groups.

4.2.2.1. Accuracy of Conceptual Understanding

In line with the above theme, students in both groups were asked the following questions to reflect on the conceptualization of the CBMG. The responses from four participants in the BL group and three participants in the CTM group are presented below.

What is chemical bonding? Why are atoms combined? How are they formed?

BL group

Student C described it as "*Chemical bonding is the process by which atoms combine to form compounds to lower their energy and become stable, and is classified as ionic, covalent, and metallic bonds. Ionic bonds are formed by the transfer of electrons, covalent bonds by the sharing of electrons, and metallic bonds by the delocalization of free electrons.*"

Student E: *The most impressive idea that the interviewee E explained was the application of the chemical bonding concept in connection with his real-life experience; for instance, "in my opinion, cooking of food in the home purposefully used to break the chemical bond that connects the entities of the material, which is similar to the concept that energy is needed to break bonds during the chemical reaction."*

CTM Group

Student G: "*The interviewer also asked the interviewee to explain the concepts of ionic, covalent, and metallic bonds and responded correctly; however, the interviewee misdescribed metallic bonding as "the kind of chemical bond formed when different metallic atoms react together."*

4.2.2.2. Depth of Reasoning and Application

Students were also asked to reflect on the question: "What is the difference between ionic and covalent compounds? Mention the classification of compounds as ionic, covalent, and metallic bonds with examples. Why do they differ?

BL Group

Student A: *"Compounds made from cations and anions are ionic compounds, while those from non-metallic molecules are covalent compounds. The interviewee also described the existence of other molecules formed from polyatomic cations and anions or non-metallic anions that comprised both covalent and ionic bonds (e.g., NH_4Br)."*

CTM Group

Student H: "*I think that all molecules that contain non-metal atoms (e.g., NH_4Br) are categorized under covalent molecules, and all compounds that consist of only metal and non-metal atoms are ionic bonds."*

4.2.2.3. Misconceptions and Their Persistence

Students were asked to respond to the question: How would you describe molecular geometry and polarity? Can you explain how molecular geometry and polarity are connected to electron pair geometry?

BL Group

Student D: "*Okay, symmetrical molecules are polar while unsymmetrical molecules are non-polar, and molecules having similar electron pair geometry do not necessarily have different molecular geometry or shape and dipole moment, and are assumed to be polar molecules."*

CTM Group

Student I: The interviewer also asked the semi-structured interview question: Describe molecular geometry and polarity. What is the relationship between molecular geometry and polarity with electron pair geometry? *The interviewee described it as "In my understanding, the molecules that have different electron pair geometry had the same molecular geometry or shape, and also stated that polar molecules with no dipole moments always had non-polar bonds."*

4.2.2.4. Conceptualization of Electron Pair Geometry, Molecular Geometry, and Polarity

Can you explain the relationship between electron pair geometry, molecular geometry, and molecular polarity? What factors are used to predict these properties?

BL Group

Student B: "*I think molecular geometry depends on the number of electron domains and the presence of lone pairs around the central atom. Polarity, however, depends on both the molecular geometry and the polarity of the bonds. When bonds are polar, a molecule can still be nonpolar if its geometry is symmetrical and the dipole moments are zero. Number of electron pair domains around the central atom, electronegativity, and symmetry of the molecule."*

CTM group

Student G: "*The interviewee described it as "In my understanding, the molecules that have different electron pair geometry had the same molecular geometry or shape, and also stated that polar molecules with no dipole moments always had non-polar bonds."*

Overall, students in the BL group displayed stronger CU and deeper reasoning about CBMG. They not only explained ionic, covalent, and metallic bonds accurately but also recognized the coexistence of different bond types in compounds like NH_4Br and applied these concepts to real-life situations, such as cooking. In contrast, CTM group students often relied on oversimplified rules and showed persistent MCs, particularly about metallic bonding, molecular polarity, and electron pair geometry. These differences underscore the effectiveness of BL in promoting accurate knowledge, nuanced reasoning, and meaningful application compared to CTMs.

4.3. Blended Learning and Students' Engagement

In this section, the results and discussions of quantitative and Qualitative data in relation to SE are presented. The data are presented using descriptive statistics, inferential statistics (mean, standard deviation, parametric tests, non-parametric tests), and thematically, wherever appropriate.

4.3.2. Comparison of Mean Scores of IG and CG in SE

Research Question Two: What is the effect of BL on undergraduate SE in CBMG concepts?

4.3.1.1. Comparison of Posttest Mean Scores of IG and CG in SE

Descriptive Statistics

Table 4.14 presents the descriptive statistics of post-SES scores for both groups. The descriptive statistics for the post-test of 31 SES items were analyzed following the employment of assumption tests. The descriptive statistics also confirmed that the mean score of the overall post-SES score (M = 3.89; SD = 0.48) for IG was higher than that of the post-SES score for CG (M = 3.55; SD = 0.35). The results indicate that the mean scores on the five-point Likert scale for the overallSE and its various dimensions fall within the agreement level (Nyutu et al., 2021). This suggests that the intervention may have successfully increased SE levels compared to the CG. Additionally, the descriptive statistics results for post-SES IG in all dimensions are higher than those of the CG. This suggests that participants generally expressed SE or high levels of SE across the measured dimensions.

Table 4. 14: Descriptive statistics of posttest student engagement scores (post-SES)

		Intervention Group (IG)			**Comparison Group (CG)**		
Observation	Category	N	M	SD	N	M	SD
Post-SES	OverallSE	42	3.89	.48	44	3.55	.35
	CogSE	42	3.93	.45	44	3.52	.49
	EmSE	42	3.96	.57	44	3.69	.51
	BehSE	42	4.01	.55	44	3.70	.46
	SocSE	42	3.79	.46	44	3.41	.51

Inferential Statistics

The assumption test was conducted before the commencement of data analysis to verify the normality of the posttest data distribution. Preliminary screening indicated that the data for post-intervention student engagement (post-SES), including OverallSE and its dimensions (CogSE, EmSE, BehSE), were approximately normally distributed. Tests of assumptions, including normality (Shapiro–Wilk), homogeneity of variance (Levene's test), and inspection for outliers, revealed no substantial violations that would affect the validity of subsequent analyses. Accordingly, parametric tests were applied to compare the intervention and comparison groups. However, for the SocSE dimension, where normality was not fully met, a non-parametric alternative was employed. Preliminary analysis confirmed that the assumption of homogeneity of variances was met for overallSE and its dimensions. An independent samples t-test was therefore conducted to compare post-SES scores between the IG and CG. The results presented in Table 4.15 revealed a statistically significant difference in overall SE in favor of the IG (M = 3.89, SD = 0.48) compared to the CG (M = 3.55, SD = 0.35), $p < .05$, with a large effect size (d = 0.83). This finding indicates that the BL intervention had a substantial positive effect on SE compared to the CTM (Cohen, 1988).

Table 4.15: Independent-samples t-test for post-SES results across dimensions

Dimension	**Group**	**N**	**M**	**SD**	**Levene's test for EoV**		**t-test for equality of means**			
					F	**Sig.**	**t**	**df**	**p**	**Cohen's d**
OverallSE	IG	42	3.89	0.48	3.762	.056	3.859	84	0.000	0.83
	CG	44	3.55	0.35						
CogSE	IG	42	3.93	0.45	0.078	.780	3.800	84	0.000	0.89
	CG	44	3.52	0.49						
EmSE	IG	42	3.96	0.57	0.540	.464	2.299	84	0.024	0.42
	CG	44	3.69	0.51						
BehSE	IG	42	4.01	0.55	0.392	.533	2.795	84	0.006	0.60
	CG	44	3.70	0.46						

Furthermore, the descriptive statistics indicate that the mean scores of the post-SES dimensions fall within the "agree" range for both groups, suggesting relatively high levels of reported SE across all dimensions. However, the findings of the independent t-test asserted that there was a statistically significant mean difference between the groups on all dimensions; post-CogSES scores (IG: M = 3.93, SD = 0.45; CG: M = 3.52, SD = 0.49), $P < 0.05$, d = 0.89; post-EmSES (IG: M = 3.96, SD = 0.57; CG: M = 3.69, SD = 0.51), $p < 0.05$, d = 0.42; post-BehSES (IG: M = 4.01, SD = 0.55; CG: M = 3.70, SD = 0.46), $p < 0.05$, d = 0.60. These results also highlight the effectiveness of the BL intervention in enhancing SE across the CogSE, EmSE, BehSE, and SocSE dimensions, thereby improving teaching and learning outcomes. The results of the post-SES analysis revealed that CogSE demonstrated a large effect size, suggesting a substantial impact of the intervention on students' cognitive involvement. The Post-EmSES and Post-BehSES exhibited small to medium effect sizes, respectively, indicating meaningful yet varying degrees of influence (Cohen, 1988).

Despite the assumption test for post-SocSE data indicating that the CG was normally distributed, the data for the IG were not normally distributed. Therefore, a non-parametric test, specifically the Mann-Whitney test, was used to analyze the mean rank differences between the groups. Accordingly, Table 4.16 shows the Mann–Whitney U-test and reveals that there is a statistically significant mean difference in SocSE between the groups, $p < 0.05$, with a moderate effect size ($r = .34$). The IG had a higher mean rank (53.23) compared to the BL (35.07), suggesting the intervention (BL) positively influenced student engagement.

Table 4.16: Mann-Whitney U-test of post-SES results

	Group	**N**	**Mean rank**	**Sum of ranks**	**U**	**Z**	**p-value**	**r**
SocSE	IG	42	53.23	2198	553.000	-3.215	0.001	0.34
	CG	44	35.07	1543				

In summary, the results indicated that students in the IG were more actively engaged than their counterparts in the CG across all dimensions. Descriptive statistics indicated that the highest level of SE was observed in the BehSE for the IG ($M = 4.01$, $SD = 0.55$), followed by emotional (EmSE; $M = 3.96$, $SD = 0.57$) and CogSE ($M = 3.93$, $SD = 0.45$). All group differences were statistically significant ($p < .05$). The largest between-group difference was found in CogSE, with a large effect size ($d = 0.89$), followed by BehSE ($d = 0.60$) and EmSE ($d = 0.42$). These findings indicate that while students in the IG reported the highest engagement in behavioral aspects, the BL intervention had the strongest relative impact on CogSE compared to the CTM. In contrast, EmSE, while still significant, showed a smaller effect size, indicating that there may be additional factors influencing students' emotional responses to learning. This finding contrasts with the study's finding on mobile learning, which showed that BehSE was significantly higher than CogSE and EmSE in chemistry learning in HEIs (Lok & Hamzah, 2021).

The researcher utilized line plots to illustrate the mean difference in SE between the BL in the IG and the CTM in the CG. Figure 4.5 presents a visual comparison of post-SES on SE between the IG, which experienced BL, and the CG, which followed the CTM. Line plots were used to illustrate the mean differences in overall SE as well as its individual dimensions, allowing readers to easily visualize the magnitude of the differences. Across all dimensions, IG students demonstrated higher mean SE scores than CG students, indicating greater SE in the BL environment when learning CBMG concepts in higher education. Furthermore, the mean scores of the IG students in overallSE are higher than those of the CG students. To enhance clarity in the presentation of SE measures, a y-axis label indicating the mean scores on the five-point Likert scale and an x-axis displaying the SE dimensions have been added to Figure 4.5.

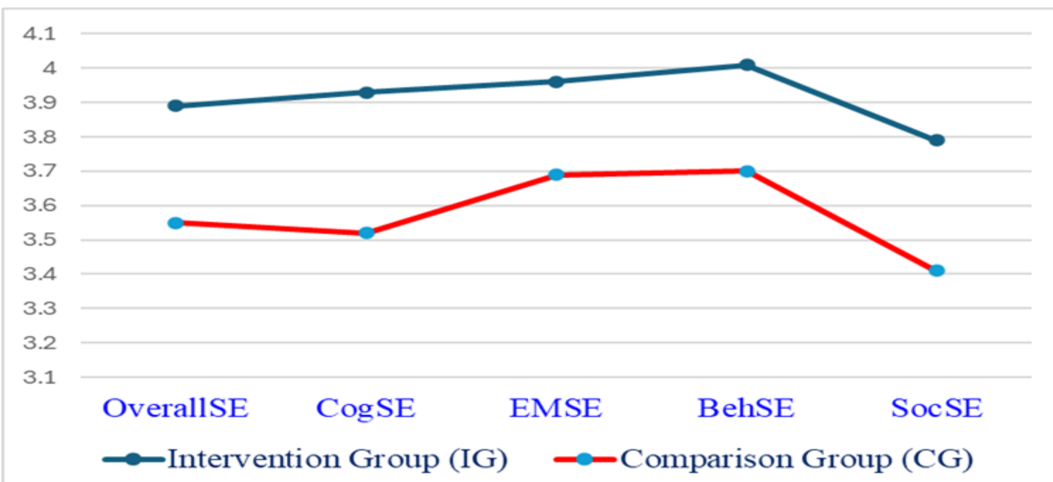


Figure 4.5: A visual representation of the mean comparison of post-SES in the overallSE and its dimensions between the IG and CG students

The findings of this study showed that the BL significantly increased undergraduate SE in learning CBMG concepts compared to the CTM. To address changes in the engagement of students in the IG, various strategies were implemented during the BL intervention to examine how undergraduate SE changes when BL is used. In this context, the BL allows IG students to experience real phenomena related to abstract concepts through interactive activities such as videos, simulations, and animations. Using these technologies to foster interactive learning can motivate students by making the educational experience engaging and enjoyable. Additionally, students have access to unlimited online resources at any time and from anywhere with internet access, allowing them to learn at their own pace. Furthermore, IG students participated in collaborative learning opportunities, including discussion forums with their instructors and peers. They also provided feedback on assignments, class activities, and exercises through an online platform to address learning challenges in the environment. During classroom observations, students in the IG showed noticeable attentiveness and enthusiasm toward learning activities, actively engaging with the content and participating meaningfully in the learning process.

4.3.1.2.Comparison of Gender Effect within Groups in Student Engagement

Research question: Is there a significant difference in student engagement between males and females when learning CBMG concepts through the BL compared to CTM?

Descriptive statistics of post-SES scores across gender

The descriptive statistics for the post-SES scores were analyzed across gender. The analysis of the overall SES scores revealed that male and female students within groups exhibited only a slight difference in mean engagement levels when learning about CBMG concepts. This finding suggests that the instructional methods and materials were similarly beneficial for both male and female students. Furthermore, the analysis of the SES scores across various SE dimensions revealed that the mean scores showed a slight difference between male and female students. This analysis shows that, except for the EmSE for IG, the mean scores of IG male students' post-SES for OverallSE, CogSE, BehSE, and SocSE slightly surpass the mean scores of female students in both groups across this learning experience. Interestingly, at the group level, male and female students in the IG demonstrated slightly higher mean scores than those in the CG for both the overallSE and SE dimensions. To determine whether this difference in means was statistically significant, inferential statistical analysis was conducted across gender, offering further insights into the effectiveness of varied instructional strategies in enhancing SE.

Inferential statistics for post-SES across gender

The inferential statistics indicate that Levene's test for equality of variances across gender was not significant in IG: Overall SE, $F (1, 84) = .163$, $p > 0.05$; CogSE, $F (1, 84) = 1.603$, $p > 0.05$; EmSE, $F (1, 84) = 1.556$, $p > 0.05$; BehSE, $F (1, 84) = 2.2124$, $p > 0.05$. Similarly, the test for equality of variances across gender is also not statistically significant in CG: Overall SE: $F (1.84) = 0.098$, $p > 0.05$; CogSE: $F (1, 84) = 0.722$, $p > 0.05$; EmSE: $F (1, 84) = 1.729$, $p > 0.05$; BehSE: $F (1, 84) = 1.144$, $p > 0.05$. These outcomes suggest that there is no statistically significant difference in the variances between males and females being analyzed within groups. This indicates that the variances are equal across the groups. Similarly, the results indicate that Levene's test for equality of variances across all dimensions was not significant, with a p-value greater than 0.05. This finding suggests that the variances are equal across the groups being analyzed. The non-significant result implies that the variances among the groups are homogeneous.

Table 4.17 presents the results of an independent t-test conducted to analyze the post-scores of overall SE, CogSE, EmSE, and BehSE across gender within groups. The inferential statistics indicate that there is no significant difference in the mean between male and female students in both SE dimensions, with a small effect size. This implies that the students had the same level of engagement with negligible differences. Additionally, the independent t-test results indicate no statistically significant mean difference in all engagement dimensions across gender in SES scores ($p > 0.05$). This finding suggests that gender does not play a significant role in influencing SE levels as measured by the SES scores. The findings of the presented study indicate that students exhibited a similar level of engagement in both the BL and CTM approaches, regardless of gender. This suggests that the teaching methods employed were effective in engaging students uniformly across genders. These similar engagement levels across genders in both teaching approaches imply that neither method favors males or females over the other.

Table 4.17: Independent t-test for post-SES scores across gender

						t-test for equality of means			
Dimensions	**Group**	**Gender**	**N**	**M**	**SD**	**t**	**df**	**p-value**	**Cohen's d**
OverallSE	IG	M	25	3.93	0.48	0.148	40	0.633	0.240
		F	17	3.85	0.50				
	CG	M	34	3.57	0.35	0.758	42	0.452	0.249
		F	10	3.48	0.36				
CogSE	IG	M	25	3.96	0.47	0.553	40	0.583	0.180
		F	17	3.87	0.51				
	CG	M	34	3.53	0.54	0.252	42	0.803	0.153
		F	10	3.49	0.33				
EmSE	IG	M	25	3.94	0.54	-0.267	40	0.791	0.324
		F	17	3.99	0.64				
	CG	M	34	3.73	0.49	0.829	42	0.412	0.294
		F	10	3.57	0.61				
BehSE	IG	M	25	4.03	0.54	0.341	40	0.735	0.106
		F	17	3.97	0.57				
	CG	M	34	3.73	0.44	0.696	42	0.490	0.251
		F	10	3.61	0.55				

Table 4.18 presents the results of the Mann–Whitney U test, which was used because the IG data were non-parametric, whereas the CG data were parametric. Accordingly, the Mann–Whitney U test showed no statistically significant gender difference for SocSE in IG: U = 154.500, z = -1.494, p > 0.05, with a small effect size (r = .161), with males' mean rank (23.82) compared to the females (18.09), and CG: U = 149.000, z = -.591, p > 0.05, with males' mean rank (23.12) compared to females (20.40) with a small effect size (r = 0.064), suggesting the intervention didn't influence SocSE in either group, indicating that BL and CTM are equally supportive of both male and female students within groups.

Table 4.18: Mann-Whitney U-test of post-SEQ results across gender

Variable	**Group**	**Gender**	**N**	**Mean rank**	**Sum of ranks**	**U**	**Z**	**p-value**	**r**
SocSE	IG	M	25	23.82	595.50	154.500	-1.494	0.135	0.161
		F	17	18.09	307.50				
	CG	M	34	23.12	786.00	149.000	-.591	0.555	0.064
		F	10	20.40	204.00				

4.4. Qualitative Comparison of Groups in Student Engagement

Semi-structured interviews were conducted to explore SE in learning CBMG concepts. The interview protocol was designed to assess engagement across two instructional approaches: BL and CTM. Each question was aimed at eliciting common and comparable responses from participants in both groups. The interviews focused on students' experiences, levels of engagement, and perceptions of instructional impact. Responses were transcribed and systematically organized under emergent themes to facilitate comparative analysis between the BL and CTM groups.

4.4.1. Student Participation and CU

In relation to the above theme, students were asked to respond to the item: Does the learning approach used in a lesson delivery affect your participation in learning the CBMG concepts? Please describe how this learning approach has affected your learning participation. Why?

BL group

Student B: "*The online learning component, which included videos, animations, and simulations, effectively illustrated the reality of chemical phenomena… visual repetition enhances their involvement and understanding.*"

Student C: "*Technology rendered the concepts more tangible and relevant to real-life application, created unforgettable memories, and contributed to my participation and mental development.*"

Student E: "*Computer technology provided me with the opportunity to visualize and make tangible the real images of abstract concepts.*"

CTM group

Student G*: "While classroom instruction initially helped me grasp concepts, I frequently found that what seemed clear in the moment did not stay with me over time… lacked concrete examples or tangible applications."*

Student I: "*I understood the chemistry concepts during lectures, but later struggled to recall… predicting molecular shapes felt like completing a puzzle without a deeper understanding.*"

In summary, students in the BL group consistently reported deeper CU and improved retention of CBMG concepts as there is engagement during the lesson. The integration of multimedia tools such as videos, animations, and simulations was credited with transforming abstract chemical phenomena into tangible, memorable experiences. Student B noted that visual repetition enhanced memory, while Student C emphasized the role of technology in making concepts relevant to real-life applications. In contrast, students in the CTM group described their understanding as transient and surface-level. Although initial lectures helped them grasp concepts, retention was limited due to the absence of concrete examples and real-world connections. Student G explicitly stated that what seemed clear during instruction often faded over time, highlighting a key limitation of the conventional approach. These findings suggest that BL fosters deeper CogSE by contextualizing abstract content, whereas CTM may fall short in sustaining long-term understanding due to its predominantly theoretical nature.

4.4.2. Engagement and motivation

In relation to the above theme, students were asked to respond to the item: How would you describe your level of engagement when learning CBMG concepts during classroom lessons? Can you describe a specific moment when you felt especially engaged with this topic? What aspects of that experience do you think contributed to your engagement? Why?

BL group

Student C: "*The process was highly engaging… technology encouraged me to grasp and comprehend the ideas… relevant to real-life applications.*"

Student E: "*The learning approach was interesting and joyful… excited me to learn CBMG concepts.*"

CTM group

Student I: *"I was moderately engaged… followed the lessons and took notes, but felt like I was just memorizing."*

Student H: **"***The learning approach was highly theoretical… didn't provide opportunities to relate abstract concepts to real-life… reduced motivation."*

In summary, students in the BL group demonstrated a relatively higher level of EmSE and intrinsic motivation compared to their counterparts. They described the learning process as joyful, exciting, and intellectually stimulating. Technology was seen not only as a tool for comprehension but also as a source of inspiration and career relevance. Student E, for example, linked his excitement to the participatory nature of BL and its connection to real-life chemical applications. Conversely, students in the CTM group demonstrated relatively lower levels of engagement, often characterized by passive note-taking and reliance on rote memorization. Student I acknowledged the importance of chemistry but reported feeling disconnected from the learning process, describing it as primarily focused on memorization rather than genuine understanding. BL appears to activate emotional and motivational dimensions of SE more effectively than CTM, likely due to its interactive design.

4.4.3. Participation and learning agency

In relation to the above theme, students were asked to respond to the item: Would you describe your learning experience with CBMG concepts as active and participatory? Could you share specific examples of how you engage in the learning process, such as completing assignments, asking questions, participating in discussions, or working collaboratively with your peers?

> **BL group**
>
> **Student E:** *"I regularly completed assignments and activities on time… asked questions on unclear ideas, actively participated via the discussion forum."*
>
> **CTM group**
>
> **Student H**: *"Moderately participatory… asked and answered questions during group tasks… rarely involved in asking questions encountered… feedback was not sufficient to engage me."*

In summary, students in the BL group, a member of which is demonstrated above, showed strong learning agency by actively completing assignments, asking questions, and engaging in online discussions. Student E's account reflects a self-directed and participatory approach, facilitated by digital platforms. In contrast, the CTM groups showed limited agency. While Student H mentioned occasional participation in group tasks, the lack of timely feedback and interactive opportunities diminished their sense of involvement and ownership of learning. BL supports autonomy and active participation, while CTM may constrain student agency due to its rigid, lecture-driven format.

4.4.4. Social interaction and collaboration

In relation to the above theme, students were asked to respond to the item: Do you believe that the learning process in CBMG has influenced your interactions with your peers and instructors? Do you feel more or less connected to others? How has this sense of connection affected your willingness to collaborate or participate in classroom discussions?

BL group

Student A: *"The teaching approach was very influential in my interactions with both the instructor and peers… collaborative problem-solving tasks created opportunities for dialogue and sharing ideas via the online platform."*

CTM group

Student H: *"Group tasks and problem-solving sessions existed… but the highly theoretical nature of instruction restricted meaningful interaction."*

In summary, the BL group member highlighted meaningful peer and instructor interactions, especially through collaborative problem-solving and online forums. Student A emphasized the role of BL in fostering dialogue and idea-sharing, which contributed to a sense of community and belonging. The CTM group member, however, experienced minimal collaboration. Although group tasks were present, they lacked depth and consistency. Student H noted that theoretical instruction limited opportunities for meaningful interaction. BL enhances social dimensions of SE by creating collaborative spaces, whereas CTM may isolate learners due to its one-directional communication style.

4.4.5. Real-Life Relevance and Application

This theme appeared from the same research question as the first theme. Students were asked to respond to the item: Would you describe your learning experience with CBMG concepts as active and meaningful? Could you share specific examples of how you engaged in the learning process, such as completing assignments, asking questions, participating in discussions, collaborating with your peers, or relating CBMG concepts to real-life situations and applications?

BL group

Student C: *"Technology made the concepts relevant to real-life applications… contributed to future career development."*

Student E: *"The learning approach provided me with the opportunity to connect the concepts to real-life chemical applications."*

CTM group

Student G: *"Lesson delivery lacked concrete examples or tangible applications that could have reinforced my understanding."*

Student H: "Didn't provide me with the opportunities to relate abstract concepts to real-life world experience."

In summary, Students in the BL group consistently connected CBMG concepts to real-world phenomena, which reinforced understanding and engagement. This relevance was seen as both intellectually satisfying and professionally beneficial. In contrast, the CTM group struggled to find such connections. Students G and H noted that abstract CBMG concepts were rarely connected to tangible applications, which appeared to limit their ability to perceive the relevance and meaningfulness of the concepts. BL's emphasis on authenticity and application strengthens SE, while CTM's abstraction may hinder meaningful learning. The comparative qualitative analysis reveals that the IG had a better SE than the CG. BL's integration of technology, participatory design, and real-world relevance creates a dynamic learning environment that supports deeper understanding, sustained motivation, and collaborative interaction. In contrast, CTM, while capable of delivering foundational knowledge, lacks the flexibility and interactivity needed to foster holistic SE development.

4.5. Effect of Blended Learning on Epistemological Beliefs

In this section, the results and discussions of quantitative and Qualitative data are presented. The data are presented using descriptive statistics, inferential statistics (mean, standard deviation, parametric tests, non-parametric tests), and thematically, wherever appropriate**.**

4.5.1. Comparison of Mean Scores of IG and CG in Epistemological Beliefs

Research Question Three: What is the effect of blended learning (BL) on undergraduate students' epistemological beliefs (EBs) about chemical bonding and molecular geometry (CBMG) concepts?

4.5.1.1. Comparison of Pretest Mean Scores of IG and CG in Epistemological Beliefs

Descriptive Statistics

The pretest data obtained from the CLASS-Chem were analyzed to assess students' prior EBs regarding the nature of knowledge and knowing in relation to CBMG concepts before the intervention. The posttest data were collected after the completion of the intervention, during which students learned CBMG concepts through either the BL or CTM approaches. The descriptive statistics of the pre-EBs scores for both groups are presented in Table 4.19. The results indicate that, before the intervention, slight differences existed between the groups across the measured dimensions. Specifically, except for the Consistency of Conceptual Connection (CC) dimension in the IG, the mean scores for the overallEBs and the remaining eight dimensions were slightly higher in the CG than in the IG.

Table 4.19: Descriptive statistics for pre-CLASS-Chem across groups.

	Pretest EBS			
	IG (n = 42)		CG (n = 44)	
Observation	**M**	**SD**	**M**	**SD**
Overall EBs	3.51	0.46	3.59	0.38
PI	3.48	0.64	3.69	0.49
RWC	3.49	0.48	3.63	0.61
PSG	3.62	0.57	3.71	0.50
PSC	3.46	0.69	3.68	0.56
PSS	3.24	0.55	3.42	0.67
SME	3.75	0.55	3.75	052
CC	3.33	0.45	3.29	0.64
CL	3.22	0.63	3.27	0.52
AMPC	3.74	0.68	3.75	0.42

Inferential Statistics

Before the examination of data analysis, the students' prior knowledge was examined using pretest scores of CLASS-Chem. Table 4.20 presents the inferential statistical analysis of the pretest CLASS-Chem (EBs) scores comparing the IG and CG.

Table 4. 20: Independent t-test for pre-CLASS-Chem results

					Levene's test for EoV			t-test for equality of means			
Dimension	**Group**	**n**	**M**	**SD**		**F**	**Sig**	**t**	**df**	***p***	**Cohen's d**
OverallEBs	IG	42	3.51	0.46	EVA	0.284	0.595	-0.919	84	0.361	0.197
	CG	44	3.59	0.38							
PI	IG	42	3.48	0.64	EVA	1.285	0.260	-1.396	84	0.167	0.368
	CG	44	3.69	0.49							
PSG	IG	42	3.62	0.57	EVA	0.543	0.463	-0.717	84	0.475	0.156
	CG	44	3.71	0.50							
PSC	IG	42	3.46	0.69	EVA	2.061	0.155	-1.661	84	0.100	0.287
	CG	44	3.68	0.56							
PSS	IG	42	3.24	0.55	EVA	1.628	0.206	-1.392	84	0.168	0.301
	CG	44	3.42	0.67							
CL	IG	42	3.22	0.63	EVNA	4.241	0.043	-0.159	79	0.578	0.073
	CG	44	3.27	0.52							
AMPC	IG	42	3.74	0.68	EVNA	9.940	0.002	-0.129	68	0.898	0.027
	CG	44	3.75	0.42							

Note: *EVA = Equal variances assumed; EVNA = Equal variances not assumed; EoV= Equality of variances*

Normally distributed data were analyzed using parametric tests. Independent samples t-test analysis shows that the differences between the EBs' mean scores (MIG = 3.51, SDIG = 0.46, NIG = 42, and MCG = 3.59, SDCG = 0.38, NCG = 44; t(84) = 0.919, $p > .05$) of the groups were not significant, implying that before the intervention, the groups were similar. At the sub-scale level, independent samples t-test analysis shows that the differences between the PI mean scores (MIG = 3.48, SDIG = 0.64, NIG = 42 and MCG = 3.69, SDCG = 0.49, NCG = 44; t(84) = 1.396, $p > .05$) of the groups were not significant, implying that before the intervention, the groups were similar.

At the sub-scale level, independent-samples t-test analysis shows that the differences between the PSG mean scores (MIG = 3.62, SDIG = 0.57, NIG = 42, and MCG = 3.71, SDCG = 0.50, NCG = 44; t(84) = -0.717, $p > .05$) were not significant, implying that before the intervention, the groups were similar. Similarly, the differences between the PSC mean scores (MIG = 3.46, SDIG = 0.69, NIG = 42 and MCG = 3.68, SDCG = 0.56, NCG = 44; t(84) = -1.661, $p > 0.05$)

were not statistically significant, indicating that the groups were comparable before the intervention. In the same way, the differences between the PSS mean scores (MIG = 3.24, SDIG = 0.55, NIG = 42, and MCG = 3.42, SDCG = 0.67, NCG = 44; t(84) = -1.392, *p* > .05) were not significant, suggesting that both groups had similar baseline levels. For the CL dimension, independent samples t-test analysis (equal variances not assumed) indicates that the differences between the mean scores (MIG = 3.22, SDIG = 0.63, NIG = 42 and MCG = 3.27, SDCG = 0.52, NCG = 44; t(79) = -0.159, *p* > .05) were not statistically significant, implying no initial difference between the groups. Likewise, for the AMPC dimension, the independent samples t-test analysis (equal variances not assumed) shows that the differences between the mean scores for IG (M = 3.74, SD = 0.68, N = 42) and CG (M = 3.75, SD = 0.42, N = 44); t(68) = -0.129, *p* > .0) were not significant, indicating that the groups were similar before the intervention.

As the data were not normally distributed, non-parametric statistical tests were applied. Table 4.21 presents the results of the Mann–Whitney U test conducted to compare the pre-CLASS-Chem scores of RWC, SME, and CC between the groups. Similarly, the Mann–Whitney U test was employed to examine whether there were any statistically significant differences between the groups in their pre-CLASS-Chem (EBs) scores. The results indicated that there was no statistically significant mean difference between the groups. This suggests that students had the same prior beliefs about the nature of knowledge and knowing in chemistry in general and CBMG in particular. The overall EBs and all dimensions of CLASS-Chem-EBs had a small effect size. This result also implied further analysis of students.

Table 4. 21: The Mann-Whitney U-test for pre-CLASS-Chem (EBs) results

	Group	n	**Mean Rank**	**Sum of Ranks**	**U**	**Z**	***p***	**r**
RWC	IG	42	39.82	1672.70	769.500	-1.348	0.178	0.145
	CG	44	47.01	2068.50				
SME	IG	42	43.52	1828.00	923.000	-0.009	0.993	0.001
	CG	44	43.48	1913.00				
CC	IG	42	42.33	1778.00	875.000	-0.425	0.670	0.046
	CG	44	44.61	1963.00				

For dimensions that violated the assumption of normality, non-parametric tests were employed. The Mann–Whitney U test analysis indicates that the differences between the RWC scores of the IG (mean rank = 39.82, n = 42) and CG (mean rank = 47.01, n = 44; U = 769.500, Z = -1.348, p >.05, r = 0.145) were not statistically significant, implying that the groups were similar before the intervention. Similarly, the Mann–Whitney U test analysis for the SME dimension shows that there was no statistically significant difference between the IG (mean rank = 43.52, n = 42) and CG (mean rank = 43.48, n = 44; U = 923.000, Z = -0.009, p > .05, r = 0.001), indicating comparable baseline levels between the groups In the same way, the results for the CC dimension reveal that the difference between the IG (mean rank = 42.33, n = 42) and CG (mean rank = 44.61, n = 44; U = 875.000, Z = -0.425, p > .05, r = 0.046) was not statistically significant, suggesting that both groups were similar before the intervention.

4.5.1.2.Comparison of Posttest Mean Scores of IG and CG in Epistemological Beliefs

Descriptive Statistics: Table 4.22 shows the descriptive statistics for post-CLASS-Chem (EBs) dimensions for both groups. This provides a clear picture of the data before the analysis of inferential statistics. The mean scores of post-CLASS-Chem (EBs) of IG were higher than those of CG across the overall EBs and in all dimensions. Meanwhile, the statistical significance of the difference between groups can be confirmed by conducting further analysis using inferential statistics.

Table 4. 22: Descriptive statistics of post-CLASS-Chem

	Post-CLASS-Chem (EBs)			
	Intervention Group (n = 42)		**Comparison Group (n =44)**	
Observation	**M**	**SD**	**M**	**SD**
Overall EBs	3.94	0.33	3.57	0.39
PI	3.99	0.47	3.69	0.46
RWC	4.02	0.51	3.64	0.61
PSG	4.09	0.34	3.67	0.48
PSC	4.04	0.44	3.72	0.57
PSS	3.81	0.49	3.31	0.51
SME	4.24	0.35	3.77	0.49
CC	3.84	0.31	3.26	0.66
CL	3.61	0.36	3.12	0.54
AMPC	4.13	0.47	3.73	0.43

The descriptive statistics of the post-CLASS-Chem scores are presented in Table 4.22. The results indicate that students in the IG obtained higher mean scores than those in the CG for the overall CLASS-Chem and across all nine dimensions of EBs. The overall EBs mean score for the IG (M = 3.94, SD = 0.33, N = 42) was higher than that of the CG (M = 3.57, SD = 0.39, N = 44), suggesting more favorable EBs among students who participated in the BL intervention. At the dimension level, the IG demonstrated higher mean scores across all dimensions, including PI (M = 3.99, SD = 0.47, N = 42), RWC (M = 4.02, SD = 0.51, N = 42), PSG (M = 4.09, SD = 0.34, N = 42), PSC (M = 4.04, SD = 0.44, N = 42), PSS (M = 3.81, SD = 0.49, N = 42), SME (M = 4.24, SD = 0.36, N = 42), CC (M = 3.84, SD = 0.31, N = 44), CL (M = 3.61, SD = 0.36, N = 44), and AMPC (M = 4.13, SD = 0.47, N = 44). In contrast, the CG showed comparatively lower mean scores across the corresponding dimensions. Among the nine dimensions, the highest mean score for the IG was observed in the SME dimension (M = 4.24, SD = 0.35, N = 42), followed by AMPC (M = 4.13, SD = 0.47, N = 42) and PSG (M = 4.09, SD = 0.34, N = 24). Conversely, the lowest mean score was observed in the CL dimension (M = 3.61, SD = 0.36, N = 42). Similarly, within the CG, the highest mean score was found in SME (M = 3.77, SD = 0.49, N = 44), whereas the lowest mean score was observed in CL (M = 3.12, SD = 0.54, N = 44).

Overall, the descriptive findings demonstrate that students exposed to the BL approach exhibited relatively more developed EBs across all measured dimensions compared with students who experienced the CTM. However, inferential statistical analyses were conducted to determine whether these observed differences between groups were statistically significant after controlling for possible pre-existing differences.

The normality assumption for the post-CLASS-Chem (EBs) data was examined using skewness, kurtosis, and the Shapiro–Wilk test. The skewness and kurtosis values were within the acceptable range of −1 to +1, indicating approximately normal distributions. The Shapiro–Wilk test results showed that most EBS dimensions were normally distributed, except for PSC in the IG and CC in the CG, which showed significant deviations from normality. Accordingly, parametric tests were applied for normally distributed data, whereas non-parametric tests were used for dimensions that violated the normality assumption. After the intervention, the post-CLASS-Chem was administered to evaluate students' beliefs about learning CBMG concepts through BL and CTM across groups. The independent t-test was employed to examine the effectiveness of the intervention using the post-CLASS-Chem scores across groups. Table 4.23 presents the analysis of the posttest-CLASS-Chem scores for the two groups. This analysis examined the effect of the BL approach on students' EBs compared with the CTM during the delivery of the CBMG lessons.

Table 4. 23: Independent t-test for post-CLASS-Chem (EBs) results

					Levene's test for EoV			**t-test for equality of means**			
Dimension	**Group**	**N**	**M**	**SD**		F	Sig	t	df	P	Cohen's d
OverallEBs	IG	42	3.94	0.33	EVA	2.505	0.117	4.702	84	0.000	0.718
	CG	44	3.57	0.39							
PI	IG	42	3.99	0.47	EVA	0.088	0.768	2.969	84	0.004	0.682
	CG	44	3.69	0.46							
RWC	IG	42	4.02	0.51	EVA	1.443	0.233	3.096	84	0.003	0.669
	CG	44	3.64	0.61							
PSG	IG	42	4.09	0.34	EVNA	9.348	0.003	4.698	78	0.000	1.008
	CG	44	3.67	0.48							
PSS	IG	42	3.81	0.49	EVA	0.421	0.518	4.652	84	0.000	1.004
	CG	44	3.72	0.51							
SME	IG	42	4.24	0.35	EVNA	4.085	0.046	5.147	77	0.000	1.105
	CG	44	3.31	0.49							
CL	IG	42	3.61	0.36	EVNA	5.645	0.020	5.011	76	0.000	1.075
	CG	44	3.77	0.53							
AMPC	IG	42	4.23	0.47	EVA	0.299	0.586	4.113	84	0.000	0.886
	CG	44	3.11	0.43							

Descriptive statistics demonstrated in Table 4.21 for the post-test scores of groups indicated a mean difference between IG and CG for the overall and all dimensions of EBs. This indicates that the mean scores of post-CLASS-Chem (EBs) of IG are higher than those of CG in both the overall and EBs categories. Furthermore, Table 4.22 shows that the inferential analysis of post-CLASS-Chem (EBs) results revealed a statistically significant difference in EBs between the groups. As post-test data were normally distributed, independent samples t-test analysis shows that the differences between the EBs' mean scores (MIG = 3.94, SDIG = 0.33, NIG = 42 and MCG = 3.57, SDCG = 0.39, NCG = 44; t(84) = 4.702, $p < .05$, d = 0.718), of the groups were significant, implying that after the intervention the groups were different. This is a large-sized effect (Cohen, 1988). At the sub-scale level, independent samples t-test analysis shows that the differences between the PI mean scores (MIG = 3.99, SDIG =0.47, NIG = 42 and MCG = 3.69, SDCG = 0.46, NCG = 44; t(84) = 2.969, p < .05, d = 0.682), of the groups were significant, implying that after the intervention, the groups were different. This is a large effect size (Cohen, 1988). At the sub-scale level, independent samples t-test analysis shows that the differences between the PI mean scores (MIG = 3.99, SDIG = 0.47, NIG = 42 and MCG = 3.69, SDCG = 0.46, NCG = 44; t(84) = 2.969, p < .05, d = 0.682) of the groups were significant, implying that after the intervention, the groups were different. This is a large effect size (Cohen, 1988).

Similarly, significant differences were observed for RWC (MIG = 4.02, SDIG = 0.51 and MCG = 3.64, SDCG = 0.61; t(84) = 3.096, p < .05, d = 0.669), indicating a large effect size. For PSG, where the assumption of equal variances was violated, the results of the unequal-variance t-test revealed a significant difference (MIG = 4.09, SDIG = 0.34 and MCG = 3.67, SDCG = 0.48; t(78) = 4.698, p < .05, d = 1.008), representing a large effect size. Likewise, a statistically significant difference was found in PSS (MIG = 3.81, SDIG = 0.49 and MCG = 3.72, SDCG = 0.51; t(84) = 4.652, p < .05, d = 1.004), which also reflects a large effect. In addition, SME showed a significant difference under unequal variance conditions (MIG = 4.24, SDIG = 0.35 and MCG = 3.31, SDCG = 0.49; t(77) = 5.147, p < .05, d = 1.105), indicating a very large effect size. For CL, the unequal variance t-test results indicated a statistically significant difference (MIG = 3.61, SDIG = 0.36 and MCG = 3.77, SDCG = 0.53; t(76) = 5.011, p < .05, d = 1.075), also representing a large effect size. Furthermore, AMPC showed a statistically significant difference (MIG = 4.23, SDIG = 0.47 and MCG = 3.11, SDCG = 0.43; t(84) = 4.113, p < .05, d = 0.886), indicating a large effect size. Overall, these results demonstrate that the intervention group outperformed the comparison group across all EBs dimensions, with effect sizes ranging from large to very large.

These findings suggest that students who learned CBMG concepts through the BL approach demonstrated more favorable EBs than those who were taught using the CTM approach. The overall EBS and its dimensions showed statistically meaningful differences with moderate to large effect sizes. Specifically, the overall CLASS-Chem (EBs) demonstrated a large effect size (Cohen’s d = 0.718). Similarly, the dimensions of PSG, PSS, SME, CL, and AMPC exhibited large effect sizes, with Cohen's d values of 1.008, 1.004, 1.105, 1.075, and 0.886, respectively. In addition, the PI and RWC dimensions showed moderate effect sizes, with Cohen's d values of 0.682 and 0.669, respectively (Cohen, 1988). These results indicate that the BL approach was associated with greater improvements in students' EBs compared with the CTM approach. Table 4.24 presents the Mann-Whitney U test to examine the effectiveness of the intervention using the post-CLASS-Chem across groups.

Table 4. 24: Mann-Whitney U test of post-CLASS-Chem results

	Group	**N**	**Mean Rank**	**Sum of Ranks**	**U**	**Z**	**p-value**	**r**
PSC	IG	42	51.33	2156.00	595.000	-2.883	0.004	0.310
	CG	44	36.02	1585.00				
CC	IG	42	55.12	2315.00	436.000	-4.237	0.000	0.457
	CG	44	32.41	1426.00				

The descriptive results indicated that the mean scores of the overall EBs and all categorical dimensions for the IG were above their respective midpoints, whereas the mean scores of the CG were below or close to the midpoints. Since the post-test data for two subscales (PSC and CC) did not meet the normality assumption, the Mann–Whitney U test was conducted to examine differences between the IG and CG in these dimensions. As presented in Table 4.23, statistically significant differences were observed between the two groups. For the PSC dimension, students in the IG demonstrated a higher mean rank (51.33) than those in the CG (36.02), with the difference reaching statistical significance, U = 595.000, Z = −2.883, $p < .05$. The effect size was small to moderate (r = .310), indicating that students who participated in the BL intervention developed more favorable EBs in the PSC dimension compared with those who received the CTM approach. Similarly, for the CC dimension, the IG obtained a higher mean rank (55.12) than the CG (32.41), and the difference was statistically significant, U = 436.000, Z = −4.237, $p < .05$, with a moderate effect size (r = .457). This finding suggests that the BL approach was associated with greater improvements in students' beliefs related to CC compared with the CTM approach. Overall, the results demonstrate that students in the BL group exhibited significantly higher post-EBS scores in the PSC and CC dimensions than students in the CTM group.

4.5.1.3. Paired-Samples t-test Results for Pretest and Posttest EBS Scores

The students' responses to the five-point Likert scale CLASS-Chem (EBs) were categorized into three groups: agree (combining strongly agree and agree), neutral, and disagree (combining strongly disagree and disagree). After checking the assumption tests, the respondents' pre- and post-test overall percentage responses obtained from CLASS-Chem (EBs) were divided into favorable and unfavorable categories (Barbera et al., 2008). The students' overall response percentages align with the experts' responses, termed favorable, while those who disagree with the experts' responses are deemed unfavorable. The choice “neutral” was not classified as either a favorable or an unfavorable category. Accordingly, Table 4.25 presents the percentage of students' responses for pre-post-test data obtained from CLASS-Chem for the overall and all dimensions of EBs that agreed with the experts’ responses, which was taken into consideration in this analysis. However, the students expressed disagreement, and their neutral responses did not align with the experts' views, leading to their exclusion from this analysis. Moreover, after the intervention, the percentage of responses in agreement with experts increased for IG in all dimensions.

Table 4. 25: Percent agreement of CLASS-Chem pre-post-test of expert-like scores, effect size, and paired t-test significance between groups

	Intervention Group				**Comparison Group**			
EBs	**% Agreement with experts**				**% Agreement with experts**			
Category	**Pretest**	**Posttest**	**Effect size**	**P-value**	**Pretest**	**Posttest**	**Effect size**	**P-value**
OverallEBs	70.22	77.22	1.139	0.000	71.92	71.00	0.079	0.736
PI	53.97	80.56	0.904	0.000	68.18	71.21	0.001	0.998
RWC	55.36	80.16	0.561	0.000	64.77	67.61	0.018	0.928
PSG	60.71	82.86	1.097	0.000	65.27	68.86	0.131	0.777
PSC	57.74	81.55	0.626	0.000	66.48	68.75	0.071	0.774
PSS	45.92	70.07	1.099	0.000	57.79	50.65	0.191	0.426
SME	68.21	87.57	0.587	0.000	70.45	73.48	0.002	0.990
CC	47.62	67.01	1.299	0.000	52.27	47.08	0.051	0.736
CL	44.22	60.88	1.3832	0.004	49.03	39.94	0.2822	0.239
AMPC	64.68	85.30	0.6696	0.009	73.86	71.21	0.0457	0.829

The paired-sample t-test analysis (Table 4.24 above) indicated that the IG students had expert-like EBs in both the overall and the nine EBs dimensions as compared to the CG students. Furthermore, the percent agreement of CLASS-Chem pretest and posttest scores of the paired-sample t-test shows a statistically significant difference between groups as compared to the CG in both the overall and categorical dimensions of EBs. The paired-sample t-test results of the pretest and posttest data of students in the IG reported a large effect size, suggesting that the students scored higher in the posttest than in the pretest. Similarly, this result indicated that the students who were taught via the BL approach had more expert-like EBs of CBMG concepts than the students in CG who were taught this topic through CTM. For the IG, the percentage agreement with experts increased significantly from pretest to posttest for the overall EBs (70.22% to 77.22%), with a large effect size ($d = 1.139$, $p < .001$). Consistent improvements were also observed across all nine dimensions, with the most notable gains in CL (44.22% to 60.88%, $d = 1.383$), CC (47.62% to 67.01%, $d = 1.299$), PSG (60.71% to 82.86%, $d = 1.097$), and PSS (45.92% to 70.07%, $d = 1.099$). The remaining dimensions (PI, RWC, PSC, SME, and AMPC) similarly showed statistically significant improvements with moderate to large effect sizes. In contrast, the CG showed no statistically significant changes in either the overall EBS or its dimensions. The overall agreement slightly decreased (71.92% to 71.00%, $d = 0.079$, $p > .05$), and several dimensions exhibited minor, non-significant declines. These results indicate that the BL intervention led to substantial improvements in students' EBs, whereas the CTM approach resulted in minimal change.

4.5.1.4. Comparison of Gender Effect within Groups in Epistemological Beliefs

Research question: Are there statistically significant gender differences in students' EBs within and between the instructional groups?

Descriptive Statistics for Post-CLASS-Chem Across Gender

The descriptive statistics for post-CLASS-Chem test scores were computed across gender. Accordingly, the post-CLASS-Chem (EBs) results were analyzed, and the descriptive statistics indicated that the mean score of males was slightly higher than that of females in both the overall and CLASS-Chem (EBs) dimensions. In contrast, the mean scores of females were somewhat higher than those of males in the PI and AMPC dimensions for CG. An inferential statistics test was conducted to determine if the observed differences are statistically significant.

Inferential Statistics for Post-CLASS-Chem Across Gender

Independent-samples t-tests were conducted to examine whether students' EBs differed by gender within the IG and CG. Before conducting the analyses, Levene's test was performed to assess the homogeneity of variance assumption. The results showed that the assumption was satisfied for most epistemological belief dimensions ($p > .05$). However, unequal variances were observed for the Real-World Connection (RWC) and Atomic and Molecular Perspective of Chemistry (AMPC) dimensions in the intervention group; therefore, Welch-adjusted t-test results were considered for these dimensions.

An analysis of inferential statistics was employed to examine the gender effect on students' EBs in post-CASS-Chem data. The results shown in Table 4.26 revealed that there were no statistically significant gender differences in overall EBs or any of the individual dimensions within either group (p > .05). In the intervention group, male students showed slightly higher mean scores than female students in overall EBs (M = 4.00, SD = 0.308 vs. M = 3.84, SD = 0.355), but this difference was not statistically significant, t(40) = 1.645, $p > .05$, d = 0.476. Similarly, no significant gender differences were observed in the CG, t(42) = 0.142, $p >.05$, d = 0.409. For the individual EBs dimensions, none of the comparisons reached statistical significance. For example, within the IG, males had higher mean scores than females in Real World connection (M = 4.12 vs. 3.87), Problem Solving-general (M = 4.15 vs. 4.02), Problem Solving Sophisticated (M = 3.89 vs. 3.69), Sense Making Effort (M = 4.27 vs. 4.21), Conceptual Connections (M = 3.85 vs. 3.82), and Atomic and Molecular perspective of Chemistry (M = 4.17 vs. 4.07); however, these differences were statistically nonsignificant (p > .05) with small effect size (Cohen, 1988). This implies that both approaches affected the groups equally. Similar patterns were observed among students in the comparison group. Overall, the findings suggest that gender did not significantly influence students' EBs. The small-to-moderate effect sizes indicate that although some mean differences existed between male and female students, these differences were not strong enough to reach statistical significance. Therefore, the development of EBs appears to be independent of gender within the current study context.Table 4. 26: Independent t-test results of post-CLASS-Chem across gender

						Levene's test of EoV		t-test for equality of means			
Dimension	**Group**	**Gender**	**N**	**M**	**SD**	**F**	**Sig**	**t**	**df**	**p**	**d**
OverallEBs	IG	M	25	4.00	0.308	0.906	0.347	1.645	40	0.108	0.476
		F	17	3.84	0.355						
	CG	M	34	3.57	0.392	0.127	0.723	0.142	42	0.888	0.409
		F	10	3.55	0.410						
PI	IG	M	25	4.04	0.462	0.306	0.583	0.859	40	0.396	0.246
		F	17	3.91	0.493						
	CG	M	34	3.68	0.484	0.594	0.445	0.210	42	0.935	0.064
		F	10	3.71	0.401						
RWC	IG	M	25	4.12	0.382	9.113	0.004	1.450	24	0.160	0.484
		F	17	3.87	0.644						
	CG	M	34	3.75	0.601	0.068	0.795	0.636	42	0.528	0.106
		F	10	3.69	0.477						
PSG	IG	M	25	4.15	0.357	0.007	0.935	1.211	40	0.233	0.358
		F	17	4.02	0.319						
	CG	M	34	3.50	0.500	0.007	0.933	0.464	42	0.645	0.308
		F	10	3.34	0.518						
PSS	IG	M	25	3.89	0.445	0.182	0.672	1.319	40	0.195	0.406
		F	17	3.69	0.530						
	CG	M	34	3.40	0.518	0.005	0.942	0.763	42	0.450	0.387
		F	10	3.20	0.486						
SME	IG	M	25	4.27	0.311	2.149	0.151	0.525	40	0.603	0.168
		F	17	4.21	0.398						
	CG	M	34	3.79	0.481	0.198	0.659	0.607	42	0.542	0.206
		F	10	3.69	0.546						
CC	IG	M	25	3.85	0.312	0.116	0.735	0.395	40	0.695	0.093
		F	17	3.82	0.321						
	CG	M	34	3.27	0.636	0.944	0.337	0.306	42	0.761	0.151
		F	10	3.20	0.754						
AMPC	IG	M	25	4.17	0.369	5.285	0.007	0.609	25	0.548	0.207
		F	17	4.07	0.589						
	CG	M	34	3.71	0.461	2.380	0.130	0.578	42	0.566	0.221
		F	10	3.80	0.281						

The post-PSC scores for the IG and pre-CC scores for the CG were non-parametric. The Mann–Whitney U tests in Table 4.27 revealed no significant gender differences in post-PSC for IG(U =

175.000, z = -.988, p > .05, r = .106); CG (U = 119.000, z = -1.445, *p* > .05, r = .156). Similar result was found in post-CC for IG (U = 158.500, z = -1.397, *p* > 0.05, r = 0.151; CG (U = 142.000, z = -0.787, *p* > 0.05, r = 0.085. These results suggest that both learning approaches supported male and female students equally in developing problem-solving confidence and conceptual connections in CBMG concepts.

Table 4.27: Mann-Whitney U-test: post-CLASS-Chem scores across gender

Dimension	Group	Gender	N	Mean of Ranks	Sum of Ranks	U	z	p-value	r
PSC	IG	M	25	23.00	575.00	175.000	-.988	0.323	0.106
		F	17	19.29	329.00				
	CG	M	34	24.00	816.00	119.000	-1.445	0.149	0.156
		F	10	17.40	174.00				
CC	IG	M	25	23.66	591.50	158.500	-1.397	0.163	0.151
		F	17	18.32	311.50				
	CG	M	34	23.32	793.00	142.000	-.787	0.431	0.085
		F	10	19.70	197.00				

4.6. Qualitative Comparison of Groups in Epistemological Beliefs

After the intervention was completed, semi-structured interviews were conducted to explore students' EBs in learning CBMG concepts. The interview protocol was designed to assess students' EBs in learning CBMG topics via the BL and CTM. Each sample question aimed to elicit common and comparable responses from participants in both groups. The interviews focused on key dimensions of students' EBs, including conceptualizations of knowledge and learning, sources of chemistry knowledge, problem-solving approaches, and conceptual connections, as well as their CU, reasoning processes, and the nature and persistence of misconceptions related to CBMG. Responses were transcribed and systematically organized under emergent themes to facilitate comparative analysis of their beliefs between the BL and CTM groups.

4.6.1. Conceptualizing Knowledge and Learning Aspects

In connection with the above theme, students were asked to respond to the item: How do you view the process of learning CBMG concepts? Do you see it as mostly memorizing facts, or do you feel it involves understanding and applying concepts?"

BL group

Student A: *"In my opinion, the learning process, especially when supported by technology, was engaging and helped me understand the learning concepts. I tried to connect ideas such as electronegativity to explain CBMG concepts."*

Student C: *"In my view, I utilize mind maps during the learning process to assess my understanding (self-checking), such as when comparing ionic and covalent compounds."*

CTM Group

Student G: *"In the learning settings, I try to understand concepts, but I have to memorize the steps (formulae) for solving problems in my study time."*

Student H: *"In this learning process, I understand why atoms form bonds, but I still memorize the theories for exams."*

The responses from both BL and CTM groups reveal a belief in understanding of the learning process in CBMG. Students in the BL group emphasized the importance of conceptual engagement and self-regulated learning strategies. Student A highlighted the role of technology in fostering meaningful connections, such as linking electronegativity to bonding concepts, while Student C demonstrated metacognitive awareness through the use of mind maps for comparative analysis.

In contrast, CTM group members acknowledged the importance of CU but also pointed to the necessity of memorization, particularly for procedural knowledge and exam preparation. Student G and Student H both expressed a dual approach: grasping the "why" behind atomic interactions while relying on memorized theories and formulae to navigate assessments. Overall, the data indicated that while understanding and application are central to learning CBMG concepts, memorization remains a complementary strategy, especially in CG with CTM. This underscores the need for instructional designs that balance conceptual depth with practical recall, fostering both analytical thinking and academic performance.

4.6.2. Effort and Persistence in Learning Aspects

In connection with the above theme, students were asked to respond to the item: "Does learning CBMG influence the effort you put into making sense of complex concepts? Do you find the learning structure encourages more effort in understanding difficult topics?"

BL group

Student B: *"Yes, learning about CBMG through BL encourages me to invest more energy by linking these concepts together, which helps me comprehend what happens to different structures".*

Student D: *"Yes, learning CBMG has taught me that complex concepts take time to truly understand, and I find that revisiting lessons, using models, and checking my reasoning really help me make sense of them."*

CTM Group

Student G: *"Not really, I find it hard to put in more effort because the concepts are quite complicated in this approach, so I usually end up just memorizing the learned material."*

Student I: *"Sometimes, I try to focus more when the teacher explains the concepts of CBMG; however, I find it difficult to understand the explanations without real-life contexts related to the learning of these concepts."*

Students from the BL and CTM groups reveal clear differences in their learning experience and engagement in CBMG concepts. Students in the BL group reported that the BL approach encouraged deeper CogSE by allowing them to connect ideas, revisit lessons, and use multiple representations, such as models, to enhance understanding. For instance, Student B emphasized how BL facilitated the integration of concepts, leading to a clearer comprehension of molecular structures, while Student D acknowledged that the iterative nature of the BL environment through revisiting materials and self-checking understanding supported gradual conceptual mastery. These responses suggest that BL promotes active learning, metacognitive regulation, and conceptual integration, aligning with previous findings that blended environments enhance students' capacity to construct and apply knowledge meaningfully.

In contrast, the CTM group responses reflect more surface-level engagement. Student G described finding the material complicated and resorting to memorization rather than meaningful understanding, while Student I highlighted difficulties in relating theoretical explanations to real-life contexts. These remarks suggest that the CTM limited opportunities for students to engage with content in various ways, leading to passive learning and a dependence on rote memorization. Overall, the contrast between the two groups underscores the pedagogical advantages of BL in fostering motivation, engagement, and conceptual comprehension.

4.6.3. Problem-Solving Aspects

In relation to the above theme, students were asked to respond to the item: "When solving CBMG problems, do you feel it is more important to find the right answer quickly or to understand the process? Can you describe a time when you worked through a challenging problem?"

BL Group

Student A: *"In my opinion, understanding the learning process is crucial when solving CBMG problems, as it allows me to apply this knowledge to new challenges when I understand the underlying concepts."*

Student E: "*In solving CBMG problems, I focused on understanding the underlying concepts, such as electron sharing and electronegativity, to grasp the material."*

CTM group

Student G: *"In fact, understanding the learning process is important; however, because many of the concepts are abstract and lack tangible, real-world phenomena, I often find it more practical to focus on getting the right answer quickly so I can complete solving the problem."*

Student I: "*In my learning experience, the lack of accessible representations of abstract concepts often led me to focus on finding the right answer by memorizing formulas or theories and applying them without fully understanding the concepts".*

The students' reflections illustrate contrasting cognitive approaches to problem-solving in CBMG between the BL and CTM groups. Participants in the BL group emphasized the importance of understanding underlying concepts and the learning process itself as a foundation for solving problems. For instance, Student A highlighted that a deep understanding of the learning process enables the application of knowledge to novel contexts, while Student E described focusing on key conceptual elements such as electron sharing and electronegativity to construct a meaningful understanding of CBMG. Both Student G and Student I noted the abstract nature of CBMG concepts and the lack of concrete representations in CTM, which led them to prioritize obtaining correct answers over developing deep CU. Their reliance on memorization and formula application suggests that the CTM approach may not sufficiently support students in visualizing or contextualizing abstract chemical ideas. Overall, these contrasting reflections underscore the pedagogical effectiveness of the BL approach in promoting CU, reflective problem-solving, and transfer of learning. In contrast, the CTM approach appears to limit SE with the learning process, emphasizing correctness over comprehension

4.6.4. Conceptual Connection Aspects

In relation to the above theme, students were asked to respond to the item: "Can you describe a time when you made a meaningful connection between two ideas or concepts from different areas of study or experience? How did the connection influence your understanding or approach to the CBMG topic?

BL group

Student A: "*Yes, in learning CBMG, I tried to connect it with electronegativity and polarity, and realized that the molecule has polar bonds, which helped me determine the overall geometry".*

Student D: "*When learning CBMG, I strive to understand how molecular geometry shapes the accessibility of reaction sites; for example, by relating the electronegativity of atoms to molecular structure, I can visualize interactions in a more meaningful way".*

CTM group

Student H: "*I try to connect the concept of molecular geometry with hybridization, recognizing that molecules with* sp^3 *hybridization adopt a tetrahedral shape, which helps me accurately determine the structure of a molecule".*

Student I: "*When I learned CBMG concepts, I began to recognize that bond polarity influences molecular geometry, prompting me to consider how differences in electronegativity work, and so I looked at the values to grasp the concept".*

The reflections of the BL and CTM groups indicate that students attempted to integrate multiple concepts while learning CBMG. Students in the BL group demonstrated a more conceptually integrated and application-oriented understanding of CBMG. For instance, Student A connected the ideas of electronegativity and polarity to molecular geometry, showing an awareness of how submicroscopic interactions determine macroscopic molecular properties. Similarly, Student D described understanding the relationship between molecular geometry and chemical reactivity by linking electronegativity and spatial structure, suggesting the development of higher-order conceptual reasoning. Conversely, students in the CTM group also exhibited efforts to connect related ideas such as hybridization, bond polarity, and electronegativity, but their reflections suggested a more formula-based and descriptive understanding. Student H's focus on recognizing hybridization types to predict molecular shapes and Student I's reliance on numerical electronegativity values indicate engagement at a procedural level rather than a conceptual one. Overall, the contrast between the two groups highlights how BL fosters conceptual integration and visualization, whereas the CTM approach tends to reinforce procedural and rule-based reasoning.

Students in the BL group consistently connect the CBMG concepts with their real-life experience, which helps them to understand the concepts and develop expert-like beliefs. This relevance was seen as both intellectually satisfying and professionally beneficial. In contrast, the CTM group struggled to find such connections. The CTM group students both noted that surface recognition, rather than deep linkage to geometry or molecular structure concepts, weakened their understanding of the knowledge they acquired. BL's emphasis on authenticity and application strengthens the development of expert-like EBs, while CTM's struggle with novice beliefs may hinder meaningful learning. Accordingly, the comparative qualitative analysis revealed that the IG students had expert-like EBs compared to the CG. BL's integration of technology, participatory design, and real-world relevance creates a dynamic learning environment that supports deeper understanding, sustained expertise beliefs, and collaborative interaction. In contrast, CTM, while capable of delivering foundational knowledge, lacks the flexibility and interactivity needed to foster the holistic development of EBs.

4.7. Interrelationships Among Dependent Variables Under BL

This section presents the results of the quantitative data. Pearson correlation analysis was used to examine the interrelationships among the dependent variables under BL, and the results are interpreted in relation to the research questions and relevant literature.

4.7.1. Relationships among CU, SE, and EBs

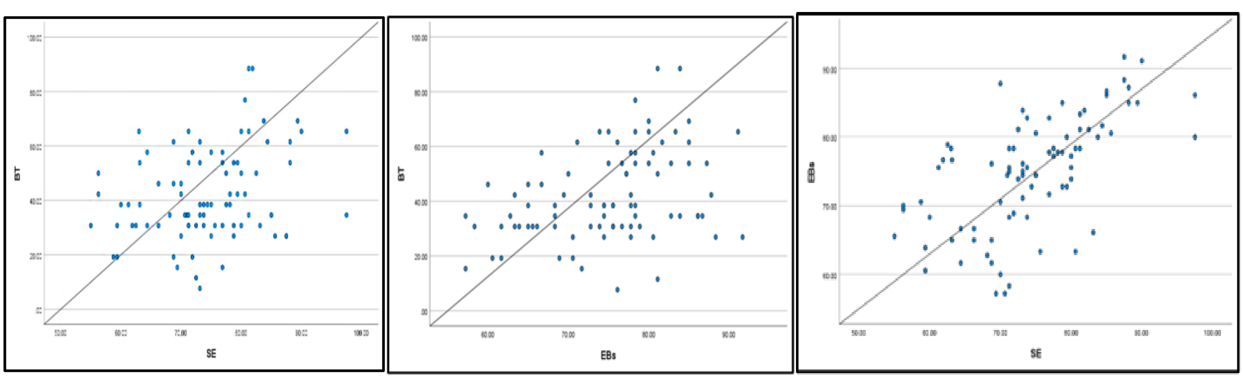
Research Question Five: What relationships exist among undergraduate students' CU, SE, and EBs in learning CBMG concepts through the BL approach?

To answer the research question above, data from the TTCUDT test, SES scale, and CLASS-Chem (EBs) scale scores of the two groups were correlated to see the nature of the relationship. The size of the correlation coefficient between variables is described by the guidelines (Cohen, 1988; Cresswell, 2012). The fourth research question aimed to analyze the correlation between the main variables, including CU-BT, SE, and EBs. Correlation analysis was conducted to examine the relationships between posttest scores of both tiers (BT), representing conceptual understanding (CU-BT), and the variables of student engagement (SE) and EBs. To ensure comparability across variables, all scores were converted into percentage values, thereby harmonizing the data for analysis. Table 4.28 examines the correlation between both tiers (CU-BT), SE, and EBs. Thus, examining the correlation between CU at the two-tier level (CU-BT) and the corresponding study variables is important for understanding how students' cognitive development relates to meaningful SE and EBs.

Table 4. 28 : The relationship between CU-BT, SE, and EBs

Variables	CU-BT	SE	EBs
CU--BT	1		
SE	0.288**	1	
EBs	0.365**	0.612**	1

The results in Table 4.27 revealed that there is a statistically significant positive relationship between each of the variables. Consequently, the findings of this study revealed that there is a statistically significant positive relationship between CU corresponding to both tiers (CU-BT) and SE, with a small Pearson correlation coefficient (r = 0.288, $p < .05$). This finding suggests that there is a positive relationship between students' CU-BT and SE. This implies that students who are more actively engaged in learning tend to develop deeper CU within the BL environment. On the other hand, there was a statistically significant positive relationship between students' CU-BT and EBs, with a medium Pearson correlation coefficient (r = 0.365, $p < .05$). This result indicates a moderate association between CU and EBs, suggesting that improvements in CU at the basic tier are associated with more sophisticated EBs. This shows that students who hold more sophisticated EBs (e.g., knowledge is evolving, constructed, and understandable through effort) are more likely to achieve deeper CU. This finding suggests that instruction should not only focus on content delivery but also support students in developing more sophisticated EBs about knowledge and learning. Besides, there is a strong positive, statistically significant relationship between SE and EBs, with a large Pearson correlation coefficient (r = 0.612, $p < .05$) (Cohen, 1988; Cresswell, 2012). This result indicates that there is a very good relationship between SE and EBs in learning CBMG through the BL approach. The result indicates that instructional practices should aim not only to increase participation but also to develop students' views about knowledge. The relationship between the scores of CU-BT vs SE, CU-BT vs EBs, and SE vs EBs. The scatter plot in Figure 4.6 demonstrates a positive linear relationship between BT vs SE, BT vs EBs, and SE vs EBs. As SE increases, BT and EBs also tend to increase. Similarly, the students' EBs tend to increase with BT. However, the data points around the regression line indicate a moderate relationship between these variables, suggesting that SE contributes to the development of students' CU and EBs. In addition, the students' CU may support the development of their EBs.



(a) BT vs SE (b) BT vs EBs (c) SE vs EBs

Figure 4.6 (a), (b), and (c): The relationships among the scores of CU-BT and SE, CU-BT and EBs, and SE and EBs

4.8. Challenges in Implementing Blended Learning

Research Question six: What challenges are associated with implementing BL for teaching and learning of CBMG concepts at Bahir Dar University?

In this sub-section, the results and discussion of the qualitative data obtained through semi-structured interviews are presented and analyzed. The data were organized and analyzed thematically. BL is designed to enhance instructional delivery by providing learners with extended opportunities for engagement within and beyond the classroom setting. The qualitative data regarding the challenges of BL in the teaching and learning of CBMG topics were collected through interviews. The qualitative data were obtained from the interviews and the researcher's observation during the teaching and learning of CBMG concepts. Classroom observation was used only as a supplementary source to identify and contextualize challenges during the teaching and learning process of CBMG concepts, and was not subjected to formal coding or thematic analysis. Accordingly, the obtained data were organized and analyzed using a thematic approach involving theme development. This process resulted in five major themes: technological challenges, pedagogical challenges, student-related challenges, instructor-related challenges, and institutional challenges. Collectively, these challenges underscore the complexity of implementing BL effectively in classroom contexts. In light of these documented challenges, the present study sought to address the above research question.

4.8.1.Technological Challenges

During the interviews, respondents were asked: "What challenges did you encounter when learning CBMG using the BL?" How did these affect your learning?

> **Student A:** "*I experienced difficulty accessing the online learning platform due to weak internet connectivity while learning CBMG, which negatively affected my understanding of the concepts.*"
>
> **Student C:** *"I found that limited computer skills and technological literacy were the challenges in online BL, making it difficult to access the required resources on time to understand the abstract concepts of CBMG."*

4.8.2. Pedagogical Challenges

During the interview, students were asked the following question: “What challenges did you experience when learning CBMG topics within the blended learning (BL) environment?”

> **Student D:** *“I noticed difficulties in understanding CBMG concepts when face-to-face sessions were followed by online learning, as this sequence limited my understanding of abstract concepts and the effective use of online resources, particularly complex videos, simulations, and animations, and reduced opportunities for instructor presence to clarify these abstract concepts.”*
>
> **Student E: “***I think abstract concepts require sufficient time to understand. In particular, videos, simulations, and animations used in online learning are difficult to follow and understand within the limited time given.”*

Both students reported challenges in understanding abstract CBMG concepts within the blended learning environment. They emphasized that the limited time during online sessions makes it difficult to effectively follow videos, simulations, and animations. Additionally, the sequence of face-to-face sessions followed by online learning was perceived as less supportive, as it reduces opportunities for instructor guidance and clarification. Overall, the students highlighted that insufficient time, complex digital materials, and limited instructor presence hinder their CU.

4.8.3. Student-related Challenges

These challenges were identified through the researcher's and instructor's classroom observations during the teaching and learning process of CBMG in the online BL environment. Students’ readiness for BL depends on their digital literacy, self-regulation skills, and motivation. In this study, students were generally highly motivated to engage in the online BL environment; however, some struggled to access the online platform during the learning process. In particular, students who were less familiar with technology or lacked confidence in managing online tasks faced additional difficulties. Moreover, students’ use of social media during online blended learning sessions distracted some learners from academic activities. In addition, limited computer skills and time constraints further hindered their participation in the BL model. Consequently, BL requires instructors to invest additional time in supporting learners and ensuring consistent follow-up throughout the instructional process. The study found that while students were generally motivated to engage in BL, challenges such as limited digital literacy, difficulties in accessing online platforms, distractions from social media, and time constraints affected their participation. These issues required instructors to provide additional support and continuous follow-up during the learning process (Researcher's observation note).

4.8.4. Institutional Challenges

Through observations of the online BL approach, several institutional challenges were identified during the pre-intervention phase and throughout the intervention sessions. Institutions that do not provide sufficient infrastructure, training, or guidance may unintentionally hinder both instructors and students, reducing the overall effectiveness of BL for teaching CBMG concepts. Many educational settings may lack consistent access to computers, tablets, or high-speed connectivity required for active participation in the online components of BL, while teachers may also experience difficulties in effectively using Learning Management Systems (LMS) and digital tools due to insufficient training or technical support. Thus, BL requires that all students and teachers have access to computers, tablets, or laptops, as well as a sufficient internet connection. For the present study, electricity outages, network interruptions, slow internet connectivity, and internet interference further hinder the instructional process, potentially disrupting in the teaching and learning activities of CBMG concepts. Hence, HEIs should implement comprehensive strategies to improve electricity supply and internet connectivity to mitigate frequent power outages, network interruptions, and the resulting disruptions to teaching and learning activities. Additionally, the lack of earphones, cables, speakers, and adequate internet bandwidth posed challenges during the implementation of BL, particularly in the online sessions for learning CBMG (Researcher's observation notes).

In summary, the challenges identified from the interviews and the researcher's classroom observations can be grouped into four key areas. Technological challenges include limited access to computers, unreliable internet connectivity, low levels of digital literacy, and the complexity of technologies that may distract students from learning tasks. Pedagogical challenges involve inadequate instructional design, limited instructor expertise in effectively integrating face-to-face and online components of BL, and difficulties in developing interactive and well-designed learning activities. Student-related challenges arise from insufficient self-regulation skills, differences in digital competencies, time management difficulties, and susceptibility to distraction from social media use. Finally, participants reported institutional and contextual challenges, including inadequate infrastructure, limited technical and administrative support, unclear guidelines for implementing blended learning, and limited professional development opportunities in e-learning, which were perceived to affect the effective implementation of BL in CBMG instruction.

CHAPTER FIVE

5. DISCUSSIONS AND IMPLICATIONS

5.1. Introduction

This chapter presents and discusses the findings of the study in relation to the variables of CU, SE, and EBs. It also examines the relationships among these variables, explores the challenges of BL implementation, and outlines the implications of the study derived from the research questions. In addition, the chapter integrates and interprets both quantitative and qualitative data to provide a comprehensive understanding of students' CU, SE, and EBs in learning CBMG concepts. Finally, the findings are triangulated and discussed in relation to relevant literature, and the implications for theory, practice, and future research are highlighted.

5.2. Conceptual Understanding

This study examines the effects of BL on undergraduate students' CU in learning CBMG concepts. The CBMG concepts addressed in this study include ionic, covalent, and metallic bonding; Lewis structures, formal charges, and resonance; the strength of ionic and covalent bonds; molecular structure and polarity; and valence bond and molecular orbital theories. Two intact classes were randomly assigned to the IG and CG, with the intervention implemented over nine weeks using a mixed-methods pretest-posttest quasi-experimental comparison group design. Data were collected using the TTCUDT, SES, and CLASS-Chem instruments, along with semi-structured interviews for triangulation. Pretest results indicated that the two groups possessed comparable prior levels of EBs, thereby establishing an equivalent baseline for examining their CU of CBMG concepts. This was due to the fact that they were drawn from the same population of first-year undergraduate students who had not yet received formal instruction on CBMG concepts. In addition, both groups had similar educational backgrounds and prior exposure to general chemistry content in secondary school. Posttest analyses revealed that students in the IG outperformed those in the CG across the content-tier (FT), both-tier (BT), and all-tier (AT), indicating strong students' CU in CBMG concepts. The superior performance of the IG can be attributed to the BL approach, which provided interactive, multimodal, and student-centered learning experiences that enhanced CU of CBMG, whereas the CG received CTM with fewer opportunities for active engagement and visualization. The first-tier primarily assesses answer recognition; the subsequent tiers require scientifically valid reasoning and confidence judgment, reveal underlying MCs, and indicate uncertainty.

The IG students developed higher levels of scientific knowledge (SK), reduced MCs, and lower levels of lack of knowledge compared to the CG students. However, both groups exhibited similar levels of lucky guess (LG) or lack of confidence, as confidence-related aspects of learning are more resistant to short-term instructional interventions. This finding is consistent with earlier studies (Irmak et al., 2023; Milenković et al., 2016), which demonstrate that the three-tier diagnostic test effectively enhances students' scientific knowledge and reduces their MCs. Although both groups exhibited some persistent MCs, the IG showed a greater reduction, indicating that BL was more effective in identifying and correcting MCs. Complementary TTCUDT assessments reinforced these results, providing multidimensional support and strengthening the internal validity of the study. Overall, the findings suggest that BL not only enhances CU and problem-solving skills but also promotes meaningful application of complex chemistry concepts.

In contrast, CTM was less effective in fostering higher-order reasoning and addressing MCs, highlighting the advantages of BL for deeper, more engaged learning in chemistry education. These findings align with existing research highlighting the benefits of BL in chemistry education. BL environments are shown to enhance SE, conceptual processing, and knowledge retention by combining the strengths of CTM and online instruction (Means et al., 2013). Similarly, BL fosters active, collaborative, and reflective learning conditions that support conceptual change, particularly in abstract areas like chemistry (Garrison & Vaughan, 2008). Consistent with prior studies, BL improves CU, visualization, and accessibility of science content (Alammary, 2019) and effectively addresses MCs, which often arise from passive teaching methods (Çalik et al., 2010). Similarly, BL fosters active, collaborative, and reflective learning conditions that support conceptual change, particularly in abstract areas like chemistry (Garrison & Vaughan, 2008). The findings align with existing research highlighting the benefits of BL in chemistry education. BL environments are shown to enhance SE, conceptual processing, and knowledge retention by combining the strengths of CTM and online instruction (Means et al., 2013).

Despite the significant improvements in students' CU observed in the present study, prior research on BL has reported inconsistent and sometimes contradictory findings. Several studies indicate that BL does not necessarily yield superior learning outcomes compared to CTM, with some reporting no statistically meaningful differences or only marginal gains. For example, a systematic review by the researchers (Müller & Mildenberger, 2021) and an empirical study (Müller & Wulf, 2022) concluded that BL with reduced classroom time is not systematically more or less effective than CTM, highlighting the absence of a consistent advantage across contexts. Similarly, meta-analytic evidence suggests that the overall effect of BL on student performance is relatively small, indicating modest rather than transformative impacts (Vo et al., 2017). Furthermore, systematic reviews highlight substantial variability across studies, with outcomes ranging from positive to negligible depending on instructional conditions and study design (Liu et al., 2016).

Research in school and higher education contexts also emphasizes that findings on BL effectiveness remain inconsistent, reflecting differences in implementation quality and contextual factors (Li & Wang, 2022). In relation to CU specifically, studies in science and mathematics domains report heterogeneous effects, suggesting that blended approaches do not uniformly enhance deep conceptual learning (Helsa et al., 2023). Additionally, evidence from adjusted meta-analytic models shows that the apparent advantages of BL may diminish when accounting for publication bias and study heterogeneity, in some cases approaching negligible effects (Liu et al., 2016). These contradictions imply that BL is not inherently effective; rather, its success depends on critical factors such as instructional design quality, duration of intervention, alignment with learning objectives, and the degree of structured guidance provided to learners. In contrast to these mixed findings, the positive results obtained in this study may be attributed to the carefully structured integration of face-to-face instruction with guided online activities, which were explicitly designed to promote conceptual change and active engagement in learning CBMG concepts.

Additionally, the study found no significant gender differences in posttest performance, indicating that BL provides equitable benefits for both male and female students; this may be attributed to the equitable design of the BL environment, which provided equal access to instructional materials, interactive resources, and learning opportunities for both male and female students. This supports earlier findings that inquiry-based and technology-enhanced instruction can reduce gender gaps in achievement and engagement (Hofstein & Mamlok-Naaman, 2007). Furthermore, findings showed that students in both groups held significant MCs about the learned materials (CBMG). The persistence of MCs in both groups may be attributed to the abstract and conceptually challenging nature of CBMG concepts, which are known to be difficult for students to fully grasp. Additionally, students often enter instruction with pre-existing alternative conceptions that are resistant to change and may not be completely addressed through short-term instructional interventions. As a result, despite improvements in conceptual understanding, some MCs remained in both groups. These MCs were sometimes accompanied by high confidence, suggesting strongly held understandings, and at other times by low confidence, indicating uncertainty and partial awareness of misunderstandings. This finding is consistent with the results reported in the literature (Arslan et al., 2012; I. Caleon & R. Subramaniam, 2010; Irmak et al., 2023). The interactive, multimodal nature of BL facilitates the restructuring of MCs more effectively than CTM.

The quantitative findings showed that the IG outperformed the CG across the FT, BT, and AT, indicating stronger CU of CBMG concepts. This is supported by the qualitative results, where BL students demonstrated more accurate explanations, deeper reasoning, and better application of concepts to real-life contexts. In contrast, CG students often relied on oversimplified rules and exhibited partial understanding. Although MCs were observed in both groups, they were more frequent among CG students. Overall, the qualitative evidence verifies the quantitative results, confirming that BL enhanced students’ understanding, reasoning, and conceptual integration.

5.3. Student Engagement

The findings of this study revealed that BL had a significant positive impact on SE, with students in the IG demonstrating significantly higher overallSE and greater engagement across all dimensions (CogSE, EmSE, BehSE, and SocSE) compared with those in the CG. Among the engagement dimensions, BehSE showed the highest level, whereas CogSE demonstrated the greatest improvement relative to the CG, with medium-to-large effect sizes. Furthermore, no statistically significant gender differences were observed in students’ SE during the learning of

CBMG concepts, suggesting that BL provided comparable engagement benefits for both male and female students. Qualitative findings from student interviews further supported these quantitative results, as IG participants reported increased interest, active participation, sustained attention, and deeper involvement in learning activities facilitated by online resources, interactive tasks, and face-to-face discussions. This convergence between quantitative and qualitative evidence strengthens the validity of the findings and suggests that a well-designed BL environment can promote active participation, cognitive investment, meaningful peer interaction, and personalized learning experiences. These findings are consistent with previous research indicating that BL enhances SE by providing flexible opportunities for interaction, learner autonomy, and active engagement (Bernard et al., 2014; De Bruijn-Smolders & Prinsen, 2024).

The findings of this study are consistent with previous research demonstrating that BL positively influences overall SE (Cao, 2023; de Brito Lima et al., 2021; Han, 2025; Song & Lai, 2025). In particular, the present study extends this evidence to the Ethiopian higher education context, where BL was also found to enhance students' overallSE during the learning of CBMG concepts (Bekele et al., 2025). The positive effects observed across the engagement dimensions are consistent with prior studies indicating that BL environments promote CogSE, EmSE, BehSE, and SocSE by encouraging active participation, independent preparation, interaction, and self-regulated learning (Chandola, 2023; De Bruijn-Smolders & Prinsen, 2024; Mohd et al., 2016; Villa et al., 2023). The improvements observed in CogSE, EmSE, BehSE, and SocSE align with theoretical perspectives that conceptualize engagement as a multidimensional construct involving students' cognitive investment, emotional involvement, behavioral participation, and social interaction (Blumenfeld & Paris, 2004). Previous research suggests that BL supports these dimensions by providing flexible access to learning resources, opportunities for collaboration, and interactive learning experiences that promote active learning and self-regulation (Bond et al., 2021; Graham, 2013; Halverson & Graham, 2019). Similarly, studies have shown that teacher autonomy support within BL environments can enhance multiple dimensions of SE, including CogSE, EmSE, BehSE, and SocSE, by fostering students' motivation, active participation, and meaningful interaction (Chinwendu et al., 2020). The improvement in SocSE observed in this study is also consistent with evidence that BL facilitates cognitive and social connections among learners through collaborative activities and communication opportunities (Li & Zeng, 2025).

However, the extent to which BL influences specific engagement dimensions may vary across contexts. Although the present study found significant improvements in all SE dimensions, previous studies have reported inconsistent effects, with some identifying improvements primarily in BehSE but limited changes in CogSE or EmSE (Cubacub & Jimenez, 2025; Lin, 2018). These variations may be explained by differences in course design, disciplinary characteristics, students' prior experiences, self-regulation abilities, and the instruments used to assess engagement. Moreover, systematic reviews indicate that BL does not automatically enhance engagement; rather, its effectiveness depends on the quality of instructional design, the integration of online and face-to-face components, and the level of learner support provided (Müller & Mildenberger, 2021; Vo et al., 2017). Poorly structured BL environments may lead to cognitive overload, reduced interaction, or insufficient guidance, thereby limiting SE (Geberkidan et al., 2025). In contrast to these challenges, the positive engagement outcomes observed in the present study may be attributed to the structured integration of Moodle-based activities with face-to-face instruction. The use of guided online tasks, interactive discussions, timely feedback, and collaborative learning opportunities likely provided continuous support and reduced potential barriers associated with BL implementation. Thus, this study contributes to the growing evidence that BL, when carefully designed and contextually adapted, can effectively enhance multiple dimensions of SE in chemistry education.

5.4. Epistemological Beliefs

Similarly, students in the IG developed more sophisticated EBs than those in the CG. The IG students demonstrated the highest performance across most dimensions of CLASS-Chem (EBs), including personal interest (PI), real-world connection (RWC), problem solving general (PSG), problem solving confidence (PSC), problem solving sophisticated (PSS), sense making/Effort (SME), conceptual connection (CC) and atomic and molecular perspectives of chemistry (AMPC) compared to the CG students. In conclusion, implementing BL in learning environments supports students in developing more expert-like EBs about CBMG concepts than CTM. The findings suggest that BL supports students' epistemic growth by promoting reflective, inquiry-based, and technology-enhanced learning experiences. Consistent with prior research (Abebe et al., 2023; Choung et al., 2020; Erdem, 2008; Kaya, 2017; Koraneekij & Khlaisang, 2019). These results indicate that BL fosters the development of more mature EBs. The results demonstrated significant improvements across multiple EBs dimensions in favor of the intervention group, highlighting the effectiveness of BL in enhancing students' beliefs about knowledge and learning. Moreover, the observed associations among improvements in different EBs dimensions support the view that EBs are multidimensional and interrelated constructs (Hofer & Pintrich, 1997; Schommer, 1990). These quantitative findings are reinforced by qualitative interview data, which revealed a shift in students' perspectives from viewing chemistry knowledge as fixed and authority-driven to understanding it as evolving, interconnected, and applicable to real-life contexts. Students reported that engagement with Moodle-based activities, simulations, and collaborative discussions encouraged reasoning, interpretation, and evidence-based justification rather than rote memorization. This convergence of quantitative and qualitative evidence strengthens the validity of the findings and suggests that BL facilitates more sophisticated epistemic cognition through active engagement, reflection, and knowledge construction (Mason, 2016; Schommer-Aikins, 2004).

The results are also aligned with previous studies showing that technology-enhanced and student-centered learning environments positively influence epistemological development by encouraging learners to perceive knowledge as complex and evolving (Akyol & Garrison, 2011; Bing & Redish, 2009; Tsai, 2004). However, contrasting evidence indicates that EBs can be relatively stable and resistant to short-term instructional interventions, particularly when instructional designs do not explicitly target epistemic cognition (Mason, 2016; Schommer-Aikins, 2004). The divergence between these findings and the present study may be explained by differences in instructional design and context. Specifically, the BL approach employed in this study deliberately integrated guided inquiry, interactive tasks, and reflective activities aimed at fostering epistemic development, which likely promoted deeper cognitive and metacognitive engagement.

Similarly, the study reported no significant difference between BL and CTM in flipped classroom models in students' EBs (Murat & Cam, 2021), reflecting methodological limitations. In such cases, both IG and CG may be exposed to similarly effective inquiry-based approaches (5E-learning model), thereby minimizing observable differences. Additionally, short intervention durations, small sample sizes, and variations in students' access to technology and engagement with pre-class materials may constrain the effectiveness of the intervention and limit the detection of changes in the complex EBs construct. Nevertheless, an exception was observed in the conceptual learning dimension, where students in the CG demonstrated relatively more expert-like beliefs than those in the IG. This unexpected result may suggest that certain epistemic dimensions are more resistant to change or influenced by factors beyond the instructional approach. Overall, while acknowledging the complexity and relative stability of EBs, the findings provide strong evidence that well-designed and contextually adapted BL environments can effectively support the development of more sophisticated EBs in chemistry education.

5.5. The Relationship Between Students' CU, SE, and EBs

Correlation analysis was employed to examine the relationships among CU, SE, and EBs in response to the research question. The findings showed a consistent positive relationship among these variables, suggesting they are meaningfully interconnected within the context of CBMG concepts. Particularly, students' CU at deeper application-oriented levels was associated with their level of engagement. This suggests that as students are actively involved cognitively and socially, their ability to develop and apply conceptual changes improves. Moreover, students' CU correlated with their EBs, implying that students who develop a more sophisticated understanding of scientific concepts are more likely to hold more advanced views about knowledge and learning. The strongest association was observed between SE and EBs, suggesting that highly engaged students tend to adopt more expert-like beliefs. Overall, these results emphasize that CU, SE, and EBs are mutually reinforcing constructs, and their integration is essential for promoting meaningful learning in science education, particularly within a BL environment (Cresswell, 2012; Cohen, 1988; Means et al., 2013). A possible explanation for this improvement is that the BL environment provided opportunities for repeated exposure to content, interactive learning experiences through videos, simulations, and animations that support the visualization of abstract CBMG concepts, and reflective engagement, all of which are essential for conceptual change and deep learning.

The findings of the study are consistent with the findings of other studies, which revealed that undergraduate students’ EBs correlated with their CU in learning physics in problem-based learning instruction (Sahin, 2010b). Furthermore, the study revealed a significant relationship between students' EBs and their CU of biology (Baytelman et al., 2023). Pearson correlation analysis was used to examine the relationships between students' EBs and their conceptions of learning science. The results revealed positive, moderate relationships between these variables (Kapucu, 2021). In addition, students' EBs significantly correlated with their conceptual change in the learning of evolutionary theory (Cho et al., 2011). The results of the regression analysis further indicated that EBs and knowledge-building reflection were significantly associated with conceptual change in science learning (Lam & Chan, 2008). On the other hand, Chemistry-specific EBs change as students' progress through their study of Chemistry (Mazzarone & Grove, 2013). Furthermore, the study findings are consistent with the findings of the prior reported research, which found a positive relationship between CU and SE in Mathematics (Balacuit et al., 2025). In the same vein, this finding aligns with previous research that reported a positive relationship between SE in science learning and their EBs (Çelik et al., 2025) and in chemistry (Rovan et al., 2017). In addition, the findings of the study indicated a strong positive relationship between students' EBs and their level of engagement in STEM education (Ondap & Hornejas, 2022).

Additionally, the study examined the effect of BL on gender differences in the students' CU, SE, and EBs. The results of the study found no significant gender differences in CU, SE, and EBs, indicating that BL provides equitable benefits for both male and female students, supporting earlier findings that inquiry-based and technology-enhanced instruction can reduce gender gaps in achievement and engagement (Hofstein & Mamlok-Naaman, 2007). Furthermore, the results revealed no significant gender differences in SE, supporting evidence from the researchers (Chinwendu et al., 2020; Yilmaz, 2017). That BL environments provide inclusive opportunities for all learners. Similarly, gender differences were not statistically significant, underscoring the inclusive nature of BL and its potential to support diverse learners' epistemic development.

Qualitative data reinforced these results, showing that BL students expressed a more reflective and connected understanding of CBMG concepts. Their responses revealed greater metacognitive awareness and a transition from rote memorization to reasoning-based and integrative learning. This convergence of quantitative and qualitative findings suggests that BL transforms not only what students know but also how they think about and construct scientific knowledge. Taken together, the results across the three variables, CU, SE, and EBs, illustrate the comprehensive benefits of BL in promoting deep and meaningful learning. The convergence of data from different instruments and qualitative interviews strengthens the internal validity and credibility of the findings. The BL approach facilitated students' ability to link theory to practice, engage collaboratively, and reflect critically on their learning experiences. These outcomes align with constructivist principles, which emphasize active participation, reflection, and interaction as foundations of knowledge construction. The findings from both quantitative and qualitative analyses collectively demonstrate that BL is more effective than CTM in promoting conceptual change, active SE, and sophisticated beliefs about knowledge and learning. These findings align with existing research highlighting the benefits of BL in chemistry education (Means et al., 2013).

However, not all studies report such aligned relationships. For instance, the researcher (Schommer-Aikins, 2004) argued that EBs are relatively stable and may not significantly shift alongside short-term instructional interventions. Likewise, some research on blended and technology-enhanced learning (Kirschner et al., 2006) suggests that increased engagement, particularly in minimally guided or technology-rich environments, does not necessarily translate into improved CU, as students may experience cognitive overload or engage superficially with learning materials. In addition, studies such as (Deng et al., 2011) have reported inconsistent correlations between engagement and conceptual gains, indicating that engagement alone may not guarantee deep learning outcomes without carefully structured instructional support. The divergence between previous findings and those of the present study may be attributed to contextual and pedagogical differences, particularly the structured design of the BL intervention, which integrated guided activities, scaffolding, and opportunities for reflection. Therefore, the convergence of quantitative gains and qualitative insights in this study strengthens the claim that, when effectively designed, BL environments can simultaneously enhance CU, SE, and epistemological development. At the same time, the contrasting evidence highlights that these relationships are not automatic but depend critically on instructional quality, learner support, and contextual factors, underscoring the importance of cautious interpretation and contextualized generalization.

5.6. Challenges of BL Implementation

Despite its benefits, the study highlights that successful implementation of BL depends on addressing interconnected technological, pedagogical, and contextual challenges. Technological barriers, including limited digital literacy, inadequate access to devices, unreliable internet connectivity, and electricity interruptions, can hinder learning, particularly in resource-constrained settings. Pedagogically, effective BL requires well-structured instructional design that meaningfully integrates face-to-face and online components, supported by teachers' strong technological, pedagogical, and content knowledge (TPACK). In addition, learner- and institution-related factors, such as students' self-regulation, motivation, and time management, as well as institutional infrastructure, policy support, and technical assistance, play a vital role in determining the effectiveness and sustainability of BL. These findings imply that educators should adopt interactive, inquiry-based, and student-centered instructional strategies that incorporate simulations, digital tools, and diagnostic assessments to support the learning of abstract chemistry concepts. At the same time, successful adoption of BL requires coordinated efforts, including continuous teacher professional development, improved technological infrastructure, and strong institutional and policy support. Overall, the study affirms that BL is pedagogically effective, practically applicable, and theoretically grounded, supporting its integration into classroom practice, curriculum design, and educational policy to promote meaningful and sustainable learning in chemistry education.

The findings of this study are consistent with previous research, which identified the lack of pedagogical planning and instructional design as one of the most prevalent challenges in implementing BL in higher education (Ashraf et al., 2022). The findings of the present study are consistent with those of a systematic review, which identified the provision of appropriate instructional technologies and effective teacher training as major challenges faced by educational institutions (Rasheed et al., 2020). Similarly, the findings of this study are consistent with those of previous research, which reported that although the BL system was generally perceived as technically accessible, students encountered challenges related to login procedures, unstable internet connectivity, and the high cost of data, all of which negatively affected their perceived ease of use and usefulness (Kyei-Akuoko et al., 2025). Furthermore, challenges related to technological access, digital literacy, and contextual constraints, especially in developing country settings, have been identified as barriers to the successful implementation of BL (Graham, 2013). These factors can limit students' participation in online activities and reduce the potential benefits of BL for enhancing their engagement and epistemological development. In some cases, students may focus more on completing tasks rather than reflecting on the nature of knowledge, thereby weakening the expected relationship between SE and EBs. Addressing these challenges requires coordinated efforts to improve technological infrastructure, enhance teacher professional development, strengthen learner readiness, and provide sustained institutional and policy support.

The qualitative findings reveal that BL implementation for CBMG is challenged by interconnected factors. Thematic analysis identified four categories of challenges: technological, pedagogical, student-related, and institutional. Technological issues, such as poor internet connectivity and limited digital skills, hinder access to online resources and reduce conceptual understanding. Student-related challenges include variations in digital literacy, weak self-regulation, time-management difficulties, and social media distractions, which negatively affect engagement in BL. Institutional challenges, such as inadequate infrastructure, limited technical support, and insufficient training, further constrain effective implementation. Overall, these findings indicate that successful adoption of BL requires coordinated improvements in technology, learner readiness, instructional design, and institutional support systems.

Within the pedagogical dimension, challenges arise mainly from weak integration of face-to-face and online components, which limits the effective clarification of abstract CBMG concepts. In particular, inconsistencies in sequencing online and classroom activities, insufficient alignment between Moodle tasks and in-class instruction, and limited opportunities for guided feedback and scaffolding reduced the effectiveness of learning support. These issues reflect gaps in the effective application of Technological Pedagogical Content Knowledge (TPACK), particularly in designing coherent blended learning environments that meaningfully integrate technology, pedagogy, and content. Without strong TPACK-based instructional design, the connection between digital tools and classroom teaching becomes fragmented, affecting students' conceptual development. Therefore, professional development is recommended to strengthen educators' TPACK, especially in integrating digital tools, aligning instructional strategies across modalities, and facilitating meaningful learning interactions in BL environments.

The implementation of BL in this study revealed several interconnected challenges that may influence its effectiveness in promoting CU. Technological challenges, such as poor internet connectivity and limited digital skills, restricted students' access to online resources. Pedagogically, difficulties in effectively integrating face-to-face and online components reduced opportunities for clarifying abstract CBMG concepts. In addition, student-related challenges, including weak self-regulation, time-management difficulties, and distractions from social media, hindered active engagement in learning activities. Institutional constraints, such as inadequate infrastructure, limited technical support, and insufficient training, further limited smooth implementation. Overall, these challenges suggest that the success of BL depends not only on instructional design but also on adequate technological, learner, and institutional support.

CHAPTER SIX

6. SUMMARY, CONCLUSIONS, RECOMMENDATIONS, AND LIMITATIONS

6.1. Introduction

This chapter of the dissertation consists of four main sections. Section 6.2, Section 6.3, Section 6.4, and Section 6.5 focus on summary, conclusions, recommendations, and limitations, respectively.

6.2. Summary

This subsection provides a concise summary of the key findings and discussion presented in Chapter Four, organized according to the research questions. The results of the study show that BL had a positive effect on students' CU, SE, and EBs in CBMG concepts. The findings also indicate that BL was generally effective, although its implementation was influenced by several contextual and instructional factors discussed earlier. Overall, the results demonstrate the pedagogical value of BL in supporting students' learning in chemistry education. These were:

1. To evaluate the effect of BL on undergraduate students' CU CBMG concepts.
2. To assess the impact of BL on undergraduate SE in learning CBMG concepts.
3. To investigate how BL influences undergraduate students' EBs in learning CBMG concepts.\
4. To examine whether statistically significant gender differences exist in students' CU, SE, and EBs in learning CBMG across the two instructional groups.
5. To analyze the relationships among CU, SE, and EB in undergraduates in learning CBMG concepts.
6. To examine the challenges associated with implementing BL for teaching and learning of CBMG concepts at Bahir Dar University.

Correspondingly, the following research questions were answered in this study.

1. What is the effect of BL on undergraduate students' conceptual understanding of CBMG concepts, and in what ways does their understanding change?
2. What is the effect of BL on undergraduate SE in learning CBMG concepts?

3. What is the effect of BL on undergraduate students' EBs about CBMG concepts?
4. Are there statistically significant gender differences in students' CU, SE, and EBs within and between the instructional groups?
5. Is there a statistically significant relationship among undergraduate students' CU, SE, and EBs in learning CBMG concepts through the BL approach?
6. What are the challenges associated with implementing BL to teach CBMG concepts at Bahir Dar University? Why have challenges emerged at this stage?

Multiple data collection instruments were used in this study for gathering data and answering the six research questions above. The BL approach in this dissertation yielded findings that have demonstrated its usefulness of BL for teaching CBMG. This sub-section of the study summarizes results obtained through TTCUDT, SES scale, CLASS-Chem survey, semi-structured interview, and observations as per the research questions.

Research Question One

What is the effect of BL on undergraduate students' conceptual understanding of CBMG concepts, and in what ways does their understanding change?

This study investigated the effect of BL on undergraduate students' CU of CBMG and examined how their understanding changed over time. The findings revealed that students exposed to the BL approach demonstrated significantly greater improvements in CU compared to those taught using the CTM. This was evident across all three tiers of the diagnostic test: the instrument assesses three hierarchical levels of understanding: the content–concept or first tier (FT), which measures factual knowledge; the content–concept reasoning or both tiers (BT), which evaluates students' conceptual reasoning; and the content–concept reasoning-with-certainty or all tiers (AT), which captures students' confident and well-substantiated understanding. In particular, students in the IG showed substantial gains not only in recalling concepts but also in explaining underlying principles and applying their knowledge to complex CBMG problems. The progressive decline in scores from FT to AT observed in both groups highlights the increasing cognitive demand of higher-order understanding; however, this decline was considerably less pronounced among BL students, indicating deeper conceptual development. The results suggest that the integration of face-to-face instruction with online learning components, such as simulations, animations, and interactive activities, enhanced students’ ability to visualize abstract chemical concepts, engage actively with the content, and construct meaningful understanding. As a result, BL helped reduce MCs and promoted more scientifically accurate reasoning about CBMG concepts. Overall, the study concludes that BL is an effective instructional approach for improving both the depth and quality of undergraduate students’ CU in chemistry, particularly in CBMG concepts.

Research Question Two

What is the effect of BL on undergraduate SE in learning CBMG concepts?

This study examined the effect of BL on undergraduate students' engagement in learning CBMG concepts. The findings indicated that students exposed to the BL approach demonstrated significantly higher levels of overall engagement compared to those taught through the CTM. Specifically, BL students showed notable improvements across multiple dimensions of engagement, including CogSE, EmSE, BehSE, and SocSE, with moderate to large effect sizes observed. The integration of face-to-face instruction with online components, such as interactive simulations, multimedia resources, and discussion forums, enhanced students’ active participation, interest, and persistence in learning CBMG concepts. Additionally, the BL environment fostered collaborative learning and increased student involvement, particularly in SocSE, as supported by non-parametric analysis. The findings suggest that the interactive and flexible nature of BL creates a more student-centered learning environment, which promotes deeper involvement and sustained engagement. Overall, the results confirm that BL is an effective instructional approach for enhancing undergraduate SE in complex chemistry topics, particularly CBMG.

Research Question Three

What is the effect of BL on undergraduate students’ EBs about CBMG concepts?

This study investigated the effect of BL on undergraduate students’ EBs regarding CBMG concepts. The findings revealed that students in the BL group developed significantly more sophisticated EBs compared to those in the CTM group. Statistically significant improvements were observed in overall EBs, as well as across multiple EBs dimensions, including personal interest, real-world connection, problem-solving generalization, problem-solving confidence, problem-solving sophistication, sense-making/effort, conceptual connection, conceptual learning, and the application of chemical knowledge to real-world contexts. The BL environment, integrating face-to-face instruction with interactive online resources such as simulations, guided activities, and discussion forums, encouraged students to view knowledge as interconnected, evolving, and grounded in reasoning rather than as isolated facts. As a result, students became more reflective, critical, and confident in constructing and applying CBMG concepts. This finding suggests that BL fosters a more inquiry-oriented and student-centered learning experience, which supports the development of expert-like EBs. Overall, the study concludes that BL is an effective pedagogical approach for enhancing the quality and sophistication of undergraduate students' EBs in chemistry, particularly in CBMG topics.

Research Question Four

Are there statistically significant gender differences in students' CU, SE, and EBs within and between the instructional groups?

Gender differences in students' CU, SE, and EBs were examined across the BL and conventional teaching groups. The results revealed that there were no statistically significant differences between male and female students in CU of CBMG concepts. Similarly, gender did not produce statistically significant differences in students' overallSE or its dimensions, including CogSE, EmSE, BehSE, and SocSE. In addition, no statistically significant gender differences were found in students' EBs measured using CLASS-Chem. These findings indicate that male and female students demonstrated comparable levels of CU, SE, and EBs across the two instructional groups, suggesting that the observed differences in learning outcomes were associated more with the instructional approach than with students' gender.

Research Question Five

Is there a statistically significant relationship among undergraduate students' CU, SE, and EBs in learning CBMG concepts through the BL approach?

This study examined the relationships among undergraduate students' CU at the content-concept-reasoning level (CU-BT), SE, and EBs in learning CBMG concepts within a BL environment. The findings revealed significant and positive relationships among all three variables, indicating that students who demonstrated higher engagement in BL activities also tended to exhibit deeper reasoning-based CU and more sophisticated EBs. In particular, SE showed strong associations with CU-BT, suggesting that active involvement in learning tasks and sustained effort contributed to improved reasoning and explanation of CBMG concepts. Similarly, students with more advanced EBs, such as viewing knowledge as interconnected and constructed through reasoning, were more likely to achieve higher CU and engage more meaningfully in learning processes. The results highlight that the interactive and student-centered nature of BL fosters these interrelated developments by promoting active participation, critical thinking, and reflective learning. Overall, the results suggest that CU-BT, SE, and EBs are mutually reinforcing constructs within a BL context, collectively enhancing students' meaningful learning of complex CBMG concepts.

Research Question Six

What are the challenges associated with implementing BL to teach CBMG concepts at Bahir Dar University? Why have challenges emerged at this stage?

This study explored the challenges of implementing BL in teaching CBMG concepts at Bahir Dar University, while examining its effects on students' CU, SE, and EBs. The findings indicated that, despite the positive impacts of BL on students' reasoning-based understanding, active engagement, and development of more sophisticated EBs, several institutional and practical challenges constrained its effective implementation. Key challenges included limited access to technological resources such as computers, earphones, and reliable internet connectivity, as well as insufficient infrastructure and bandwidth to support online learning activities. Additionally, time constraints, varying levels of students' digital literacy, and initial resistance to adopting new learning approaches affected participation in the online components. Instructor workload and the need for continuous technical and pedagogical support also emerged as notable concerns. The discussion suggests that although BL creates a more interactive and student-centered learning environment that enhances CU, SE, and EBs, addressing these contextual and resource-related challenges is essential for its sustainable and effective integration in higher education settings like Bahir Dar University.

6.3. Conclusions

The present study investigated the effects of BL on undergraduate students' CU, SE, and EBs in learning CBMG topics. The findings of this study demonstrate that the BL approach enhances CU in learning CBMG concepts. Additionally, BL enhances the students' conceptual clarity, reduces MCs, and promotes a stronger scientific understanding. The study further demonstrated that BL significantly enhanced SE and positively influenced students' EBs, promoting more sophisticated views about knowledge and learning. Furthermore, CU, SE, and EBs were found to be positively interconnected, with SE playing a central role in supporting meaningful learning. SE also significantly improved the students' CU in the BL environment. Students who actively participate in the BL environment tend to develop a stronger grasp of abstract concepts in chemistry education. In the same vein, the BL approach significantly enhanced students' EBs, shifting them from naïve to more sophisticated levels. Furthermore, a positive relationship was observed between SE and their EBs. This suggests that students who view knowledge as evolving and constructed are more likely to benefit from the BL approach. Importantly, no statistically significant gender differences were observed across CU, SE, and EBs, indicating that BL is an equitable instructional approach. The study also revealed that students' confidence levels varied, with some instances of overconfidence associated with incorrect responses, highlighting the complexity of students' understanding and reasoning processes.

Despite these positive outcomes, the implementation of BL was associated with technological, pedagogical, and contextual challenges, including limitations in digital access, instructor preparedness, and institutional support. Overall, the findings underscore the effectiveness of BL as a comprehensive instructional approach that enhances CU, promotes engagement, and supports the development of sophisticated ways of thinking. These results highlight the potential of BL to contribute to improving the quality of science education in higher education contexts.

6.4. Recommendations

6.4.1. Instructional Integration of Blended Learning

Higher education institutions (HEIs) should systematically integrate well-designed BL approaches into instructional practices, as they have demonstrated effectiveness in enhancing students' CU, SE, and EBs. A structured BL model that combines face-to-face instruction, interactive digital tools, and post-instructional activities can promote visualization, exploration, and active learning. Therefore, instructors should adopt pedagogically grounded BL approaches that meaningfully integrate technology with effective teaching strategies rather than simply adding digital components to traditional instruction.

6.4.2. Professional Development for Instructors

Continuous professional development programs are essential for strengthening instructors' Technological Pedagogical Content Knowledge (TPACK) and equipping them with the competencies needed to design, implement, and sustain effective BL environments. Training should focus on the meaningful integration of digital tools, student-centered instructional strategies, and constructivist approaches that promote deeper engagement and improved learning outcomes. Therefore, HEIs should provide ongoing professional development, digital resources, and technical support to enable instructors to implement BL as a transformative and sustainable teaching practice.

6.4.3. Curriculum Design and Pedagogical Innovation

Curriculum designers should embed BL as a core pedagogical approach by integrating digital resources, simulations, and inquiry-based activities into instructional frameworks, particularly for abstract chemistry topics such as CBMG. BL curricula should be designed to provide flexible, interactive, and student-centered learning experiences that combine online and face-to-face components coherently. Additionally, regular diagnostic assessments should be incorporated to identify students' MCs, monitor learning progress, and provide timely feedback, thereby promoting deeper CU and the development of students' EBs.

6.4.4. Institutional and Policy Support

Policymakers and institutional leaders should establish supportive policies and invest in digital infrastructure to enable the sustainable and equitable implementation of BL across higher education institutions. Reliable internet access, effective digital learning platforms, and technical support systems are essential for reducing disparities in access and ensuring inclusive learning opportunities. By embedding BL within institutional teaching and learning strategies and adopting a system-wide approach, HEIs can move beyond isolated interventions toward student-centered learning environments that enhance engagement and meaningful learning outcomes.

6.4.5. Future Research Directions

Further research is recommended to examine the long-term effects of BL on students' learning outcomes, including retention, engagement, and epistemological development. Studies should also explore the applicability of BL across different subject areas, educational levels, and institutional contexts to determine the generalizability of findings. The use of four-tier diagnostic tools is particularly valuable for providing deeper insights into students' MCs and reasoning processes. Moreover, future investigations should consider variations in infrastructure, resources, and student backgrounds to ensure that BL strategies are adaptable to diverse educational settings.

6.5. Limitations

Although this study demonstrates the potential benefits of BL in improving students' CU, SE, and EBs, several limitations should be acknowledged. First, the study was conducted using a relatively small sample drawn from a single university, which limits the generalizability of the findings to broader educational contexts. This limitation is further compounded by the focus on a specific content area, CBMG, which may restrict the transferability of the results to other subject areas or disciplines. Additionally, the small interview sample size and unequal gender distribution of participants may constrain the depth and representativeness of the qualitative findings. Second, the relatively short duration of the intervention may not have been sufficient to capture the long-term effects of BL on students' knowledge retention and sustained engagement. Third, the study relied primarily on the Three-Tier Conceptual Understanding Diagnostic Test (TTCUDT) as the main assessment tool. Although this instrument incorporates reasoning and confidence tiers, its reliance on structured, content-based items and a single confidence rating may limit the precision in distinguishing between students' CU and reasoning processes, particularly in diagnosing MCs. Finally, the study focused exclusively on undergraduate students, which may limit the applicability of the findings to other educational levels or learner populations.

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8. APPENDICES

Appendix A: Contents, Sub-contents, and Objectives related to the topic Chemical Bonding and Molecular Geometry

No.	Contents and sub-contents of the topic	Objectives of the content
1	**Chemical bonding**	
	• The Formation of Ionic Compounds	✓ Explain the formation of cations, anions, and ionic compounds.
	• Electronic Structures of Cations and Anions	✓ Describe the electronic structures of cations and anions
2	**Covalent Bonding**	
	• .Formation of Covalent Bonds	✓ Describe the formation of covalent bonds
	• Polarity of Covalent Bonds	✓ Define electronegativity and identify the polarity of covalent bonds.
3	**Metallic Bonding**	
	• Formation of metallic bonding	✓ Describe the formation of metallic bonding
	• Properties of metallic bonding	✓ Explain the properties of metallic bonding
4	Lewis structures	
	• Writing Lewis Structures with the Octet Rule	✓ Draw Lewis structures depicting the bonding in simple molecules and ions.
	• Exceptions to the Octet Rule	✓ Compute formal charges for atoms in any Lewis structure.
		✓ List the molecules/ions with exceptional Lewis structures
5	**Formal Charges and Resonances**	
	• Calculating Formal Charge	✓ Identify the most reasonable Lewis structure for a given molecule using formal charges.
	• Predicting Molecular Structure Using Formal Charge	✓ Explain the concept of resonance and draw Lewis structures representing resonance forms for a given molecule
	• Resonance	✓ Draw Lewis structures representing resonance forms for a given molecule
6	**Strengths of ionic and covalent bonds**	
	• Ionic bond strength and lattice energy	✓ Compute lattice energies for ionic compounds using the Born-Haber cycle.

	• Bond strength of a covalent bond	✓ Determine the strengths of covalent bonds
7	**Molecular structure and polarity** • VSEPR Theory • Molecular structure and dipole moment	✓ Predict the structures of molecules using valence shell electron pair repulsion (VSEPR) theory ✓ Explain the concepts of polar covalent bonds and molecular polarity.
8	**Valence bond and Molecular orbital theory** • Valence bond theory in covalent bonds • Molecular orbital theory	✓ Determine the hybridization of molecules ✓ Determine the energy of orbitals of the molecules ✓ Determine the bond order of the molecule

Appendix B: Propositional Knowledge Statements for CU of CBMG

The propositional knowledge statements are identified for the target concepts of chemical bonding and molecular structure regarding the contents such as chemical bonding, Lewis structure of molecules, formal charge and resonance, strengths of ionic and covalent bonds, intermolecular forces, molecular structure and polarity, valence bond theory, and molecular orbital theory.

Chemical Bonding

1. Chemical bonding is the attractive force that holds together the constituent particles (atoms, ions, or molecules) in chemical species.
2. The tendency or urge of atoms of various elements to attain a stable configuration of eight electrons in their valence shell is the cause of chemical combination.
3. The atoms do so either by transfer or sharing of valence electrons, while inner shell electrons are not involved in the combination process.

Ionic bonding

1. Metallic elements tend to transfer (lose) valence electrons to form cations, while non-metals tend to gain valence electrons and form anions.
2. Transition and inner transition metal elements behave differently from main group elements.
3. Most transition metal cations have 2+ or 3+ charges that result from the loss of their outermost s electron(s) first, sometimes followed by the loss of one or two d electrons from the next-to-outermost shell.
4. The different types of chemical bonding are determined by how the valence electrons are shared or transferred among the bonded atoms.
5. The electrostatic force of attraction that holds the oppositely charged ions together is known as an ionic bond or an electrovalent bond.
6. Ionic compounds do not contain molecules; however, they are aggregates of positive ions and negative ions.
7. An ionic compound is stable because of the electrostatic attraction between its positive and negative ions.
8. In the solid state, each ion is surrounded by ions of the opposite charge, producing an orderly array of ions called a crystal.

9. At room temperature, ionic compounds are hard and rigid crystalline solids due to the existence of strong electrostatic forces of attraction between the ions.
10. Ionic compounds have relatively high melting and boiling points due to the presence of strong electrostatic forces between the ions.
11. These forces can be overcome only by applying very large amounts of energy.
12. Ionic compounds can conduct electric currents when molten or in aqueous solution due to the presence of mobile ions in the molten state or solution; however, ionic compounds do not conduct electricity in a solid state.
13. Ionic compounds are soluble in polar solvents

Covalent bonding

1. Nonmetal atoms frequently form covalent bonds with other nonmetal atoms by sharing of valence electrons.
2. Electrons shared in pure covalent bonds have an equal probability of being near each nucleus to form a non-polar covalent bond.
3. When the atoms linked by a covalent bond are different, the bonding electrons are shared, but no longer equally; instead, the bonding electrons are more attracted to one atom (the more electronegative atom) than the other, giving rise to a shift of electron density toward that atom to form a polar covalent bond.
4. The bonding electrons are more attracted to one atom than the other, giving rise to a shift of electron density toward that atom.
5. This unequal distribution of electrons is known as a polar covalent bond, characterized by a partial positive charge on one atom and a partial negative charge on the other.
6. The atom that attracts the electrons more strongly acquires the partial negative charge and vice versa.
7. The bond formed by equal sharing of electrons is known as nonpolar covalent bonding.
8. Compounds formed from covalent bonds are known as covalent compounds.
9. Most covalent molecules/compounds are liquids (e.g., H_2O) and gases (CH_4, CO_2) at room temperature, while some are solids (e.g., sugar).
10. As compared to ionic compounds, covalent compounds have relatively lower melting points and boiling points.

11. Covalent compounds do not conduct electric current when molten or in aqueous solution, because they consist of molecules rather than of ions.
12. Covalent compounds are insoluble in polar solvents such as water, while they are soluble in non-polar solvents such as benzene and carbon tetrachloride.
13. Some compounds that are formed from the positive ions and the negative ions of the covalently bonded atoms have both ionic and covalent bonds.

Metallic bonding

1. Atoms of the same metal held together to form metallic bonding in the solid.
2. It is possible to think of them as positive ions floating in a sea of electrons.
3. Electrons are free to move through the solid due to delocalized electrons.
4. Metals conduct electricity by mobile electrons as current carriers in metallic bonding.
5. Metallic bonds have high melting and boiling points due to strong electrostatic interaction between metal positive ions and delocalized electrons.
6. Unlike ionic and covalent bonding, metallic bonding cannot form new substances.

Lewis structure of molecules/ions

1. Lewis structures are molecular formulas that show the bonding and free electrons around the central atom and provide a simplified basis for explaining the properties of molecules.
2. Lewis symbols are used to indicate the formation of covalent bonds, which are shown in Lewis structures, drawings that describe the bonding in molecules and polyatomic ions.
3. The valence electron pairs, which are responsible for the formation of bonds, determine the Lewis structures of molecules.
4. The electrons in a compound should be arranged to reflect the bonding; ionic bonds result from the transfer of electrons, and covalent bonds are due to the sharing of electrons.
5. The process of writing Lewis structures can be facilitated by recognizing that electron pairs account for the covalent and ionic bonding; otherwise, the molecule would not exist.
6. For very simple molecules and molecular ions, we can write the Lewis structures by merely pairing up the unpaired electrons on the constituent atoms.
7. For more complicated molecules and molecular ions, it is helpful to follow the step-by-step procedure outlined (a-f) to draw the Lewis structure of molecules/ions.

i) Determine the total number of valence (outer shell) electrons; for cations, subtract one electron for each positive charge. For anions, add one electron for each negative charge.

ii) Draw a skeleton structure of the molecule or ion, arranging the atoms around a central atom. (Generally, the least electronegative element should be placed in the center.)

iii) Connect each atom to the central atom with a single bond (one electron pair).

iv) Distribute the remaining electrons as lone pairs on the terminal atoms (except hydrogen), Completing an octet around each atom. Place all remaining electrons on the central atom.

v) Rearrange the electrons of the outer atoms to make multiple bonds with the central atom to obtain octets wherever possible.

8. Place the atoms relative to each other. For compounds of molecular formula ABn, place the atom with the lower group number in the center because it needs more electrons to attain an octet; usually, this is also the atom with the lower electronegativity.
9. If the atoms have the same group number, as in SO3 or CIF_3, place the atom with the higher period number in the center. H can form only one bond. So, it is never a central atom.
10. Many covalent molecules have central atoms that do not have eight electrons in their Lewis structures. These molecules fall into three categories:
    i) Odd-electron molecules have an odd number of valence electrons and therefore have an unpaired electron.
    ii) Electron-deficient molecules have a central atom that has fewer electrons than needed for a noble gas configuration.
    iii) Hypervalent molecules have a central atom that has more electrons than needed for a noble gas configuration.

Formal Charge and Resonance

1. The formal charge of an atom in a molecule is the hypothetical charge the atom would have if we could redistribute the electrons in the bonds evenly between the atoms.
2. The concept of formal charges helps us predict the most appropriate Lewis structure when more than one is reasonable.
3. The formal charge of the atom in a molecule can be determined by the number of valence electrons of a neutral atom, subtracting the nonbonding electrons, and then subtracting half of the number of bonds connected to that atom in the Lewis structure.

4. The sum of the formal charges of all atoms in a molecule must be zero; the sum of the formal charges in an ion should equal the charge of the ion.
5. Multiple Lewis structures satisfying the duet/octet rule for a given molecule are called resonance structures.
6. When a molecule cannot be represented by a single structure, but its characteristic properties can be described by two or more structures, then the actual structure is said to be a resonance hybrid of these structures.
7. A molecule or polyatomic ion for which two or more Lewis formulas with the same arrangements of atoms can be drawn to describe the bonding is said to exhibit resonance.
8. The concept of formal charge can be used to resolve ambiguous structures.
9. The possible resonance contributors can be performed by involving the pi (π) and delocalized electrons in a molecule/ ion.
10. One way to select the more important resonance form is to determine each atom's formal charge, the charge it would have if the bonding electrons were shared equally.
11. Three criteria help us choose the more important resonance structures:
12. Smaller formal charges (positive or negative) are preferable to larger ones.
13. Formal charges on adjacent atoms are not desirable.
14. A more negative formal charge should reside on a more electronegative atom.

Strengths of ionic and covalent bonds

1. A bond's strength describes how strongly each atom is joined to another atom, and therefore how much energy is required to break the bond between the two atoms.
2. The lattice energy of a compound is a measure of the strength of this attraction.
3. The lattice energy of an ionic compound is defined as the energy required to separate one mole of the solid into its component gaseous ions.
4. On the other hand, lattice energy is released when separate ions combine to form a lattice and gives negative (exothermic) values.
5. The bond energy needed to break the bond is released when the bond is formed.
6. The lattice energy of an ionic crystal increases rapidly as the charges of the ions increase and the sizes of the ions decrease.

7. Different interatomic distances produce different lattice energies. For example, we can compare the lattice energy of MgF2 (2957 kJ/mol) to that of MgI2 (2327 kJ/mol) to observe the effect on lattice energy of the smaller ionic size of F– as compared to I-.
8. Lattice energies calculated for ionic compounds are typically much higher than bond dissociation energies measured for covalent bonds.
9. Stable molecules exist because covalent bonds hold the atoms together.
10. We measure the strength of a covalent bond by the energy required to break it, that is, the energy necessary to separate the bonded atoms.
11. The energy required to break a specific covalent bond in one mole of gaseous molecules is called the bond energy or the bond dissociation energy.
12. The strength of a bond between two atoms increases as the number of electron pairs in the bond increases.
13. Bond strength of triple bond > double bond > single bond, and bond length of Single bond > double bond > triple bond.
14. The enthalpy change, ΔH, for a chemical reaction is approximately equal to the sum of the energy required to break all bonds in the reactants (energy "in", positive sign) plus the energy released when all bonds are formed in the products (energy "out," negative sign).
15. The bond strength depends on the attraction of the nuclei for the shared electrons, so the greater the orbital overlap, the stronger (more stable) the bond.

Molecular structure and polarity

1. Polar covalent bonds connect two atoms with differing electronegativities, leaving one atom with a partial positive charge (δ+) and the other atom with a partial negative charge (δ–), as the electrons are pulled toward the more electronegative atom. This separation of charge gives rise to a bond dipole moment (μ).
2. This bond moment can be represented as a vector, a quantity having both direction and magnitude.
3. Dipole vectors are shown as arrows pointing along the bond from the less electronegative atom toward the more electronegative atom.
4. A small plus sign is drawn on the less electronegative end to indicate the partially positive end of the bond.

5. A whole molecule may also have a separation of charge, depending on its molecular structure and the polarity of each of its bonds.
6. If such a charge separation exists, the molecule is said to be a polar molecule (or dipole); otherwise, the molecule is said to be nonpolar.
7. The dipole moment measures the extent of net charge separation in the molecule as a whole.
8. We determine the dipole moment by adding the bond moments in three-dimensional space, considering the molecular structure.
9. For diatomic molecules, there is only one bond, so the bond dipole moment determines the molecular polarity.
10. Homonuclear diatomic molecules such as Br2 and N2 have no difference in electronegativity, so their dipole moment is zero.
11. For heteronuclear molecules such as CO, there is a small dipole moment. For HF, there is a larger dipole moment because there is a larger difference in electronegativity.
12. Intermolecular force is the force between molecules.
13. Intermolecular forces are the forces between molecules that determines the state of molecules at room temperature.
14. Intermolecular forces determine the strength of the bond between the molecules and their boiling point.
15. When a molecule contains more than one bond, the geometry must be considered.
16. If the bonds in a molecule are arranged such that their bond moments cancel (vector sum equals zero), then the molecule is nonpolar.
17. This is the situation in CO_2; each of the bonds is polar, but the molecule as a whole is nonpolar.
18. Molecules of less geometric symmetry, however, may be polar even when all bond moments are identical.
19. For these molecules, the directions of equal bond moments are such that they sum to give a nonzero dipole moment and a polar molecule.
20. For a molecule to be polar, it must

    i) contain at least one polar covalent bond

ii) Have a molecular structure such that the sum of the vectors of each bond dipole moment does not cancel.

21. Also, polar solvents are better at dissolving polar substances, and nonpolar solvents are better at dissolving nonpolar substances.
22. Valence shell electron-pair repulsion theory (VSEPR theory) enables us to predict the molecular structure, including approximate bond angles around a central atom, of a molecule from an examination of the number of bonds and lone electron pairs in its Lewis structure.
23. The VSEPR model assumes that electron pairs in the valence shell of a central atom will adopt an arrangement that minimizes repulsions between these electron pairs by maximizing the distance between them.
24. VSEPR theory predicts the arrangement of electron pairs around each central atom and, usually, the correct arrangement of atoms in a molecule.
25. With two bonds and no lone pairs of electrons on the central atom, the bonds are as far apart as possible, and the electrostatic repulsion between these regions of high electron density is reduced to a minimum when they are on opposite sides of the central atom.
26. When the molecule has no lone pair around the central atom, its number of electron-pair geometry/electron-group/ and shapes are the same, and the molecules that have different regions for electron pair arrangement may not have the same shape.
27. Two regions (bond and/or lone pairs) of electron density around a central atom in a molecule form a linear geometry; three regions form a trigonal planar geometry; four regions form a tetrahedral geometry; five regions form a trigonal bipyramidal geometry; and six regions form an octahedral geometry.
28. Electron-pair geometry around the central atom is not the same thing as its molecular structure. Molecular structure describes the location of the atoms, not the electrons.
29. The structure that includes only the placement of the atoms in the molecule is called the molecular structure.
30. The electron-pair geometries will be the same as the molecular structures when there are no lone electron pairs around the central atom, but they will be different when there are lone pairs present on the central atom.

31. The presence of lone-pair electrons around the central atom in a molecular structure influences the shape of the molecule.
32. VSEPR theory predicts the distortions from the ideal angles by establishing an order of repulsions and an order of the amount of space occupied by different kinds of electron pairs.
33. The order of electron-pair repulsions from greatest to least repulsion is: Lone pair-lone pair > lone pair-bonding pair > bonding pair-bonding pair. This order of repulsions determines the amount of space occupied by different regions of electrons.
34. A lone pair of electrons occupies a larger region of space than the electrons in a triple bond; in turn, electrons in a triple bond occupy more space than those in a double bond, and so
35. The order of sizes from largest to smallest is: Lone pair > triple bond > double bond > single bond.

Valence bond and molecular orbital theory

1.The valence bond theory explains molecular shapes from the interactions of atomic orbitals.
2. The basic principle of VB theory is that a covalent bond forms when orbitals of two atoms overlap, and the overlap region, which is between the nuclei, is occupied by a pair of electrons.
3.The bond strength depends on the attraction of the nuclei for the shared electrons, so the greater the orbital overlap, the stronger (more stable) the bond.
4.The extent of overlap depends on the shapes and directions of the orbitals; an s orbital is spherical, but p and d orbitals have more electron density in one direction than in another.
5. Thus, whenever possible, a bond involving p or d orbitals will be oriented in the direction that maximizes overlap; however, any other direction would result in less overlap and, thus, a weaker bond.
6. The shape of the molecules/ions through the overlap of orbitals can be determined by considering the valence atomic orbitals in the molecule, which are different from those in the isolated atoms, through the mixing of atomic orbitals to produce new atomic orbitals.
7. The spatial orientations of these new orbitals lead to more stable bonds and are consistent with observed molecular shapes.
8. The process of orbital mixing is called hybridization, and the new atomic orbitals are called hybrid orbitals.
9. Two key points about the number and type of hybrid orbitals are that:

i) The number of hybrid orbitals obtained equals the number of atomic orbitals mixed.

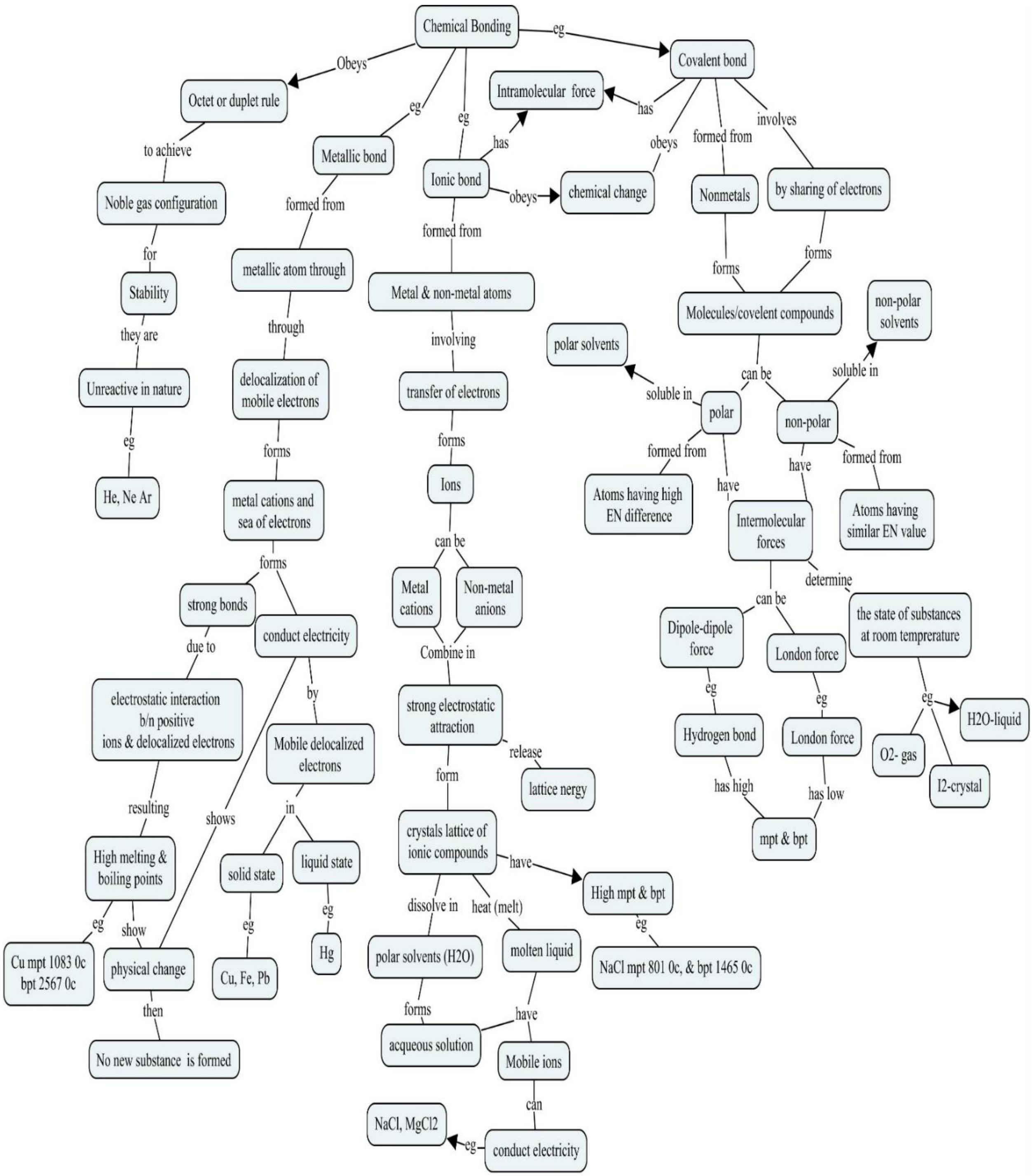
ii) The type of hybrid orbitals obtained varies with the types of atomic orbitals mixed.

10. Hybridization is a process in which atomic orbitals mix, hybrid orbitals form, and electrons enter them with spins parallel (Hund's rule) to create stable bonds.
11. VB theory explains this by proposing that mixing two nonequivalent orbitals of a central atom, one s and one p. gives rise to two equivalent sp hybrid orbitals that lie 180° apart,
12. The mixing of one s and two p orbitals of the central atom gives three hybrid orbitals that point toward the vertices of an equilateral triangle, their axes 1200 ° apart. These are called sp^2 hybrid orbitals.
13. VB theory proposes that the one s and all three p orbitals of the central atom mix and form four sp^3 hybrid orbitals, which point toward the vertices of a tetrahedron to form four sp3 hybrid orbitals.
14. On the other hand, the molecules of lone pairs of electrons at the central atom have sp^3 hybridization with tetrahedral arrangement and different shapes (e.g., the trigonal pyramidal shape of NH_3 arises when a lone pair fills one of the four sp^3 orbitals of N, and the bent shape of H_2O arises when lone pairs fill two of the Sp^3 orbitals of O).
15. The shapes of molecules with trigonal bipyramidal or octahedral electron-group arrangements are rationalized with VB theory through similar arguments.
16. The VB model proposes that the one 3s, the three 3p, and one of the five 3d orbitals of the central P atom mix and form five sp3d hybrid orbitals, which point to the vertices of a trigonal bipyramid.
17. The VB model proposes that the one 3s, the three 3p, and two of the five 3d orbitals of the central S atom mix and form six sp3d2 hybrid orbitals, which point to the vertices of an octahedron.
18. Square pyramidal and square planar molecules have lone pairs in one and two of the central atom's sp3d2 orbitals, respectively.
19. The combination of atomic orbitals on different atoms forms molecular orbitals (MOs), so that electrons in them belong to the molecule as a whole.
20. The number of molecular orbitals (MOs) formed is equal to the number of atomic orbitals that are combined.

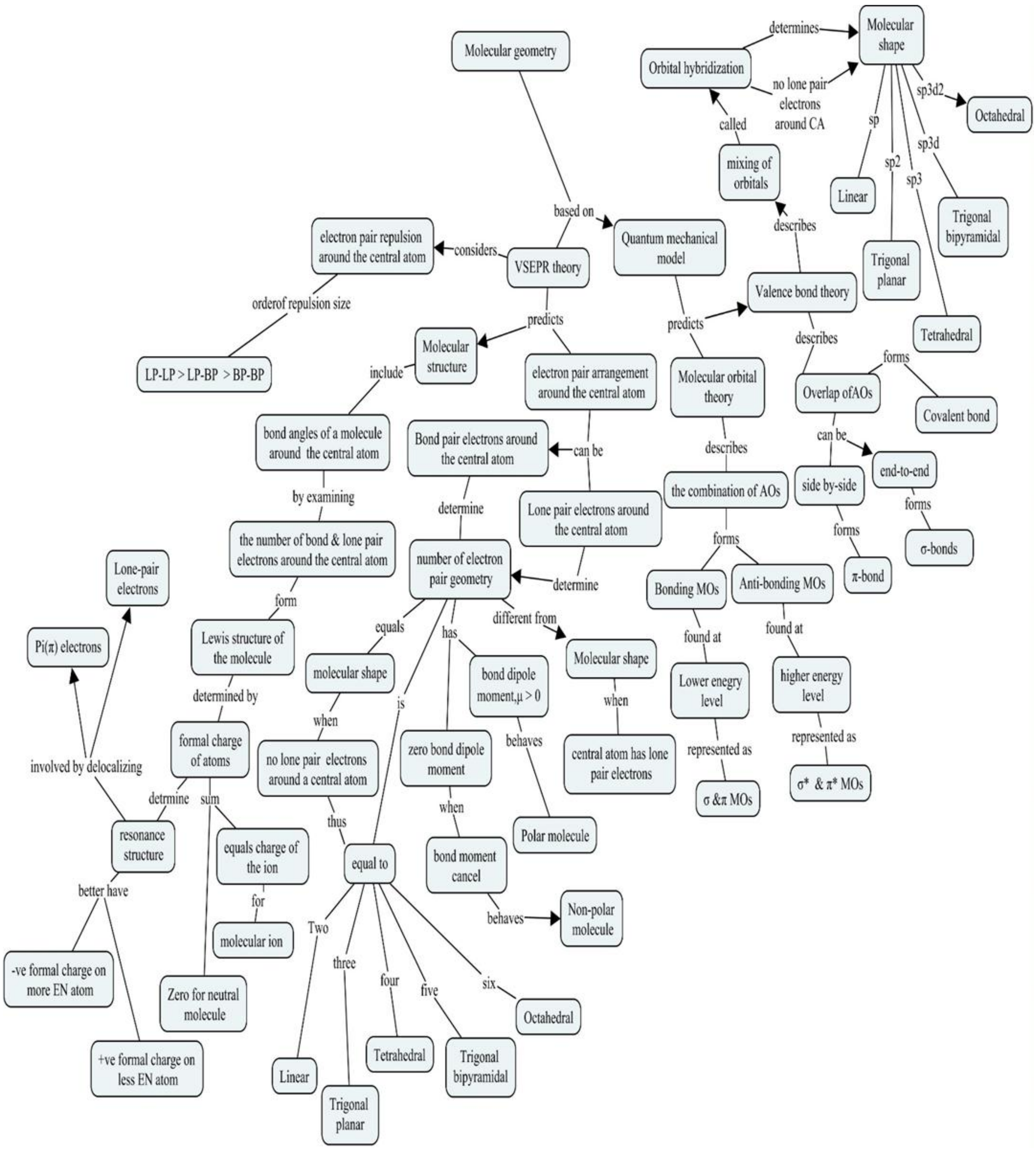
21. When two atomic orbitals are combined, one of the resulting MOs is at a lower energy than the original atomic orbitals; this is a bonding orbital and is highly stable.
22. The other MO is at a higher energy level than the original atomic orbitals; this is an antibonding orbital and is less stable.
23. In VB theory, a molecule is pictured as a group of atoms bound together through localized overlap of valence-shell atomic orbitals.
24. In MO theory, a molecule is pictured as a collection of nuclei with the electron orbitals delocalized over the entire molecule.
25. The molecular orbital formed by the addition of atomic orbitals is called the bonding molecular orbital (δ).
26. The molecular orbital formed by the subtraction of an atomic orbital is called an anti-bonding molecular orbital (δ*).
27. The sigma (δ) molecular orbitals (end-to-end orbital overlap) are symmetrical around the bond axis, while pi (π) molecular orbitals (side-by-side orbital overlap) are not symmetrical.
28. Electrons fill MOs just as they fill AOs:
    i) Orbitals are filled to increase energy (Aufbau principle).
    ii) An orbital has a maximum capacity of two electrons with opposite spins (exclusion principle).
    iii) Orbitals of equal energy are half-filled, with spins parallel, before any is filled (Hund's rule).
29. The order of MO energy levels, whether bonding or anti-bonding, is based on the order of AO energy levels and the mode of the p-orbital combination:
    i) MOs formed from 2s orbitals are lower in energy than MOs formed from 2p orbitals because 2s AOs are lower in energy than 2p AOs.
    ii) Bonding MOs are lower in energy than antibonding MOs, so δ2p < δ*2p and π2p < π*2p in energy.
    iii) Atomic p orbitals can interact more extensively end-to-end than they can side-to-side. Thus, the δ2p MO is lower in energy than the πzp MO. Similarly, the destabilizing effect of the δ*2p MO is greater than that of the π*2p MO.

30. The order of MO energy levels can be represented by the notation: δ1s < δ*1s < δ2s < δ*2s < δ2px < π2py = π2pz < π*2py = π*2pz < δ*2px…………
31. Bond order(B.O.) is defined as one-half the difference between the number of electrons present in the bonding and the anti-bonding orbitals.
32. It is the number of electron pairs being shared by any pair of bonded atoms; a single bond has a bond order of 1, a double bond has a bond order of 2, and a triple bond has a bond order of 3.
33. Bond strength: triple bond > double bond > single bond; bond length: triple bond < double bond < single bond.
34. A bond order equal to zero means that the molecule has equal numbers of electrons in bonding MOs (more stable than in separate atoms) and in antibonding MOs (less stable than in separate atoms). Such a molecule would be no more stable than separate atoms, so it would not exist.
35. A bond order greater than zero means that more electrons occupy bonding MOs (stabilizing) than antibonding MOs (destabilizing).
36. The greater the bond order of a diatomic molecule or ion, the more stable we predict it to be. Likewise, for a bond between two given atoms, the greater the bond order, the shorter the bond length, and the greater the bond energy.
37. The bond order can be calculated as ½ (bonding electrons – antibonding electrons).

Appendix C: Concept Map for Chemical Bonding Concepts



Appendix D: Concept Map for Molecular Geometry Concepts



Appendix E: Three-Tier Conceptual Understanding Diagnostic Test Items

Bahir Dar University

College of Education, School of Teacher Education

Department of Science and Mathematics Education

Instruction: The objective of this test is to collect data concerning your conceptual understanding of chemical bonding and molecular geometry concepts. Your correct and complete answers to the following questions will have great value for this study. Therefore, you are kindly requested to answer all the questions after reading them thoroughly.

Note: 1. No need to write your name

2. Respond to all questions precisely, clearly, and genuinely

3. **Encircle** the letter that corresponds to the best answer for each question

Demographic information:

Name of the University____

ID.No.__________________________Year_________Section_____________Age_______

Gender (Encircle) 1. Male 2. Female

Directions: For the questions below, select the correct answers from the alternatives given for the content knowledge tier (first tier), the reasons for content response or understanding tier (second tier), and the confidence tier (third tier). After selecting the answer, ***encircle*** your choice for both tiers.

1.1 The formation of chemical bond between Mg (Z =12) and Cl (Z =17) atoms is involved by the_______

A. sharing of electrons

B. transfer of electrons

C. presence of electrostatic forces

D. presence of metal ions and electrons

1.2 The reason for your answer is

a. The Mg atom transfers two electrons to be received by the Cl atoms
b. Elements that have different electronegativity can experience the sharing of electrons between elements
c. Metallic elements can bind to each other in the presence of electrical forces between metal ions and free-moving electrons
d. Two elements that tend to be different loads will attract each other to pull so that it can bind

1.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure.

2.1 An atom of Iron (Z=26) loses three electrons and forms an Iron (III) ion (Fe^{+3}). Which one of the following is the correct electronic structure of the ion?

A. $1s^2,2s^2,2p^6,3s^2,3p^6, 4s^1,3d^4$ C. $1s^2,2s^2,2p^6,3s^2,3p^6,4s^2,3d^3$
B. $1s^2,2s^2,2p^6,3s^2,3p^6,4s^2,3d^9$ D. $1s^2,2s^2,2p^6,3s^2,3p^6,4s^0,3d^5$

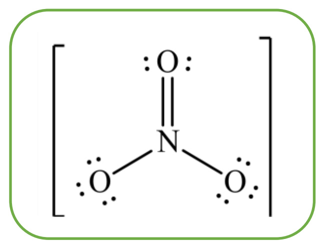
2.2 The reason for your answer is

a. Iron is a transition metal that loses 4s electrons first, then 3d electrons.
b. Iron loses three electrons from the 3d-orbital to be stable.
c. Iron loses two electrons from the 3d-orbital, and then one electron from the 4s orbital.
d. Iron metal accepts three electrons and adds them to its outermost shell to fill its vacant 3d orbitals.

2.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure.

3.1 What is the overall formal charge of the structure indicated?[At. No. N =7, O = 8]



A. 0 B. -1 C. +1 D. +2

3.2 The reason for your answer is

a. Nitrogen atoms contain high electron density in their valence shell
b. The entire structure contains an equal distribution of electrons within atoms.
c. Single-bonded oxygen atoms enable a high distribution of electrons on the given structure
d. The entire structure contains an equal distribution of electrons within atoms.

3.3 Are you sure about your answers to the previous two questions?

(a) I am sure (b) I am not sure.

4.1 Which one of the following molecules has a high bond polarity?

A. NH_3 B. H_2O C. HF D. H_2S

4.2 The reason for your answer is:

a. The high difference in electronegativity between atoms
b. Because the bond is formed by electron transfer
c. The molecule has a greater number of lone-pair electrons on the central atom
d. A greater number of electron pairs around the central atom

4.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure.

5.1 The compound sodium chloride (NaCl) conducts an electric current when it exists in

A. the solid-state C. state of sublimation
B. solution or molten state D. any state of conditions

5.2 The reason for your answer is:

a. Solid NaCl has fixed electrons in its bonds, whereas electrons are free and conduct electricity.
b. Sublimation of solid NaCl can release more electrons and then conduct electricity.
c. NaCl dissociates into Na^+ ions and Cl^- ions, which are moving charges, and then conduct electricity
d. NaCl is a molecular substance containing molecules that can conduct electricity in all conditions

5.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure.

6.1 The bromide ion (Br^-) is one of the anions readily absorbed by colloidal peat soils to increase the productivity of the plant. Some of the following compounds contain bromide nutrients:

I) $CaBr_2$ II) HCN III) NH_4Br IV) HBr

Which of the above compounds are ionic compounds?

A. I and II B. I and III C. I, II, and III D. I, II, III, and IV

6.2 The reason for your answer is:

a. $CaBr_2$ and HCN are ionic compounds because they consist of metals and non-metals.

b. $CaBr_2$, HCN, NH_4Br, and HBr are covalent compounds because they consist of non-metals.

c. $CaBr_2$ and NH_4Br are ionic compounds because they consist of cations and anions and are held by ionic bonds.

d. All compounds are ionic compounds because they consist of cations and anions.

6.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure.

7.1 Sodium iodide (NaI) can be dissolved in:

A. polar solvents B. non-polar solvents C. whatever solvent D. Insoluble in whatever solvent

7.2 The reason for your answer is:

a. NaI is insoluble in polar solvents due to covalent bonds between sodium and iodine atoms.

b. NaI is soluble in nonpolar solvents since sodium transfers its valence electron to iodine to form a molecule of NaI.

c. NaI is soluble in polar solvents due to its ionic nature; Na^+ cations are attracted to the negative end of the solvent dipole, while I^- anions are attracted to the positive end

d. NaI is soluble in both polar and nonpolar solvents because it is an instantaneous process.

7.3 Are you sure about your answers to the previous two questions?

(a) I am sure (b) I am not sure.

8.1 When two neutral atoms of different non-metallic elements reacted to form____________

A. Ionic bond B. Covalent bond C. Metallic bond D. Both ionic and covalent

8.2 The reason for your answer is:

a. Two atoms need to be together to increase their ionic properties.

b. Two atoms approach each other, and electrons (s) from each atom start to be attracted to the nucleus of the other atom, producing a molecule.

c. Two atoms react by the transfer of electrons to reach their most stable state.

d. Both atoms have incomplete-filled shells; therefore, the two atoms share electrons donated from one of these atoms to form a bond.

8.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure.

9.1 Water (H_2O) and hydrogen sulfide (H_2S) have similar chemical formulae and have V-shaped structures. At room temperature, water is a liquid, and hydrogen sulfide is a gas. This is due to the presence of high intermolecular forces between:

A. H_2O molecules B. H_2S molecules

9.2 The reason for your answer is:

a. The difference is due to differences in the strength of the O—H and S—H covalent bonds.
b. The bonds in H_2S are easily broken, whereas in H_2O they are not.
c. The difference is due to the difference in polarity of the molecules.
d. The difference is because H_2O is a polar molecule, and H_2S is a non-polar molecule.

9.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure.

10.1 At room temperature, NaCl exists as

A. a molecule B. an ionic compound C. a molecular lattice D. Na^+ and Cl^- ions

10.2 The reason for your answer is:

a. The Na atom shares a pair of electrons with the Cl atom to form a simple molecule.
b. After donating its electron to the Cl atom, the Na^+ ion forms a molecule with a Cl^- ion.
c. NaCl exists as a lattice consisting of Na^+ ions and Cl^- ions.
d. NaCl exists as a lattice consisting of covalently bonded Na and Cl atoms.

10.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure.

11.1 An atom of element A has two valence electrons, while an atom of element B has five valence electrons. When element A reacts with element B, the compound will be_________

A. Covalent compound C. Coordinate covalent compound

B. Ionic compound D. Metallic complex compound

11.2 The reason for your answer is

a. An atom of element A and two atoms of element B combine through the sharing of electrons.
b. An anion of element A and a cation of element B combine through the transfer of electrons.

c. Three cations of element A and two anions of element B combine through the transfer of electrons.

d. Three atoms of element A and two atoms of element B combine through the sharing of electrons.

11.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure.

12.1 Which one of the following groups contains all compounds with both ionic and covalent bonds?

A. NH_4Cl, KCN, $NaNO_3$ B. NaCl, Mg_3N_2, KBr C. H_2SO_4, NH_3 , PCl_5 D. H_2O_2, CO_2, CaO_2

12.2 The reason for your answer is

a. The compounds contain metal and nonmetal ions.
b. The compounds contain positive and negative ions, as well as covalently bonded atoms.
c. The compounds are formed from the combination of non-metal electrons and their nuclei.
d. The compounds are formed from the electrostatic forces of metal cations and delocalized electrons.

12.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure.

13.1 Which of the following is in increasing order of the melting points of the elements?

A. Al, Mg, Na B. Al, Na, Mg C. Mg, Al, Na D. Na, Mg, Al

13.2 The reason for your answer is

a. The fewer electrons a metal can release, the lower the density of the electron cloud and the weaker the metallic bond.
b. The more electrons a metal can release, the higher the density of the electron cloud and the stronger the metallic bond.
c. The more reactive metals can release electrons easily and hold tightly to their nuclei to form strong metallic bonds.
d. The metal releases fewer electrons with its large atomic size, which enables its nuclei to be held strongly by a sea of delocalized electrons to form strong metallic bonds.

13.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure.

14.1 Which one of the following best describes the process of energy change during bond formation in a chemical reaction?

A. Energy is released. C. Energy is both absorbed and released

B. Energy is absorbed. D. Energy is neither absorbed nor released

14.2 The reason for your answer is:

a. When bonds are formed, energy may be absorbed or released.
b. Energy is released when chemical bonds are formed, and the system becomes more stable.
c. Energy can be neither created nor destroyed; therefore, there are no overall energy changes.
d. Energy is required to form bonds in the products of a reaction. That energy is stored in the bonds.

14.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure.

15.1 What is the central atom of the formaldehyde (CH_2O) molecule in its Lewis structure?

A. Hydrogen (H) B. Carbon (C) C. Oxygen (O) D. Both Carbon (C) & Oxygen(O)

15.2 The reason for your answer is

a. The atom is relatively less electronegative and can share electrons with the other atoms, and the Lewis structure is consistent with formal charges.
b. The high electronegative oxygen atom contains an adequate number of valence electrons that can be shared with terminal atoms in a molecule to accommodate its octet.
c. The molecule has two central atoms that share three pairs of electrons to accommodate their octet with consistent formal charges in its Lewis structure.
d. One of the hydrogen atoms in a molecule can be the central atom and can share electrons with other atoms to fulfill its octet.

15.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure.

16.1 Which one of the following molecules is non-polar with polar bonds?

A. CH_4 B. CO_2 C. SO_3 D. CH_3Cl

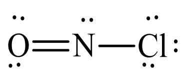
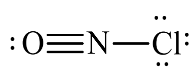
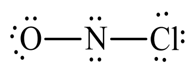
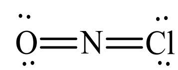
16.2 The reason for your answer is

a. The bond moments cancel due to its linear molecular geometry
b. The electronegativity difference between bonded atoms shows that each of these bonds has a zero-dipole moment to develop polar bonds.
c. The bonds in a molecule are arranged such that their bond moments reinforce each other.
d. The influence of lone-pair and bond-pair electrons on the central atom of the molecule.

16.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure.

17.1 The most acceptable Lewis structure of the molecule NOCl is [Atomic No. O = 8; Cl = 17; N = 7]

A.  B.  C.  D. 

17.2 The reason for your answer is

a. The formal charge of all atoms equals zero, with the least electronegative atom at the center.
b. All atoms of the molecule obey the octet rule and are stabilized by filling their outer shells.
c. The most electropositive atom bears a negative formal charge, while the least electronegative atom bears a positive formal charge.
d. The central atom is the most electronegative atom that can be bonded to other atoms.

17.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure.

18.1 Which one of the following is true about BF_3 and NH_3 molecules? [At. No. B=5, F=9, N=7, H=1]

A. BF_3 and NH_3 have the same molecular geometry and shape.
B. BF_3 and NH_3 have the same electronic arrangement that determines their geometry and shape.
C. BF_3 and NH_3 have different molecular geometries and shapes.
D. BF_3 and NH_3 are polar molecules.

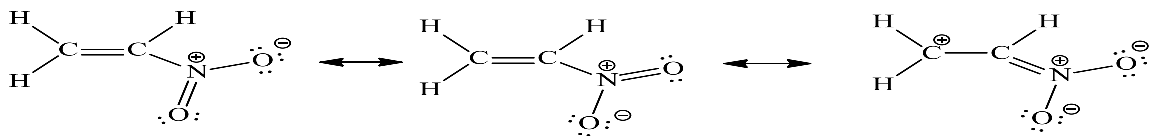
18.2 The reason for your answer is that both molecules

a. have the same number of bonding electrons.
b. have different numbers of lone pair and bonding pair electrons around their central atom.
c. have the same number of lone pair and bond pair electrons around their central atom.
d. contain atoms that have a high electronegativity difference to experience an equal sharing of electrons for the survival of their entire molecule.

18.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure.

19.1 The nitroethene (CH_2=$CHNO_2$) molecule has three resonance contributors shown below



I II III

Which are the most important resonance contributors?

A. I and II B. I and III C. II and III D. I, II and III

19.2 The reason for your answer is

a. Resonance contributors have more charges and fewer bonds than other structures.
b. Resonance contributors have a greater separation of charges on atoms than other contributors.
c. A more negative formal charge resides on a less electronegative atom, while a positive formal charge resides on a more electronegative atom.
d. Resonance contributors have relatively larger numbers of covalent bonds (sigma and pi) than others.

19.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure.

20.1 Consider the structure of cyanic acid $H-\ddot{\underset{\cdot\cdot}{O}}-C\equiv N:$, then the number of sigma (δ) and pi(π) bonds are __________ and _____respectively.

A. 5 and 2 B. 5 and 3 C. 2 and 3 D. 3 and 2

20.2 The reason for your answer is

a. Because overlapping orbitals (ends) result in sigma (δ) bonds while overlapping orbitals (sides) of two parallel orbitals result in pi (π) bonds.

b. End-to-end overlapping orbitals result in pi (π) bonds while side-by-side overlapping orbitals result in sigma (δ) bonds.

c. The bond is formed from three pairs of electrons, containing two sigma(δ) bonds, while the bond formed from a pair of electrons contains pi (π) bonds.

d. The entire molecule contains two single bonds and one triple bond, with three lone pair electrons that can form orbital overlapping bonds.

20.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure.

21.1 One of the following molecules has a dipole moment [At. No. B =5, F=9, Cl =17,N=7,C=12, Be =4]

A. BF_3 B. CH_4 C. NH_3 D. $BeCl_2$

21.2 The reason for your answer is

a. The BF_3 molecule is symmetrical, the B-F bonds reinforce each resulting in a non-zero dipole moment.

b. NH_3 is a polar molecule due to the electronegativity difference between N and H atoms, resulting in a non-zero dipole moment

c. In the CH_4 molecule, each bond pair is asymmetrically arranged results net dipole moment > 0.

d. The $BeCl_2$ molecule contains a highly electronegative Cl atom, so the Be-Cl bond is polar results a non-zero dipole moment

21.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure.

22.1 Which of the following is true about H_2O and BeH_2 molecules? [At. No. H = 1, O =8, Be = 4]

A. The H-O-H molecule is bent, whereas the H-Be-H molecule is linear.

B. Both have equal bond angles with the same electron pair geometry.

C. They have the same number of electron pairs, geometry, and molecular shape.

D. The terminal atoms of each molecule are forced equally by their central atom.

22.2 The reason for your answer is:

a. The central atom of each molecule is bonded with the same terminal atoms of equal magnitude.
b. The molecules have the same electron pair rearrangement that determines their shape.
c. The difference in lone-pair electrons around the central atoms experiences repulsion with bonded pair electrons in H_2O compared to BeH_2
d. The molecules have no lone pair electrons around their central atom that can experience the repulsive force between them.

22.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure.

23.1 Which one of the following is true about NH_3 and CH_4 molecules?

A. They have the same molecular shape and polarity
B. They have the same electron pair geometry
C. They have different orbital hybridizations
D. The H–N–H angle in NH_3 is larger than the H–C–H bond angle in CH_4

23.2 The reason for your answer is

a. The influence of lone pair electrons on the bond pair electrons in NH_3 but not in CH_4
b. The weaker repulsion force between lone-pair and bond-pair electrons in NH_3 than in CH_4
c. The influence of unhybridized $2p_z$ orbital in CH_4 molecules than NH_3
d. The molecules have different electron pair geometries and the same molecular shape

23.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure.

24.1 Which one of the following ions has a trigonal planar shape? [At. No. S = 16, O =8, N =7, C = 6, H =1]

A. SO_3^{2-} B. NH_4^+ C. NO_2^- D. CO_3^{2-}

24.2 The reason for your answer is:

a. The ion occurs in a structure with three bond pairs and no lone-pair electrons around the central atom
b. The ion contains three terminal atoms bonded to the central atom with lone-pair electrons

c. The central atom is bonded to three identical atoms that have pi(π) bonding interactions
d. The ion has more lone-pair electrons in the center and influences the three bond-pair electrons.

24.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure.

25.1 For which of the following substances is the highest energy required to convert one mole of the solid into separate ions [At. No. Mg =12, O =8, Sr = 38, K=19, F= 9]

A. MgO B. KF C. SrO D. MgF_2

25.2 The reason for your answer is:

a. MgO has higher charges (+2 and -2) and smaller ionic radii than the given compounds
b. MgF_2 has +2 charge on Mg^{2+} , though F^- ions have a smaller radius compared to O^{2-} ion
c. SrO has high charges (+2 and -2), but Sr^{2+} has a larger radius, making it hard to separate.
d. KF has high lattice energy due to the +1 and -1 charges and the larger ionic radius of K^+ .

25.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure.

26.1 Given the bond energies H-H = 436KJ/mol, F-F = 160 KJ/mol and H-F = 569kJ/mol, for the reaction $H_2 + F_2 \rightarrow 2HF$. The approximate enthalpy change, ΔH, for this reaction is___________

A. +1734KJ/mol B. +565KJ/mol C. -542KJ/mol D. -293KJ/mol

26.2 The reason for your answer is

a. The bonds in the products are stronger than the reactants, so the reaction releases more energy than it consumes.
b. The bonds in the reactants are stronger than in the products, so the reaction absorbs more energy than it releases.
c. The bond energy required to break the bond between the two reactants is greater than that of the products.
d. Because the reaction contains equal numbers of molecules on both sides, an equal amount of bond energy is required to break the bonds.

26.3 Are you sure about your answers to the previous two questions?

(a) I am sure. (b) I am not sure

Appendix F: Five-Point Likert Scale Student Engagement Survey (SES) items

Bahir Dar University

College of Education, School of Teacher Education

Department of Science and Mathematics Education

Instruction: The objective of this questionnaire is to collect data concerning your engagement in learning chemical bonding and molecular geometry topics. Your correct and complete answers to the following items will have great value for this study. Therefore, you are kindly requested to answer all the questions after reading them thoroughly.

Note: 1. No need to write your name

2. Respond to all questions precisely, clearly, and genuinely

I. Demographic information:

Name of the University____

ID.No.__________________Year____________Section____________________Age_________

Gender (Encircle) 1. Male 2. Female

Direction: For each item, indicate your response using the tick (√) mark under the five alternatives given below. The five alternatives are:

1. Strongly Disagree 2. Disagree 3. Neutral 4. Agree 5. Strongly Agree

No.	**Items**	5	4	3	2	1
1	I go through the work for the chemical bond and molecular geometry class and make sure that it's right					
2	I didn’t pay attention to the learning of chemical bond and molecular geometry topics					
3	I found ways to make the chemical bond and molecular geometry topics relevant to me					
4	I didn’t talk to other students about the chemical bond and molecular geometry topics					
5	I reviewed my course notes to make sure I mastered the chemical bond and molecular geometry content					
6	I felt comfortable talking to the other students in the chemical bond and molecular geometry topics					
7	I spent time on the chemical bond, chemical bond, and molecular geometry topics					

8	I felt intrigued by the activities in the chemical bond and molecular geometry topics					
9	I think about different ways to solve chemical bond and molecular geometry problems					
10	I tried to understand the complex concepts in the chemical bond and molecular geometry topics					
11	I was interested in the chemical bond and molecular geometry topics					
12	I felt that my point of view was considered by the other students in the chemical bond and molecular geometry topics					
13	I try to connect what I am learning about chemical bonds and molecular geometry to things I have learned before					
14	I didn't want to master the content of the chemical bond and molecular geometry topics					
15	I don't have fun with the chemical bond and molecular geometry topics					
16	I felt connected to the group of students in the chemical bond and molecular geometry topics					
17	I did my best in the chemical bond and molecular geometry topics					
18	I try to understand my mistakes when I get something wrong in learning about chemical bonds and molecular geometry topics.					
19	I looked forward to the activities in the chemical bond and molecular geometry topics					
20	I keep trying, even if something is hard in learning about chemical bond concepts					
21	I felt completely absorbed in the chemical bond and molecular geometry activities					
22	I discussed the chemical bond and molecular geometry topics with other students outside of class activities					
23	I tried to apply the content of the chemical bond and molecular geometry topics to other professional or personal situations					
24	I want to understand what is learned in chemical bond and molecular geometry topics					
25	I don't like working with classmates in learning chemical bonding and molecular geometry					

26	I didn’t want to explore topics related to the chemical bond and molecular geometry topics					
27	I think that the chemical bond and molecular geometry topics are boring					
28	I frequently interacted with my instructor on these chemical bond and molecular geometry topics.					
29	I developed better judgment skills in the chemical bond and molecular geometry topics					
30	The instructor didn’t provide timely feedback about my progress in the chemical bond and molecular geometry topics					
31	I learned from the feedback that was provided during the chemical bond and molecular geometry topics.					

Can you describe how engaged you felt while learning the concepts of chemical bonding and molecular geometry in your chemistry classes? Please feel free to share any additional thoughts or comments about your learning experience.

____

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Appendix G: Five-Point Likert Scale CLASS-Chem (EBS) items

Bahir Dar University

College of Education, School of Teacher Education

Department of Science and Mathematics Education

The objective of this questionnaire is to collect data concerning your **epistemological beliefs** about learning chemical bonding and molecular geometry courses. Your correct and complete answers to the following items will have great value for this study. Therefore, you are kindly requested to answer all the questions after reading them thoroughly.

Note: 1. No need to write your name

2. Respond to all questions precisely, clearly, and genuinely

I. Demographic information:

Name of the University____

ID.No.____________________Section_______________Age__________

Gender (Encircle) 1. Male 2. Female

Instructions: For each item, indicate your response using the tick **(√)** mark under the five alternatives given below. The five alternatives are:

1. **Strongly Disagree** **2. Disagree** **3. Neutral** **4. Agree** **5. Strongly Agree**

No.	Measurement Items	5	4	3	2	1
1	A significant problem in learning chemistry (chemical bonding and molecular geometry) is being able to memorize all the information I need to know					
2	To understand a chemical reaction, I think about the interactions between atoms and molecules					
3	I think about the chemistry (chemical bonding and molecular geometry) experience in everyday life					
4	After I study a topic in chemistry (chemical bonding and molecular geometry) and feel that I understand it, I have difficulty solving problems on the same topic.					
5	Knowledge of chemistry(chemical bonding and molecular geometry)consists of many disconnected topics					
6	I think about how the atoms are arranged in a molecule to help my understanding of its behavior in chemical reactions					

7	If I have not memorized the chemical behavior needed to answer a question on an exam, there's nothing much I can do (legally!) to figure out the behavior					
8	In learning about chemical bonding and molecular geometry, I am not satisfied until I understand why something works the way it does					
9	I do not expect equations to help my understanding of the ideas in chemistry(chemical bonding and molecular geometry)they are just for doing calculations					
10	I study chemistry (chemical bonding and molecular geometry) to learn knowledge that will be useful in my life outside of college/University					
11	In learning about chemical bonding and molecular geometry, I can usually make sense of how two chemicals react with one another					
12	If I get stuck on a chemistry (chemical bonding and molecular geometry) problem on my first try, I usually try to figure out a different way that works					
13	Nearly everyone is capable of understanding chemistry (chemical bonding and molecular geometry) if they work at it					
14	In learning chemistry(chemical bonding and molecular geometry), why chemicals react the way they do not usually make sense to me; I just memorize what happens.					
15	If I don't remember a particular equation needed to solve a chemistry problem on an exam, there's nothing much I can do (legally!) to come up with it					
16	If I want to apply a method used for solving one chemistry (chemical bonding and molecular geometry) problem to another problem, the problems must involve very similar situations					
17	In doing a chemistry (chemical bonding and molecular geometry) problem, if my calculation gives a result very different from what I'd expect, I'd trust the calculation rather than going back through the problem					
18	In chemistry(chemical bonding and molecular geometry), I need to make sense of formulas before I can use them correctly					
19	I enjoy solving chemistry (chemical bonding and molecular geometry) problems					
20	When I see a chemical formula, I try to picture how the atoms are arranged and connected					
21	In chemistry(chemical bonding and molecular geometry), mathematical formulas express meaningful relationships among measurable quantities					
22	The arrangement of the atoms in a molecule determines its behavior in					

	chemical reactions					
23	Learning chemistry (chemical bonding and molecular geometry) changes my ideas about how the world works					
24	Reasoning skills used to understand chemistry (chemical bonding and molecular geometry) can be helpful to me in my everyday life					
25	In learning chemistry(chemical bonding and molecular geometry), I usually memorize reactions rather than make sense of the underlying physical concepts.					
26	In learning chemistry(chemical bonding and molecular geometry), spending a lot of time understanding where mathematical formulas come from is a waste of time					
27	I can usually figure out a way to solve chemistry (chemical bonding and molecular geometry) problems.					
28	The subject of chemistry (chemical bonding and molecular geometry)has little relation to what I experience in the real world					
29	There are times I solve a chemistry (chemical bonding and molecular geometry) problem in more than one way to help my understanding					
30	To understand chemistry(chemical bonding and molecular geometry) I sometimes think about my personal experiences and relate them to the topic being analyzed.					
31	Thinking about a molecule's three-dimensional (3D) structure is important for learning chemistry (chemical bonding and molecular geometry)					
32	When I solve a chemistry (chemical bonding and molecular geometry) problem, I explicitly think about which chemistry ideas apply to the problem					
33	If I get stuck on a chemistry (chemical bonding and molecular geometry) problem, there is no chance I'll figure it out on my own					
34	In learning chemistry (chemical bonding and molecular geometry), spending a lot of time understanding why chemicals behave and react the way they do is a waste of time					
35	When studying chemistry(chemical bonding and molecular geometry), I relate the important information to what I already know rather than just memorizing it the way it is presented.					
36	When I'm solving chemistry (chemical bonding and molecular geometry) problems, I often don't understand what I am doing					

Please share any additional comments on your beliefs about the nature of knowledge, ways of knowing, and learning processes related to chemical bonding and molecular geometry.____

____

Appendix H: Semi-structured Interview Questions for Conceptual Understanding

1. What is chemical bonding? Why are atoms combined? How are they formed
2. What is the difference between ionic and covalent compounds? Mention the classification of compounds as ionic, covalent, and metallic bonds with examples. Why do they differ?
3. How would you describe molecular geometry and polarity? Can you explain how molecular geometry and polarity are connected to electron pair geometry?
4. Describe molecular geometry and polarity. What is the relationship between molecular geometry and polarity, and electron pair geometry?

Appendix I: Semi-structured Interview Questions for Student Engagement

1. Does the learning approach used in a lesson delivery affect your understanding and retention of the CBMG concepts? Please describe how this learning approach has affected your learning. Why?
2. How would you describe your level of engagement when learning CBMG concepts during classroom lessons? Can you describe a specific moment when you felt especially engaged with this topic? What aspects of that experience do you think contributed to your engagement? Why?
3. Would you describe your learning experience with CBMG concepts as active and meaningful? Could you share specific examples of how you engaged in the learning process, such as completing assignments, asking questions, participating in discussions, collaborating with your peers, or relating CBMG concepts to real-life situations and applications?
4. Do you believe that the learning process in CBMG has influenced your interactions with your peers and instructors? Do you feel more or less connected to others? How has this sense of connection affected your willingness to collaborate or participate in classroom discussion?
5. Would you describe your learning experience with CBMG concepts as active and participatory? Could you share specific examples of how you engage in the learning process, such as completing assignments, asking questions, participating in discussions, or working collaboratively with your peers?

Appendix J: Semi-structured Interview Questions for Epistemological Beliefs

1. How do you view the process of learning CBMG concepts? Do you see it as mostly memorizing facts, or do you feel it involves understanding and applying concepts?
2. Does learning CBMG influence the effort you put into making sense of complex concepts? Do you find the learning structure encourages more effort in understanding difficult topics?
3. When solving CBMG problems, do you feel it is more important to find the right answer quickly or to understand the process? Can you describe a time when you worked through a challenging problem?
4. Can you describe a time when you made a meaningful connection between two ideas or concepts from different areas of study or experience? How did the connection influence your understanding or approach to the CBMG topic?

Appendix K: Classroom Observation Checklists

Bahir Dar University

College of Education, School of Teacher Education

Department of Science and Mathematics Education

Name of the Univeristy:____

Region:_____________________________________ Group_______________

Address: _____________________________________

Name of the Instructor:________________________

Subject of Instruction:____________________ Duration of Observation:_____________

Name of Observer: ____________________________Date of Observation:____________

No.	Statements	Rating scale			Comments
	Instructional Design	Yes	No	Partly	
1	The instructional strategy demonstrates clear signs of planning and organization and follows a logical flow.				
2	The instructor introduces the learning objectives for this learning session, which are visible to participants.				
3	Instructional strategy provides variety in visual, textual, kinesthetic, and/or auditory activities to enhance students' learning and accessibility.				
4	Materials are made available to help students who cannot be online or have a technical difficulty (e.g., a recording of a live class is given after class for viewing, and materials for performing offline are made available)				
	Time Management				
5	The Lesson delivery session starts and ends on time.				
6	The instructor leaves time for questions, discussion/or summarizing the session of this instructional strategy.				
7	The instructor maximizes in-class time by using active learning or applications in the lesson delivery.				
8	The instructor indicates time limits for all students' activities, using a time-based agenda, and visual and auditory prompts in the lesson delivery				
9	Instructors can troubleshoot typical software and hardware problems without losing instructional time.				
10	The instructor has prepared prompt activities relevant to the lesson and gathered needed materials before the start of class.				
	Learning Environment				
11	The instructor reviews the use of technology properly and the expectations for engagement and behavior.				
12	The instructor relates today's lesson to previous/future				

	lessons.				
13	The instructor connects course content to career or real-world skills.				
14	The instructor creates opportunities for interaction between students (collaborative).				
15	The instructor checks for responsiveness (demonstrated through body language, nods, simple checks, and thumbs up to signal affirmation).				
16	The instructor uses active-learning exercises in balance with teacher-led presentations in appropriate relation to students' ages and the nature of the lesson.				
17	Before sending students to active learning tasks (group work, paired discussions, team problem-solving), the instructor provides explicit modeling and instructions.				
18	The instructor monitors and manages active-learning exercises in the lesson delivery.				
19	Students engage in active learning tasks that are goal-oriented, focused, project-based, and inquiry-oriented.				
20	The instructor promotes individualized learning in this session.				
21	The instructor utilizes appropriate tools and materials to motivate learners (interactive or competitive videos).				
22	Encourages non-participating students to engage in activities and discussions while preventing a small number of students from dominating them.				
23	The instructor builds pauses in the lesson to provide opportunities for students to ask questions and promptly respond to them.				
	Assessment and Feedback				
24	The instructor provides class-general constructive and encouraging feedback on how to improve their comprehension or performance in class.				
25	The instructor attends respectfully to students' comprehension or puzzlement.				
26	The instructor prompts all students equally for responses to questions during instruction				
27	Types of assessments are suitable for this instructional environment and provide immediate feedback.				
28	The instructor assesses students both informally and formally within learning through the use of games, quizzes, online tests, etc.				
29	The instructor seeks feedback from students on lessons, ease of learning, and accessibility of the course.				

Appendix L: Ethical Clearance Letter from the School of Teacher Education

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School of Teacher Education
Bahir Dar University
Bahir Dar, Ethiopia

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ቁጥር/Ref No./: መ/ት/ት/ 112 / 28 /16
ቀን፡ 15 / 11 / 2016 E.C.

ለኢትዮጵያ አልባሳት እና ፋሽን ቴክኖሎጂ ኢንስቲቲዩት
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ጉዳዩ፡ ትብብር እንዲደረግ ስለመጠየቅ፤

ከላይ በርዕሱ ለመግለፅ እንደተሞከረው ተማሪ ወረታው አጥናፍ በባህርዳር ዩኒቨርሲቲ ትምህርት ኮሌጅ የሂሳብና ሳይንስ ስነ-ትምህርት ት/ክፍል የ3ኛ ዲግሪ ተማሪ ሲሆን የጥናትና ምርምር ስራውን *"The Effect of Blended Learning in Chemistry Learning and University Students Conceptual Understanding, Engagement and Epistemological Beliefs"* በሚል ርዕስ በICT በመታገዝና የዩኒቨርሲቲ ተማሪዎችን በማሳተፍ እያካሄደ ይገኛል። ጥናቱን የሚያከናዉነዉ አንደኛ ዓመት ተማሪዎች ላይ ነዉ። ስለሆነም ስራዉን ተግባራዊ ለማድረግ የዩኒቨርሲቲውን ኮምፒዩተር ላብ (Computer laboratory/digital laboratory) መጠቀም ስለሚያስፈልገው ከዚህ በታች የተዘረዘሩትን ነገሮች ማለትም፦

1ኛ. የዩኒቨርሲቲውን በይነ-መረብ (E-learning platform)
2ኛ. በአማካይ ከ50-60 ተማሪዎች Username እና password (ለእያንዳንዳቸው)
3ኛ. ለሰባት ሳምንት (በሳምንት አንድ ቀን ከ2:00 - 3:00 ሰዓት ያህል የኮምፒዩተር ላቦራቶሪውን (Computer lab/digital laboratory) ለመጠቀም አስፈላጊ በመሆኑ ትብብር እንዲደረግለት በአክብሮት እንጠይቃለን።

ከሰላምታ ጋር

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Bahir Dar University College of Education School of Teacher Education

ግ//
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መልሱን ሲጽፉልን እባክዎን የእኛን ቁጥር ይጥቀሱ
In replying, please quote our ref. No.

Appendix M: Consent from Instructors

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የመምህራን ትምህርት ት/ቤት

የሳይንስና ሂሳብ ትምህርት ት/ክፍል

ውድ መምህር (Dear instructor)

እኔ የባህርዳር ዩኒቨርሲቲ በሳይንስና ሂሳብ ትምህርት ክፍል የ3ኛ ዲግሪ ተማሪ ስሆን የመመርቂያ ጥናትን ምርምር በመስራት ላይ እገኛለሁ፤ የዚህ ጥናት ዋና አላማ የዩኒቨርሲቲ ተማሪዎች የተለያዩ የማስተማር ዘዴዎችን (conventional and E-learning) በመጠቀም የኬሚስትሪ ትምህርታቸውን ማሻሻል ነው፡፡ይህ ቅፅ በምረምር ለመሳተፍ ፍቃደኝነትን ለመጠየቅ የተዝጋጀ ነው፡፡ የጥናቱ ርዕስ “The Effects of Blended Learning on Undergraduate Students’ Conceptual Understanding, Engagement, and Epistemological Beliefs in Chemical Bonding and Molecular Geometry Concepts: The Case of Ethiopian Higher Education” ነው፡፡ ጥናቱ በዩኒቨርሲቲ የትምህርት ፕሮግራም መሰርት የሚከናዎን ነው፡፡ ነገር ግን የማስተማር ዘዴን በመጠቀም አንዳንድ ጊዜ ቪዲዮ መቅረፅ፤ ክፍል ምልከታ ማድረግ ፈተናዎችን መፈተንና መጠይቆች መረጃ መሰብሰብ ሂደቶች ይኖራሉ፡፡ በጥናቱ ሂደት ይሁን ዉጤት ሲገለፅ ስም አይገለፅም በኮድ ነው የሚሰራው፡፡ ጥናቱ በርስዎ ላይ የሚያስከትለው ወጭና ጉዳት አይኖርም፡፡ ነገር ግን ተማሪዎች እንዴት መማር እንዳለባቸው እንዲያዉቁና የትምህርቱን ፅንሰ ሃሳብ በE-learning በመታገዝ እንዲረዱና በኬሚስትሪ ትምህርት ጥሩ ውጤት እንዲያስመዘግቡ ይረዳቸዋል ተብሎ ይገመታል፡፡ ስለ ጥናቱ ያለዎትን ማነኛዉም ጥያቄና አስተያየት ካለዎት በማነኛዉም ጊዜ መጠየቅ ይችላሉ፡፡

ስለትብብርዎ በቅድሚያ አምሰግናለሁ፡፡

የአጥኝው ስም፡ ወረታዉ አጥናፍ ምህረቱ

ፊርማ ____

ቀን____

የአስተማሪው (Instructor’s Name)

ስም ____

ፊርማ____

ቀን____

Appendix N: Consent from Undergraduate Students (Participants)

ባህር ዳር ዩኒቨርሲቲ

ትምህርት ኮሌጅ

የመምህራን ትምህርት ት/ቤት

የሳይንስና ሂሳብ ትምህርት ት/ክፍል

<u>በዩኒቨርሲቲ የምርምር ስምምነት ቅፅ</u>

ውድ ተማሪዎች

እኔ የባህርዳር ዩኒቨርሲቲ የ3ኛ ዲግሪ ተማሪ ስሆን የመመርቂያ ጥናትን ምርምር በመስራት ላይ እገኛለሁ፤ የዚህ ጥናት ዋና አላማ የዩኒቨርሲቲ ተማሪዎች የተለያዩ የማስተማር ዘዴዎችን (conventional and E-learning) በመጠቀም የኬሚስትሪ ትምህርታቸውን ማሻሻል ነው፡፡ይህ ቅፅ በምረምር ለመሳተፍ ፍቃደኝነትን ለመጠየቅ የተዘጋጀ ነው፡፡ የጥናቱ ርዕስ "The Effects of Blended Learning on Undergraduate Students' Conceptual Understanding, Engagement, and Epistemological Beliefs in Chemical Bonding and Molecular Geometry Concepts: The Case of Ethiopian Higher Education" ነው፡፡ ጥናቱ በዩኒቨርሲቲ የትምህርት ፕሮግራም መሰረት የሚከናዎን ነው፡፡ ነገር ግን የማስተማር ዝዴን በመጠቀም አንዳንድ ጊዜ ቪዲዮ መቅረፅ፤ ክፍል ምልከታ ማድረግ ፈተናዎችን መፈተንና መጠይቆች መረጃ መሰብሰብ ሂደቶች ይኖራሉ፡፡ ጥናቱ በፍቃደኝነት ላይ የተመሰረተ ነው፡፡ በጥናቱ ጊዜም ውጤት ሲገለፅ ስማችሁ አይፃፍም ፡፡ በኮድ ነው የሚሰራው፡፡ ከእናንተ የሚሰበሰቡ መርጃዎች ሚስጢራችዉ የተጠበቀ ይሆናል፡፡ ጥናቱ በእናንተ ላይ የሚያስከትለው ወጭና ጉዳት አይኖርም፡፡ ነገር ግን እንዴት መማር እንዳለባችሁ እንድታውቁና በኬሚስትሪ ትምህርት ጥሩ ዉጤት እንድታስመዘግቡ ይረዳችኋል ተብሎ ይጠበቃል፡፡ስለ ጥናቱ ያላችሁን ማነኛዉም ጥያቄና አስተያየት ካችሁ በማነኛዉም ጊዜ መጠየቅ ትችላላችሁ፡፡

ስለትብብራችሁ በቅድሚያ አመሰግናለሁ፡፡

የአጥኘው ስም፡ ወረታዉ አጥናፍ ምህረቱ

ፊርማ ____

ቀን____

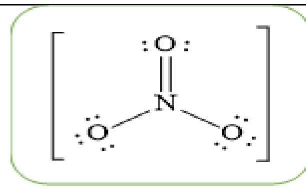
ከላይ የተገለፀዉን አንብቤና የጥናቱን ዓላማ ተረድቸ በጥናቱ ለመሳተፍ ተስማምቻለሁ፡፡

ተ.ቁ	የተሳታፊ ተማሪ ስም	ፊርማ	ተቁ	የተሳታፊ ተማሪ ስም	ፊርማ
1			35		
2			36		
3			37		

4			38		
5			39		
6			40		
7			41		
8			42		
9			43		
10			44		
11			45		
12			46		
13			47		
14			48		
15			49		
16			50		
17			51		
18			52		
19			53		
20			54		
21			55		
22			56		
23			57		
24			58		
25			59		
26			60		
27			61		
28			62		
29			63		
30			64		
31			65		
32			66		
33			67		
34			68		

Appendix O: TTCUDT Items with Misconceptions

No.	Item with choices	IG	CG
Q1.1	The formation of chemical bond between Mg (Z =12) and Cl (Z =17) atoms is involved by the______________________		
	A. sharing of electrons	9.52	13.64
	B. transfer of electrons*	90.48	77.27
	C. presence of electrostatic forces	0.000	2.27
	D. presence of metal ions and electrons	0.000	6.82
Q.1.2	The reason for your answer is		
	a. The Mg atom transfers two electrons to be received by the Cl atoms *	83.33	65.90
	b. Elements that have different electronegativity can experience the sharing of electrons between elements	**11.90**	**13.64**
	c. Metallic elements can bind to each other in the presence of electrical forces between metal ions and free-moving electrons	2.38	**15.91**
	d. Two elements that tend to be different loads will attract each other to pull so that they can bind	2.38	0.000
Q1.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	83.33	88.64
	b. I am not sure.	7.14	11.36
Q2.1	An atom of Iron (Z=26) loses three electrons and forms an Iron (III) ion (Fe^{+3}). Which one of the following is the correct electronic structure of the ion?		
	A. $1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^1, 3d^4$	19.05	0.000
	B. $1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^2, 3d^9$	0.000	0.000
	C. $1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^2, 3d^3$	26.19	27.27
	D. $1s^2, 2s^2, 2p^6, 3s^2, 3p^6, 4s^0, 3d^{5*}$	57.76	72.73
Q2.2	The reason for your answer is		
	a. Iron is a transition metal that loses 4s electrons first, then 3d electrons*	38.10	40.91
	b. Iron loses three electrons from the 3d-orbital to be stable.	**38.10**	**20.45**
	c. Iron loses two electrons from the 3d-orbital, and then one electron from the 4s orbital	2.38	6.82
	d. Iron metal accepts three electrons and adds them to its outermost shell to fill its vacant 3d orbitals.	2.38	9.09
Q2.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	88.09	88.64
	b. I am not sure	11.90	11.36
Q3.1	What is the overall formal charge of the structure indicated?[At. No. N =7, O = 8]		



	A. 0	16.67	27.27
	B. -1*	35.71	43.18
	C. +1	33.33	25.00
	D. +2	14.29	4.55
Q3.2	The reason for your answer is		
	a. The structure contains one extra electron compared to the neutral atoms, resulting in an overall −1 charge.*	21.43	22.73
	b. Nitrogen has high electron density in its valence shell.	**28.57**	**34.09**
	c. The single-bonded oxygen atom determines the overall charge of the ion.	**30.95**	**13.64**
	d. The double bond increases the total number of electrons in the structure.	**16.67**	**29.55**
Q3.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	61.90	36.36
	b. I am not sure	38.10	63.64
Q4.1	Which one of the following molecules has a high bond polarity?		
	A. NH_3	2.38	4.55
	B. H_2O	7.14	29.55
	C. HF*	90.48	65.91
	D. H_2S	0.00	0.000
Q4.2	The reason for your answer is		
	a. The high difference in electronegativity between atoms*	83.33	61.36
	b. Because the bond is formed by electron transfer	0.00	4.55
	c. The molecule has a greater number of lone-pair electrons on the central atom	**7.**14	**13.64**
	d. A greater number of electron pairs around the central atom	0.000	2.27
Q4.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	90.48	70.45
	b. I am not sure	9.52	**29.55**
Q5.1	The compound sodium chloride (NaCl) conducts an electric current when it exists in		
	A. the solid-state	2.38	11.36
	B. solution or molten state *	95.24	84.09
	C. state of sublimation	2.38	2.27
	D. any state of conditions	0.000	2.27
Q5.2	The reason for your answer is:		
	a. Solid NaCl has fixed electrons in its bonds, whereas electrons are free and conduct electricity	0.0000	2.27

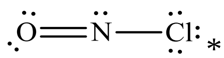
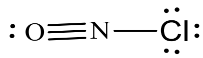
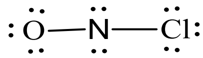
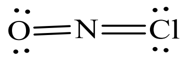
	b. Sublimation of solid NaCl can release more electrons and then conduct electricity	7.14	**11.36**
	c. NaCl dissociates into Na^+ ions and Cl- ions, which are moving charges, and then conduct electricity*	88.10	72.73
	d. NaCl is a molecular substance containing molecules that can conduct electricity in all conditions	0.000	6.82
Q5.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	90.48	90.91
	b. I am not sure	9.52	9.09
Q6.1	The bromide ion (Br^-) is one of the anions readily absorbed by colloidal peat soils to increase the productivity of the plant. Some of the following compounds contain bromide nutrients: I. $CaBr_2$ II) HCN III) NH_4Br IV) HBr Which of the above compounds are ionic compounds?		
	A. I and II	7.76	9.09
	B. I and III*	80.95	61.36
	C. I, II and III	4.76	13.64
	D. I, II III and IV	9.52	15.91
Q6.2	The reason for your answer is:		
	a. $CaBr_2$ and HCN are ionic compounds because they consist of metals and non-metals.	7.48	**17.59**
	b. $CaBr_2$, HCN, NH_4Br, and HBr are covalent compounds because they consist of non-metals.	6.82	**11.25**
	c. $CaBr_2$ and NH_4Br are ionic compounds because they consist of cations and anions and have ionic bonds*	73.29	47.36
	d. All compounds are ionic compounds because they consist of cations and anions.	**12.51**	**23.80**
Q6.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	83.33	61.36
	b. I am not sure	16.67	38.64
Q7.1	Sodium iodide (NaI) can be dissolved in:		
	A. polar solvents*	83.33	59.09
	B. non-polar solvents	16.67	34.09
	C. whatever solvent	0.000	0.000
	D. Insoluble in any solvent	0.000	6.82
Q7.2	The reason for your answer is:		
	a. NaI is insoluble in polar solvents due to covalent bonds between sodium and iodine atoms.	2.38	6.82
	b. NaI is soluble in nonpolar solvents since sodium transfers its	**14.29**	**25**

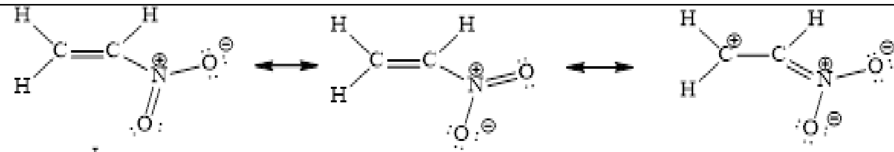
	valence electron to iodine to form a molecule of NaI.		
	c. NaI is soluble in polar solvents due to its ionic nature; Na^+ cations are attracted to the negative end of the solvent dipole, while I^- anions are attracted to the positive end*	85.00	54.55
	d. NaI is soluble in both polar and nonpolar solvents because it is an instantaneous process.	0.000	2.27
Q7.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	83.33	72.73
	b. I am not sure	16.67	27.27
Q8.1	When two neutral atoms of different non-metallic elements reacted to form__________________		
	A. Ionic bond	2.38	6.82
	A. Covalent bond*	80.95	81.82
	B. Metallic bond	11.90	4.55
	C. Both ionic and covalent	4.76	6.82
Q8.2	The reason for your answer is:		
	a. Two atoms need to be together to increase their ionic properties.	2.38	2.27
	b. Two atoms approach each other, and electrons (s) from each atoms start to be attracted to the nucleus of the other atom, producing a molecule*	38.10	27.73
	c. Two atoms react by the transfer of electrons to reach their most stable state.	2.38	**13.64**
	d. Both atoms have incomplete shells; therefore, the two atoms share electrons donated from one of these atoms to form a bond.	**40.48**	**52.27**
Q8.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	83.33	81.82
	b. I am not sure	16.67	18.18
Q9.1	Water (H_2O) and hydrogen sulfide (H_2S) have similar chemical formulae and have V-shaped structures. At room temperature, H_2O is a liquid, and H_2O is a gas. This is due to the presence of high intermolecular forces between:		
	A. H_2O molecules*	90.48	72.73
	B. H_2S molecules	9.52	27.27
Q9.2	The reason for your answer is:		
	a. The difference is due to differences in the strength of the O—H and S—H covalent bonds.	**14.29**	**31.82**
	b. The bonds in H_2S are easily broken, whereas in H_2O they are not.	**11.90**	**15.91**
	c. The difference is due to the difference in polarity of the molecules*	61.90	**20.45**

	d. The difference is because H_2O is a polar molecule, and H_2S is a nonpolar molecule.	7.14	**18.18**
Q9.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	61.90	7.14
	b. I am not sure	16.67	42.86
Q10.1	At room temperature, NaCl exists as:		
	A. a molecule	4.76	9.09
	B. an ionic compound*	76.19	65.91
	C. a molecular lattice	14.29	11.36
	D. Na^+ and Cl^- ions	4.76	13.64
Q10.2	The reason for your answer is:		
	a. The Na atom shares a pair of electrons with the Cl atom to form a simple molecule.	7.14	**22.73**
	b. After donating its electron to the Cl atom, the Na^+ ion forms a molecule with a Cl^- ion.	**35.71**	**31.82**
	c. NaCl exists as a lattice consisting of Na^+ ions and Cl- ions*	42.86	22.73
	d. NaCl exists as a lattice consisting of covalently bonded Na and Cl atoms	2.38	4.55
Q10.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	85.71	77.27
	b. I am not sure	14.29	22.73
Q11.1	An atom of element A has two valence electrons, while an atom of element B has five valence electrons. When element A reacts with element B, the compound will be__________		
	A. Covalent compound	26.19	18.18
	B. Ionic compound *	71.43	63.64
	C. Coordinate covalent compound	2.38	18.18
	D. Metallic complex compound	0.000	0.000
Q11.2	The reason for your answer is		
	a. An atom of element A and two atoms of element B combine through the sharing of electrons.	**14.29**	**27.27**
	b. An anion of element A and a cation of element B combine through the transfer of electrons.	**28.57**	**31.82**
	c. Three cations of element A and two anions of element B combine through the transfer of electrons.	47.62	22.73
	d. Three atoms of element A and two atoms of element B combine through the sharing of electrons.	4.76	**11.36**
Q11.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	73.81	79.55
	b. I am not sure	26.19	20.45
Q12.1	Which one of the following groups contains all compounds with both ionic and covalent bonds?		
	A. NH_4Cl, KCN, $NaNO_3$*	57.14	56.82
	B. NaCl, Mg_3N_2, KBr	2.38	18.18

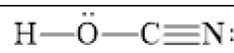
	C. H_2SO_4, NH_3 , PCl_5	11.90	11.36
	D. H_2O_2, CO_2, CaO_2	28.57	13.64
Q12.2	The reason for your answer is		
	a. The compounds contain metal and nonmetal ions.	**11.90**	**36.36**
	b. The compounds contain positive and negative ions, as well as covalently bonded atoms*	50.00	25.00
	c. The compounds are formed from the combination of non-metal electrons and their nuclei.	2.38	**11.36**
	d. The compounds are formed from the electrostatic forces of metal cations and delocalized electrons	**11.90**	9.09
Q12.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	85.71	77.27
	b. I am not sure	14.29	22.73
Q13.1	Which of the following is in increasing order of the melting points of the elements?		
	A. Al, Mg, Na	28.57	34.09
	B. Al, Na, Mg	9.52	9.09
	C. Mg, Al, Na	7.14	6.82
	D. Na, Mg, Al*	54.76	50.00
Q13.2	The reason for your answer is		
	a. The fewer electrons a metal can release, the lower the density of the electron cloud and the weaker the metallic bond.	**16.67**	9.09
	b. The more electrons a metal can release, the higher the density of the electron cloud and the stronger the metallic bond*	35.71	31.82
	c. The more reactive metals can release electrons easily and hold tightly to their nuclei to form strong metallic bonds.	**11.90**	**38.64**
	d. The metal releases fewer electrons with its large atomic size, which enables its nuclei to be held strongly by a sea of delocalized electrons to form strong metallic bonds.	**11.90**	6.82
Q13.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	71.43	63.64
	b. I am not sure	28.57	36.36
Q14.1	Which one of the following best describes the process of energy change during bond formation in a chemical reaction?		
	A. Energy is released*	59.52	27.27
	B. Energy is absorbed.	28.57	40.91
	C. Energy is both absorbed and released	7.14	20.45
	D. Energy is neither absorbed nor released	4.76	11.36
Q14.2	The reason for your answer is:		
	a. When bonds are formed, energy may be absorbed or released.	7.14	**15.91**
	b. Energy is released when chemical bonds are formed, and the system becomes more stable *	57.14	22.73
	c. Energy can be neither created nor destroyed; therefore, there are no overall energy changes.	2.38	**25.00**
	d. Energy is required to form bonds in the products of a reaction.	**30.95**	**25.00**

	That energy is stored in the bonds.		
Q14.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	80.48	75.00
	b. I am not sure	9.52	25.00
Q15.1	What is the central atom of the formaldehyde (CH2O) molecule in its Lewis structure?		
	A. Hydrogen (H)	4.76	4.55
	B. Carbon (C)*	73.81	65.91
	C. Oxygen (O)	0.000	9.09
	D. Both Carbon (C) & Oxygen(O)	21.43	20.45
Q15.2	The reason for your answer is		
	a. The atom is relatively less electronegative and can share electrons with the other atoms, and the Lewis structure is consistent with formal charges*	64.29	36.36
	b. The high electronegative oxygen atom contains an adequate number of valence electrons that can be shared with terminal atoms in a molecule to accommodate its octet.	4.76	**18.18**
	c. The molecule has two central atoms that share three pairs of electrons to accommodate their octet with consistent formal charges in its Lewis structure.	**28.57**	**27.27**
	d. One of the hydrogen atoms in a molecule can be the central atom and can share electrons with other atoms to fulfill its octet.	0.000	9.09
Q15.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	66.67	61.36
	b. I am not sure	33.33	38.64
Q16.1	Which one of the following molecules is non-polar with polar bonds?		
	A. CH_4	30.95	27.27
	B. CO_2*	45.24	27.27
	C. SO_3	4.76	15.91
	D. CH_3Cl	19.05	29.55
Q16.2	The reason for your answer is		
	a. The bond moments cancel due to its linear molecular geometry*	30.95	20.45
	b. The electronegativity difference between bonded atoms shows that each of these bonds has a zero-dipole moment to develop polar bonds.	**45.24**	**36.36**
	c. The bonds in a molecule are arranged such that their bond moments reinforce each other.	7.14	9.09
	d. The influence of lone-pair and bond-pair electrons on the central atom of the molecule.	0.000	**15.91**
Q16.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	83.33	61.36
	b. I am not sure	16.67	38.64
Q17.1	The most acceptable Lewis structure of the molecule NOCl is [Atomic No. O = 8; Cl = 17; N = 7]		

	A. 	45.24	43.18
	B. 	28.57	40.91
	C. 	2.38	0.000
	D. 	23.81	15.91
Q17.2	The reason for your answer is		
	a. The formal charge of all atoms equals zero, with the least electronegative atom at the center*	35.71	9.09
	b. All atoms of the molecule obey the octet rule and are stabilized by filling their outer shells.	**21.43**	**50.00**
	c. The most electropositive atom bears a negative formal charge, while the least electronegative atom bears a positive formal charge.	0.000	**18.18**
	d. The central atom is the most electronegative atom that can be bonded to other atoms.	9.52	**13.64**
Q17.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	78.57	65.91
	b. I am not sure	21.43	34.09
Q18.1	Which one of the following is true about BF_3 and NH_3 molecules? [At. No. B = 5, F = 9, N = 7, H = 1]		
	A. BF_3 and NH_3 have the same molecular geometry and shape.	7.14	18.18
	B. BF_3 and NH_3 have the same electronic arrangement that determines their geometry and shape.	19.05	22.73
	C. BF_3 and NH_3 have different molecular geometries and shapes*	71.43	54.55
	D. BF_3 and NH_3 are polar molecules.	2.38	45.45
Q18.2	The reason for your answer is that both molecules		
	a. have the same number of bonding electrons.	**14.29**	**25.00**
	b. have different numbers of lone pair and bonding pair electrons around their central atom*	59.52	38.64
	c. have the same number of lone pair and bond pair electrons around their central atom.	7.14	**11.36**
	d. contain atoms that have a high electronegativity difference to experience an equal sharing of electrons for the survival of their entire molecule.	9.52	**11.36**
Q18.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	69.05	52.27
	b. I am not sure	30.95	47.73
Q19.1	The nitroethene ($CH_2{=}CHNO_2$) molecule has three resonance contributors shown below		



I   II   III

	Which are the most important contributors to resonance?		
	A. I and II*	61.90	38.64
	B. I and III	14.29	15.91
	C. II and III	9.52	25.00
	D. I, II and III	14.29	20.45
Q19.2	The reason for your answer is		
	a. Resonance contributors have more charges and fewer bonds than other structures.	**11.90**	**4.55**
	b. Resonance contributors have a greater separation of charges on atoms than other contributors.	**14.29**	**15.91**
	c. A more negative formal charge resides on a less electronegative atom, while a positive formal charge resides on a more electronegative atom.	**19.05**	**40.91**
	d. Resonance contributors have relatively larger numbers of covalent bonds (sigma and pi) than others*	35.71	15.91
Q19.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	42.86	43.18
	b. I am not sure	57.14	56.82
Q20.1	Consider the structure of cyanic acid  , then the number of sigma (δ) and pi(π) bonds are __________ and _____respectively.		
	A. 5 and 2	11.90	13.64
	B. 5 and 3	11.90	25.00
	C. 2 and 3	11.90	20.45
	D. 3 and 2*	64.29	40.90
Q20.2	The reason for your answer is		
	a. Because overlapping orbitals (ends) result in sigma (δ) bonds, while overlapping orbitals (sides) of two parallel orbitals result in pi (π) bonds*	40.48	25.00
	b. End-to-end overlapping orbitals result in pi (π) bonds, while side-by-side overlapping orbitals result in sigma (δ) bonds.	**19.05**	**25.00**
	c. The bond is formed from three pairs of electrons, containing two sigma(δ) bonds, while the bond formed from a pair of electrons contains pi (π) bonds.	**19.05**	**18.18**
	d. The entire molecule contains two single bonds and one triple bond, with three lone pair electrons that can form orbital-overlapping bonds.	**11.90**	**11.36**
Q20.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	64.29	59.09

	b. I am not sure	35.71	40.91
Q21.1	One of the following molecules has a dipole moment [At. No. B = 5, F=9, Cl =17,N=7,C=12, Be =4]		
	A. BF_3	19.05	27.27
	B. CH_4	0.000	15.91
	C. NH_3 *	71.43	47.73
	D. $BeCl_2$	9.52	9.09
Q21.2	The reason for your answer is		
	a. The BF_3 molecule is symmetrical; the B-F bonds reinforce each resulting in a non-zero dipole moment.	**23.81**	**27.27**
	b. NH_3 is a polar molecule due to the electronegativity difference between N and H atoms, resulting in a non-zero dipole moment*	69.05	40.91
	c. In the CH_4 molecule, each bond pair is asymmetrically arranged results net dipole moment > 0.	2.38	**15.91**
	d. The $BeCl_2$ molecule contains a highly electronegative Cl atom, resulting in a non-zero dipole moment	4.76	9.09
Q21.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	83.33	59.09
	b. I am not sure	16.67	40.91
Q22.1	Which of the following is true about H_2O and BeH_2 molecules? [At. No. H = 1, O =8, Be = 4]		
	A. The H-O-H molecule is bent, whereas the H-Be-H molecule is linear*	83.33	70.45
	B. Both have equal bond angles with the same electron pair geometry.	**11.90**	18.18
	C. They have the same number of electron pairs, geometry, and molecular shape.	2.38	9.09
	D. The terminal atoms of each molecule are forced equally by their central atom.	2.38	2.27
Q22.2	The reason for your answer is:		
	a. The central atom of each molecule is bonded with the same terminal atoms of equal magnitude.	7.14	**29.55**
	b. The molecules have the same electron pair rearrangement that determines their shape.	9.52	**18.18**
	c. The difference in lone-pair electrons around the central atoms experiences repulsion with bonded pair electrons in H_2O compared to BeH_2*	73.81	45.45
	d. The molecules have no lone pair electrons around their central atom that can experience the repulsive force between them.	2.38	4.55
Q22.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	83.33	56.82
	b. I am not sure	16.67	43.18
Q23.1	Which one of the following is true about NH_3 and CH_4 molecules?		
	A. They have the same molecular shape and polarity	4.76	9.09
	B. They have the same electron pair geometry*	50.00	27.27

	C. They have different orbital hybridizations	21.43	31.82
	D. The H–N–H angle in NH_3 is larger than the H–C–H bond angle in CH_4	23.81	31.82
Q23.2	The reason for your answer is		
	a. The influence of lone pair electrons on the bond pair electrons in NH_3 but not in CH_4*	38.10	9.09
	b. The weaker repulsion force between lone-pair and bond-pair electrons in NH_3 than in CH_4	2.38	**27.27**
	c. The influence of unhybridized 2pz orbital in CH_4 molecules than NH_3	**14.29**	**15.91**
	d. The molecules have different electron pair geometries and the same molecular shape	7.14	**20.45**
Q23.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	71.43	61.36
	b. I am not sure	28.57	38.64
Q24.1	Which one of the following ions has a trigonal planar shape? [At. No. S = 16, O =8, N =7, C = 6, H =1]		
	A. SO_3^{2-}	19.05	45.45
	B. NH_4^+	14.29	13.64
	C. NO_2^-	23.81	11.36
	D. CO_3^{2-}*	42.86	29.55
Q24.2	The reason for your answer is:		
	a. The ion occurs in a structure with three bond pairs and no lone-pair electrons around the central atom*	33.33	13.64
	b. The ion contains three terminal atoms bonded to the central atom with lone-pair electrons	**21.43**	**56.82**
	c. The central atom is bonded to three identical atoms that have pi(π) bonding interactions	7.14	9.09
	d. The ion has more lone-pair electrons in the center and influences the three bond-pair electrons.	9.52	2.27
Q24.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	61.90	43.18
	b. I am not sure	38.10	56.82
Q25.1	For which of the following substances is the highest energy required to convert one mole of the solid into separate ions [At. No. Mg =12, O = 8, Sr = 38, K=19, F= 9]		
	A. MgO*	38.10	18.18
	B. KF	26.19	27.27
	C. SrO	14.26	22.73
	D. MgF_2	21.43	29.55
Q25.2	The reason for your answer is:		
	a. MgO has higher charges (+2 and -2) and smaller ionic radii than the given compounds*	35.71	18.18
	b. MgF_2 has +2 charge on Mg^{2+}, though F^- ions have a smaller radius compared to O^{2-} ion	**19.05**	**31.82**

	c. SrO has high charges (+2 and -2), but Sr^{2+} has a larger radius, making it hard to separate.	**21.43**	**29.55**
	d. KF has high lattice energy due to the +1 and -1 charges and the larger ionic radius of K^{+} .	**23.81**	**20.45**
Q25.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	57.14	43.18
	b. I am not sure	42.86	56.82
Q26.1	Given the bond energies H-H = 436KJ/mol, F-F = 160 KJ/mol and H-F = 569kJ/mol, for the reaction $H_2 + F_2 \rightarrow 2HF$. The approximate enthalpy change, ΔH, for this reaction is___________		
	A. +1734KJ/mol	14.29	9.09
	B. +565KJ/mol	23.81	29.55
	C. -542KJ/mol*	57.14	50.00
	D. -293KJ/mol	4.76	11.36
Q26.2	The reason for your answer is		
	a. The bonds in the products are stronger than the reactants, so the reaction releases more energy than it consumes*	38.10	20.45
	b. The bonds in the reactants are stronger than in the products, so the reaction absorbs more energy than it releases.	**21.43**	**50.00**
	c. The bond energy required to break the bond between the two reactants is greater than that of the products.	**14.29**	**22.73**
	d. Because the reaction contains equal numbers of molecules on both sides, an equal amount of bond energy is required to break the bonds	4.76	0.00
Q26.3	Are you sure about your answers to the previous two questions?		
	a. I am sure	59.52	45.45
	b. I am not sure	40.48	54.55

Note: *The total percentage of responses for the combined reason tier (BT) does not sum to 100% because scoring is awarded only when students correctly answer the first and second tiers, rather than through a single-choice response format. The scores shown in bold indicate students' misconceptions corresponding to the respective alternative reasoning statements.*

1. Articles published

Objective 1: Journal of Chemical Education (Scopus and Web of Science)

Woretaw Atinaf, Woldie Belachew, Atakilt Abebe, Tadesse Melesse; The Effects of Blended Learning on Undergraduate Students' Conceptual Understanding of Chemical Bonding and Molecular Geometry. J. Chem. Educ. 2026; https://doi.org/10.1021/acs.jchemed.5c01880

Objective 2: Chemistry Teacher International (Scopus)

Atinaf, W., Belachew, W., Abebe, A., & Melesse, T. (2026). The effects of blended learning on undergraduate students' engagement in chemical bonding and molecular geometry concepts. Chemistry Teacher International. https://doi.org/10.1515/cti-2025-0085

2. Articles under review

Objective 3: Journal of Science Teacher Education (Scopus and Web of Science)

Blended Learning and Undergraduate Students' Epistemological Beliefs in Learning Chemical Bonding and Molecular Geometry Concepts