

Topic Specific Pedagogical Content Knowledge-Based Instruction and Grade 11
students' Chemistry Learning

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DECLARATION

I, the undersigned, hereby declare that this PhD Dissertation is my own original work and has not been presented for a degree in any other University, and that all sources of materials used for the Dissertation have been duly acknowledged.

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ABSTRACT

Topic Specific Pedagogical Content Knowledge-Based Instruction and Grade 11 students' Chemistry Learning

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Chemical kinetics and equilibrium pose significant challenges to students' understanding in chemistry. Although pedagogical content knowledge (PCK) has been identified as a beneficial tool in improving learning outcomes, limited research focuses specifically on its effectiveness in these topics. This study investigated the impact of topic-specific PCK-based instruction on students' conceptual understanding, achievement, and motivation in chemical kinetics and equilibrium. Participants were 159 High school students in treatment groups receiving topic specific PCK-based instruction and a control group receiving conventional instruction. Three treatment groups, each emphasizing different PCK elements (curricular saliency-based, representation-based, and conceptual teaching strategy-based) were compared in this investigation. Data collection instruments included conceptual understanding test, chemistry achievement test, chemistry motivation questionnaire, semi-structured interviews and classroom observations. A mixed method with non-equivalent pre-test-posttest quasi-experimental design was utilized in this study. Quantitative data were analyzed using ANOVA, MANOVA, follow-up ANOVA, and multiple regressions. Interview data were analyzed based on themes generated from interview data. Moreover, classroom observation data on students engagement and teachers facilitation role in teaching chemical kinetics and equilibrium concepts were analyzed. The results indicated that the REPs and CTS methods were particularly effective, showing the highest gains in students' understanding. These interventions not only improved understanding and achievement but also mitigated common misconceptions associated with chemical kinetics and equilibrium. Notably, female students exhibited improvements in their grasp of concepts compared to their male counterparts, though no significant gender differences were observed in overall outcomes. The study underscores the effectiveness of TSPCK-based approaches in chemistry education, highlighting the importance of interactive and technology-supported teaching strategies. Results demonstrated the superiority of the treatment groups over the Comparison group in conceptual understanding, achievement, and motivation. Specifically, the representation-

based instruction group exhibited significant improvement in conceptual understanding and motivation, while the conceptual teaching strategy-based group has shown a significant enhancement in achievement. Multiple regression data revealed that intrinsic and mark motivation strongly impacted students' conceptual understanding and achievement.

Based on the findings and discussions of this study, summary, conclusions and recommendations were made.

Keywords: Achievement, Chemistry learning, Conceptual teaching, conceptual understanding, Mark motivation, motivation, Representations, TSPCK-based instruction

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ACRONYMS AND ABBREVIATIONS

Ach	Achievement
CE	Chemical Equilibrium
CK	Content Knowledge
CK'	Chemical Kinetics
CM	Conventional Method
CU	Conceptual Understanding
CSA	Curricular Saliency
CTS	Conceptual Teaching Strategies
DV	Dependent Variable
MM	Mark motivation
GPK	General Pedagogical Knowledge
IM	Intrinsic motivation
KC	Knowledge of Context
KS	Knowledge of Students
LPK	Learners Prior Knowledge
MMR	Mixed Method Research
NR	Non-Randomization
PCK	Pedagogical Content Knowledge
PTC	Pedagogical Transformation Competence
REPs	Representations
SD	Self-Determination
SE	Self-Efficacy

TG	Treatment Group
TSPCK	Topic Specific Pedagogical Content Knowledge

CHAPTER ONE: INTRODUCTION

This chapter presents background of the study, statement of the problem, objectives, research questions, significance, delimitations of the study, and operational definitions of terms.

1.1. Background of the study

Ethiopia and other developing countries have recognized and started using constructivist-learning paradigm in education, teacher development, and policy formulation (Dejene et al., 2018). A constructivist-oriented teacher education program improves student teachers' perceptions of teaching skills, resulting in higher confidence and better teaching practice (Darling-Hammond, 2000; Gordon & Debus, 2002; Hall et al., 2004; Lucas, 2001; Noble, 2005). Ethiopia has been implementing a constructivist-based teacher education program since 2003. The program aims to improve the quality of education by encouraging critical thinking, student-centered learning, and active engagement (Abebe & Woldehanna, 2013; Fenta, 2019; Hussein, 2011; Wabe & Tessema, 2011). Despite the reform efforts that advocate student-centered constructivist teaching, teachers seem to depend on conventional pedagogies at all levels. Despite consistent and concerted efforts, there has been no improvement in students' learning achievement due to the method of instruction used by teachers (MoE, 2009). The conventional teaching approach where the teacher talks and students listen still dominates the teaching and learning process in the Ethiopian education system (Biniyam, 2014; Birhanu, 2010). According to Erinosho (2013), chemistry teachers must possess knowledge of the subject's conceptual understanding, reasoning skills, and teaching strategies to improve their students' learning. Chemistry teachers are no exception to this. Critical thinking, problem-solving, and the application of concepts in many situations are made possible by conceptual understanding, which is the capacity to explain, distinguish, and link new information with preexisting knowledge (Dali, 2014; Susilaningih et al., 2019). Conceptual knowledge is acquired when a learner creates practical and scientific paths to obtain the correct answers. The representations of chemistry terminologies in the minds of learners play important role in conceptual understanding as they may misinterpret the specific chemical ideas or use vocabulary that is non-scientific (Sibomana et al., 2020). Students in upper primary and secondary school find chemical representations ambiguous and conceptually difficult (Erinosho, 2013). In the field of teaching chemistry, it is critical to emphasize on the importance of conceptual thinking and how concepts

are generated. Furthermore, chemistry instruction should prioritize the acquisition of conceptual knowledge (O'Dwyer & Childs, 2017). Unfortunately, many students struggle with essential concepts and lack a thorough comprehension of the subject (Cetin-Dindar & Geban, 2017). This could be because students' own opinions diverge from those held by the scientific community, posing a learning challenge. Alternative conceptions, in particular, can make it difficult to build meaningful links between current and newly acquired knowledge (Cetin-Dindar & Geban, 2017). Conceptual comprehension has an inseparable connection to critical thinking, problem solving, and inquiry abilities. During instruction that requires advanced conceptual understanding, students are urged to investigate the why behind chemical concepts. This method promotes understanding that is more profound than just knowledge. This strategy aligns with the overarching educational objective of preparing students to use their knowledge in various situations and adjust to novel challenges. Conceptual understanding in chemistry learning transcends memory and makes it easier to apply knowledge in novel contexts (Bunce, 2015). Conceptual understanding contributes to a thorough understanding of the fundamental ideas, principles, and concepts of a subject or discipline, allowing for critical thinking and problem-solving skills (NRC, 2012).

Students with strong academic achievement in math or science excel at problem-solving but struggle with fundamental concepts and principles (Oliveira & Maia, 2018). Students' performance suffered as a result of their difficulties in understanding science topics and principles, particularly chemistry. Achievement in chemistry emphasizes mastering content, following procedures, and applying knowledge in familiar contexts that focus on success, often relying on rote memorization (Jimoh, 2021). Both conceptual understanding and academic achievement are essential for fostering learning and academic success (Greene et al., 2018).

Noncognitive factors also influence learning and academic success. Several factors influence conceptual comprehension, including self-efficacy, motivation, and metacognitive ability. These are critical components of students' academic performance, and instructors' knowledge in these areas is important. Teachers must establish a learning atmosphere and motivate their students to learn chemistry (Johnson, 2017).

Students' motivations can be external or internal. Students who are intrinsically motivated process information more thoroughly, obtain higher grades, and demonstrate greater persistence

than those who are extrinsically motivated. Motivation is one of the most important affective aspects influencing students' learning outcomes (Sastrika et al., 2013). Teachers should understand how to motivate their students. According to Vans Teenkiste (2004), there is a progressive drop in students' motivation to study chemistry due to a loss of interest in the topic. Furthermore, studies on motivation to learn chemistry suggest that motivation declines when students proceed from secondary school to higher education institutions (Potvin & Hasni, 2014). These studies affirmed that the decline in motivation accompanied by feelings of fear, boredom, rejection, and experiences of failure (Woolfolk, 2004). The issue of student motivation in chemistry has become a global concern because it has a direct impact on grasping fundamental concepts in the subject (Findlay & Bryce, 2012; MacIntyre & Blackie, 2012).

Science in general and chemistry in particular provide students with fundamental knowledge of chemical science and technology, allowing them to make meaningful contributions in their daily lives. Chemical kinetics, as a branch of chemistry, can provide insights into chemical reactions and processes by linking observable phenomena to mathematically modeled theoretical aspects (Çakmakci et al., 2006). Chemical kinetics concepts are challenging to grasp (Bain & Towns, 2016) and necessitate mathematical skills such as differentiation and derivation of several variables (Rodriguez et al., 2019). Students who lack prior knowledge of the particulate nature of matter, chemical changes, and concentration changes in reaction species struggle with complex and difficult concepts when studying chemical kinetics (Gegios et al., 2013). As a result, when teaching chemical kinetics concepts, teachers should prefer constructivism-led, representation-based instruction. The conceptual modeling of chemical kinetics principles is easily implemented using topic-specific pedagogical content knowledge (TSPCK) frameworks (Taber, 2013). Also, chemical equilibrium is a fundamental idea in chemistry, yet it is difficult for students to grasp (Stroumpouli & Tsaparlis, 2022; Tilahun & Tirfu, 2016). The difficulties that students encounter when learning chemical kinetics and equilibrium can be related to a variety of factors, including experimental activities, reference materials, instructional methods, lesson sequencing, and textbook concept presentation (Chiu, 2005). According to Proksa et al. (2018), learners' prior knowledge and lack of using appropriate teaching method in learning chemical kinetics and equilibrium are the main factor for learning difficulties of the students. The study findings by Proksa et al. (2018) underlined the need to adapt instruction to meet the specific requirements of learners as well as the challenges that educators encounter when teaching these topics.

Recognizing and overcoming these obstacles allows educators to provide a more effective and engaging learning experience for their pupils. Ethiopian grade 11 students are not unique in struggling with and developing misconceptions while learning chemical kinetics and equilibrium (Tilahun & Tirfu, 2016; Stroumpouli & Tsaparlis, 2022), as difficulties with this subject are common among high school and college students (Yıldırım et al., 2011). In addition to the above challenges, students also struggle to connect the abstract concepts in chemistry to real-world situations (Yakmaci-Guzel, 2013). Students lack a complete understanding of concepts due to inadequacies in presenting concepts at three thought levels or representations (macro, sub-micro, and symbolic) (Johnstone, 2009; Taber, 2013). Additionally, the general understanding of terminology used in chemistry is different from that of daily language (Taber, 2013). Moreover, inadequate teacher preparation for the concept (Spaull, 2013) and learners' inadequate conceptual comprehension of the necessary subject knowledge (Gaigher et al., 2007; Mavhunga & Rollnick, 2013) led to difficulties in learning chemical concepts. These challenges are often linked to the teaching strategies used (Lewis et al., 2014; Planinic et al., 2012). When teachers use constructivist theory-based techniques, learners can benefit more during the learning-teaching process.

According to constructivism, students actively create their understanding and knowledge of the world via reflection and experience (Bruner, 1990). In contrast to passively absorbing knowledge, this method indicates that learning is an active process in which students interact with and modify the content they are studying. According to Cognitive Development Theory, learners go through phases of cognitive development, and their academic accomplishments reflect this evolution (Piaget, 1970). The approach emphasizes the necessity of giving students the opportunity to develop their cognitive skills through hands-on, constructive experiences. In contrast, social cognitive theory emphasizes the importance of self-efficacy, goal-setting, and peer learning in academic performance (Bandura, 1997). This idea proposes that students who have a high sense of self-efficacy and establish attainable goals are more likely to succeed academically. Peer learning can also help students achieve academic achievement by allowing them to cooperate and learn from one another. These theories emphasize the necessity of giving students the opportunity to actively construct their knowledge and cognitive capacities through hands-on activities and social interactions. Through application of ideas and principles of cognitive development theory and social cognitive theory, educators can assist students in

achieving academic achievement and reaching their full potential (Singh, 2017). When teachers use more effective teaching strategies (topic-specific PCK strategies, inquiry-based learning, problem-based learning, and cooperative learning) that foster conceptual knowledge, students are more likely to have a better understanding of the subject matter and achieve higher exam scores (Hmelo-Silver et al., 2007). The constructivist approach, which emphasizes active engagement, social interaction, meaning-making, and contextualization, is important.

The growth of teachers' content knowledge (CK) and its transformation for students in the teaching-learning process is the most sought-after treasure in science teacher education. The most important tool for teachers to use to make concepts understandable to students is content knowledge (CK). According to Shulman (1987), teachers' pedagogical content knowledge (PCK) is the one that entails the "transformation of content knowledge" (p. 8). Furthermore, it makes sense to invest in teachers' PCK in order to teach a CK effectively for students at any educational levels (Evens et al., 2015). Although most people believe that teachers need to be proficient in the subject matter they teach, there is still disagreement over how much more knowledge teachers need to know than their students and what specific pedagogical expertise they require (Kind, 2009; Rollnick et al., 2008). In this area, the pursuit of CK and PCK is an ongoing journey, as teachers must constantly adapt and enhance their knowledge to meet the changing demands of their students. Teachers with a thorough command of content and pedagogy may create an array of knowledge that inspires and motivates their students to become the next generation of scientific experts. Kind (2009) and Rollnick et al. (2008) have stressed the importance of teachers' CK and PCK in effective science education. However, Rollnick et al. (2017) point out that CK is not the only essential requirement for PCK advancement.

Teachers are expected to build PCK in science topics in order to get the skills and knowledge needed to translate content information into teachable form that students can understand and pay attention to (Rollnick & Mavhunga, 2016). PCK is a concept that can be contextualized at the subject level. Topic-specific PCK (hereafter TSPCK) is a new version of PCK that defines competence as the ability to convert knowledge of a topic into teaching objectives (Mavhunga, 2012). TSPCK differs from generic teacher PCK in that it focuses on specialized topic knowledge and straightforward teaching methodologies. As a result, TSPCK is the knowledge

required to turn content knowledge on a specific issue into teachable form using pedagogical reasoning (Akinyemi, 2020).

Teachers need to develop TSPCK to effectively teach a particular subject area. TSPCK consists of students' prior knowledge, curricular saliency, topic difficulty, representations, teaching strategies (Rollnick & Mavhunga, 2014), and assessment as its components (O'Brien, 2017). Teachers must consider these components to create engaging and effective lessons that meet the needs of their students. For instance, understanding students' prior knowledge (the first TSPCK component) helps teachers build on what students already know and address any misconceptions. Curricular saliency helps teachers connect the topic to other subjects and the real world, making it more relevant and engaging for students. Effective teaching strategies, such as questioning and using examples, can help students understand complex topics, while assessment methods can measure students' understanding and adjust instruction accordingly. TSPCK helps teachers to create a more personalized and effective learning experience for their students. TSPCK-based instruction is meant to help educators develop and deliver contents effectively that address the unique demands and challenges of teaching a specific topic. It also helps teachers adapt and change their classes based on student responses and suggestions (Akinyemi, 2016). TSPCK-based instruction has been used in a wide range of courses and disciplines, including chemistry, mathematics, and science.

Although there are currently six TSPCK components (O'Brien, 2017), most studies on PCK have shifted their focus to the topic level and adopted the notion as a product of transforming CK through five components (learners' prior knowledge (LPK), curricular saliency (CSA), what is difficult or easy to teach, representations (REPs), and conceptual teaching strategies (CTS)). These five TSPCK components assist teachers in thinking about and transforming content for instructional objectives. This intervention-based study focused on only three components (curriculum saliency, representations, and conceptual teaching strategies) and the researcher took previously studied two components (learners' prior knowledge and what is difficult to teach) as a supportive references for this study. Thus, this research endeavor was to investigate Grade 11 students' conceptual understanding, achievement, and motivation in chemical kinetics and equilibrium concepts using TSPCK-based instruction (curriculum saliency-based, representations-based, and conceptual teaching-based).

1.2. Statement of the problem

The teaching and learning of chemical kinetics and equilibrium topics in chemistry present formidable challenges due to their inherent complexity and the requirement for a profound comprehension, as noted by several researchers (Çalik & Ayas, 2005; Chairam et al., 2009; Coll et al., 2010). Students often find these subjects particularly difficult due to the reliance on conventional teaching methods (Justi, 2002; Stroumpouli & Tsaparlis, 2022; Tilahun & Tirfu, 2016), absence of comprehensive representations of concepts, and difficulties with mathematical aspects (Johnstone, 2009; Taber, 2013; Teo et al., 2014). Furthermore, inadequacies in teacher preparation exacerbate these challenges (Johnstone, 2009), with misconceptions, limited prior knowledge, and ineffective teaching strategies compounding the problem.

Evidence from national learning assessments in Ethiopia reveals alarming statistics, with a significant portion of students failing to meet basic proficiency levels in chemistry (NEAEA, 2017, 2020). Specifically, achievement scores in chemical kinetics and equilibrium fall below acceptable thresholds, highlighting broader regional and national concerns regarding academic performance (Planinic et al., 2012). The abstract nature of chemistry concepts further complicates matters, with students struggling to connect these topics to their daily lives (Taber, 2013; Yakmaci-Guzel, 2013).

From the researcher's long years teaching experiences in chemistry in all levels (elementary, high school and university, current teaching approaches often fall short in ensuring student understanding, achievement, and motivation. Factors such as the abstract nature of chemistry concepts requiring multiple levels of representation, concerns relating to instructional strategies, and the failure to contextualize concepts within students' lived experiences contribute to poor performance (Johnstone, 2009; Lewis et al., 2014; Taber, 2013; Planinic et al., 2012).

Addressing these challenges necessitates empirical investigation within the Ethiopian educational context. Innovative teaching approaches and materials hold promise in improving student comprehension of chemical kinetics and equilibrium concepts. The constructivist model of learning underscores the importance of interactive knowledge formation, prompting inquiries into pedagogical content knowledge (PCK) and its topic-specific variant (TSPCK) among educators (Mathabatha, 2005; Rollnick & Mavhunga, 2014; Mavhunga, 2015).

Limited research research exists concerning the effectiveness of TSPCK in teaching chemical kinetics and equilibrium. Research works focusing on TSPCK's impact on various aspects of learning, such as conceptual understanding, motivation, learning transfer, problem-solving skills, and application in real-world scenarios are scanty. Therefore, this research aimed to investigate the effects of a TSPCK-based instructional approach on grade 11 students' understanding, achievement, and motivation in chemistry concepts, specifically chemical kinetics, and equilibrium. Through this endeavor, we sought to bridge the existing research gap and contribute to the enhancement of chemistry education practices.

1.3. Objectives of the Study

1.3.1. General objective of the study

The main purpose of this study was to investigate the effect of TSPCK-based instruction on grade 11 students' conceptual understanding, achievement, and motivation in Chemical kinetics and equilibrium concepts at Addis Ababa Administrative City.

1.3.2. Specific objectives of the study

The specific purposes of this study are presented as follows:

- To examine the effect of TSPCK-based instructions on students' conceptual understanding, achievement and motivation.
- To examine the interaction effect between groups and gender in learning chemical kinetics and equilibrium concepts.
- Evaluate the effect of TSPCK-based instruction on students' conceptual understanding, achievement and motivation as measured by combined dependent variables.
- To predict the effect of motivation subscales on the students' conceptual understanding and achievement after TSPCK-based instruction was employed in learning chemical kinetics and equilibrium.
- To explore the misconceptions and check the effectiveness of TSPCK-based instruction in learning chemical kinetics and equilibrium concepts.

1.4. Research Questions

The research questions that guided this study are outlined as follows:

1. Are there significant mean score differences between intervention and comparison groups in their conceptual understanding, achievement, and motivation in learning chemical kinetics and equilibrium?
2. Do groups and gender have interaction effects on conceptual understanding, achievement and motivation?
3. Are there significant mean score differences between Intervention and comparison groups on a linear combination of conceptual understanding, achievement and motivation in learning chemical kinetics and equilibrium?
4. How well do motivation and its components predict Grade 11 students Conceptual understanding and achievement?
5. What chemical kinetics and equilibrium concepts-related misconceptions exist among Grade 11 students and how effective is TSPCK-based instruction in learning these concepts?

1.5. Significance of the Study

This investigation extends knowledge base from prevalent conventional teaching approach of treating chemical kinetics and equilibrium concepts to TSPCK-based instruction in secondary students' learning. Accordingly, researchers in the area of PCK/TSPCK, curriculum experts, policy makers, secondary school students and chemistry teachers will benefit from the findings of this study. The study will also contribute for the existing literature by changing the views of researcher on the conception of PCK and TSPCK and effect of TSPCK based instruction on the chemistry learning outcomes beyond measuring teachers' content knowledge and pedagogical content knowledge. In addition, the findings from this research will benefit teachers who teach other chemistry topics at secondary and higher education levels.

1.6. Delimitation of the Study

To provide a thorough investigation, the study was limited to one Addis Ababa sub-city and focused on chemistry students in grade 11. Only grade 11 students were included in the study;

students from other grade levels were left out to enable a more concentrated and thorough investigation. Key ideas in chemical kinetics, such as the rate of reaction, theories of reaction rates, factors affecting reaction rates, rate laws, order of reaction, and reaction mechanisms, were the focus of the study. Equilibrium concepts focusing on dynamic equilibrium, equilibrium constant calculation and expressions, factors affecting equilibrium and Le Chatlier's principle were included in this research. Therefore, this study was delimited to chemical kinetics and equilibrium concepts. Although there are different approaches to ensure students learning, TSPCK-based instructional approaches (curricular saliency-based, representation-based, and conceptual teaching strategies-based) were used in this study. Other instructional methods are not within the scope of this research.

1.7. Operational Definitions

The following terms or phrases were defined in relation to this dissertation:

Chemistry learning: refers to students' understanding, achievement, and motivation in studying chemical kinetics and equilibrium through TSPCK-based instruction.

Achievement: refers to the level of academic performance and proficiency attained by students in mastering the key concepts, principles, and skills related to these topics within the domain of chemistry education.

Analytical skills: refers to the abilities that grade 11 students' practiced to evaluate and understand data related to chemical kinetics and equilibrium, including identifying patterns and trends and using mathematical models to describe and predict the behavior of chemical systems.

Conceptual teaching strategy: refers to a set of instructional approaches, methods, and techniques designed to facilitate students' comprehension, internalization, and application of the fundamental concepts and principles underlying these topics within the domain of chemistry education. It is one of the TSPCK-based approaches employed in this study to facilitate learning of Chemical kinetics and equilibrium using Ed-puzzle and interactive simulations.

Conceptual understanding: refers to the depth of comprehension and mastery students attain regarding the fundamental principles, theories, and relationships underlying these topics within the context of chemistry education.

Curricular saliency: refers to the deliberate emphasis, prioritization, and alignment of instructional content, activities, and assessments with the key concepts, principles, and skills related to these topics within the chemistry curriculum. It is one of the TSPCK-based approaches employed in this study to facilitate learning of Chemical kinetics and equilibrium through identification of big ideas, sub-ordinate ideas and connecting with daily lives.

Mark motivation: refers to the desire to acquire high marks on specific examinations and activities in the context of learning chemical kinetics and equilibrium for grade 11 students. This motivation is centered on performing well in specific examinations, quizzes, assignments, and laboratory reports relating to these topics.

Motivation: Motivation refers to the drive and enthusiasm for learning chemical kinetics and chemical equilibrium through TSPCK-based instruction. It refers to the driving force that inspires and energizes students to engage in the learning process, leading to a deeper understanding and application of the subject matter. It also refers to the degree of engagement, persistence, and enthusiasm exhibited by students in the process of acquiring knowledge, understanding concepts, and developing skills related to these topics within the domain of chemistry education.

Pedagogical content Knowledge: is a knowledge base for teaching that is unique to the profession of teaching, and which enable teachers to bridge difficult content for integrated chemistry teachers' understanding to learn and to teach.

Problem-solving skills: refers to Students' ability to apply their knowledge of chemical kinetics and equilibrium to solve real-world problems, such as determining the rate of a chemical reaction or identifying the equilibrium conditions of a system.

Reasoning skills: refers to Students' ability to reason and think critically about chemical kinetics and equilibrium, including the ability to make connections between different concepts and principles, and to evaluate the validity of scientific arguments.

Representations-based instruction: refers to a teaching approach that emphasizes the use of multiple modes of representation (verbal, visual, symbolic, diagrams, models, graphs, equations, and simulations) with special focus on macro, micro and symbolic levels. It is one of the

TSPCK-based approaches employed in this study to facilitate learning of Chemical kinetics and equilibrium through classifying chemistry concepts in to Macro, micro and symbolic representatins.

Topic Specific Pedagogical Content Knowledge (TSPCK): refers to the specialized knowledge (with deep understanding and expertise) that teachers use to effectively teach specific topics within a subject. It includes prior knowledge of learners, curricular Saliency, what makes the topic easy or difficult to teach, representations, and conceptual teaching strategies.

CHAPTER TWO: REVIEW OF RELATED LITERATURE

2.1. Introduction

Within the confines of this dissertation chapter, a review of relevant previous research works which can provide a basis for understanding topic-specific Pedagogical Content Knowledge (TSPCK) and secondary school learner's outcomes (conceptual understanding, achievement and motivation) are considered from various dimensions. Credible sources (Journal articles, book chapters, conference proceedings, etc) were used in this review chapter. The chapter begins with the theoretical framework which guided the study. Other parts of this chapter are: knowledge that matters when teaching chemistry; PCK construct in chemistry education and its taxonomies; TSPCK as instructional approach; TSPCK components in teaching chemistry; planning versus enacting instruction in TSPCK; interactions of TSPCK components and their quality; conceptual understanding in chemistry and the three levels of representations; academic achievement and socio-emotional aspects; relationship between conceptual understanding and achievement in learning chemistry; motivation in learning chemistry; difficulties in learning and teaching chemical kinetics and equilibrium; and conceptual framework.

2.2. Theoretical Framework

The theoretical framework underpinning this study draws inspiration from Shulman's (1986, 1987) Pedagogical Content Knowledge (PCK) and Gess-Newsome's (2015)'s teachers professional knowledge and skill, which served as a foundational guide for effective classroom teaching and learning. Lee Shulman's notion of PCK focuses on the unique combination of pedagogical techniques and topic knowledge that teachers need to effectively teach certain subject matter (Shulman, 1986, 1987). In chemistry education, PCK entails understanding how to convey chemical topics in ways that students can grasp, selecting appropriate instructional techniques and materials, diagnosing student misunderstandings, and assessing learning outcomes. Shulman's framework highlights the significance of combining pedagogical approaches with deep content knowledge to promote meaningful learning experiences in chemistry education. Deborah L. Gess-Newsome's work, particularly her 2015 contribution to the concept of teachers professional knowledge and skill (TPK &S) builds on Shulman's PCK framework by emphasizing the importance of tailoring pedagogical strategies to specific topics

within a subject area (Gess-Newsome, 2015). In chemistry education, TSPCK entails learning how to effectively teach specific chemistry concepts such as chemical kinetics and chemical equilibrium. It entails understanding how to convey these concepts through various forms of representation, selecting relevant educational resources and activities, and addressing typical student misconceptions about these specific themes. Gess-Newsome's framework has the same components with TSPCK framework and it emphasizes on the understanding and specialized knowledge required to teach specific curriculum areas in chemistry education. It complements Shulman's larger PCK framework. Additionally, this dissertation study incorporates the TSPCK construct, as articulated by Mavhunga (2012). The choice of TSPCK as instructional strategy is deliberate and grounded in two essential reasons.

Firstly, the TSPCK construct emphasizes the critical transformation of content knowledge into specific topics through the utilization of five distinct knowledge components as teaching strategies. These components encompass considerations such as learner prior knowledge with misconceptions, curricular saliency, the identification of what is easy or difficult to teach, the use of representations, and the application of conceptual teaching techniques (Kind, 2009; Mavhunga, 2012; Rollnick & Mavhunga, 2014). Furthermore, Mavhunga (2012) has demonstrated that secondary school students construct knowledge of learning and teaching through practical engagement, aligning with the principles of social constructivist learning theory.

Secondly, the adaption of TSPCK-based instruction anticipated to enhance conceptual understanding, achievement, and motivation. This alignment is substantiated by constructivist, cognitive developmental theory, and achievement goal theory (Gess-Newsome et al., 2003). The constructivist theory hypothesizes that learners actively construct their own knowledge and understanding through experiences and interactions within their environment (Brooks & Brooks, 1993). Cognitive developmental theory, rooted in Jean Piaget's work, suggests that learner's progress through stages characterized by increasingly complex forms of thinking, with academic achievement reflecting cognitive development (Piaget, 1970). Social cognitive theory emphasizes the influence of learners' beliefs, motivation, and social context on academic achievement and conceptual understanding, highlighting the role of self-efficacy, goal setting, and peer learning in academic success (Ugwuanyi, 2020). Moreover, the theoretical foundation

extends to social constructivist theory and self-determination theory, both of which support Chemistry learning motivation. Social constructivist theory asserts that learners construct knowledge through social interactions and collaborative learning experiences, which TSPCK-based instruction can facilitate. On the other hand, self-determination theory underscores the significance of autonomy, competence, and relatedness in motivation (Partanen, 2020). TSPCK-based instruction anticipated to provide learners with choices, foster ownership of their learning, develop competence, and facilitate connections with peers in the learning of chemistry. Therefore, the investigation sought to ascertain whether an intervention guided by Shulman's (1986, 1987) PCK and Gess-Newsome's (2015) teachers professional knowledge and skill framework enhance conceptual understanding, achievement, and motivation in the specific domains of chemical kinetics and equilibrium concepts. Constructivist Learning Theory (emphasis on Active construction of knowledge), Cognitive Developmental Theory (Stages of cognitive development), Social Cognitive Theory (Learning through observation and social interaction), Social Constructivist Theory (Social interactions and context), and Self-Determination Theory (Motivation and psychological needs) infused into TSPCK framework served as a foundation for the empirical exploration of the interventions to impact the learning outcomes.

2.3. Knowledge that Matters when Teaching Chemistry

In classrooms, teaching and learning are inseparable. They are essential components which are tightly connected. Efforts by effective teachers ensure productive learner interaction during teaching. Teaching, viewed as a process involving teachers' reasoning (Yung et al., 2013), necessitates examining how teachers develop pedagogical transformation reasoning for effective science teaching (Aydin et al., 2014). Teaching requires a variety of skills and knowledge areas, including but not limited to reasoning skills. This viewpoint emphasizes that effective teaching requires a complex collection of cognitive processes such as reasoning, decision-making, problem-solving, and critical thinking (Loughran, 2019). Teachers must examine students' requirements, choose appropriate educational strategies, assess student comprehension, and change their approach accordingly. Viewing teaching from the perspective of teachers' reasoning skills emphasizes the intellectual aspects of the profession as well as the significance of reflective practice and ongoing professional growth (Vesterinen et al., 2014).

Teachers' reasoning abilities are considered important for teaching. This viewpoint contends that the essence of teaching is the reasoning skills that teachers use to enhance student learning (Dilekli & Tezci, 2016). It highlights the importance of cognitive processes in instructional practice and the notion that effective teaching is basically about directing and supporting students' thinking. From this perspective, teaching is defined as the use of teachers' reasoning skills to generate meaningful learning experiences, cultivate critical thinking, and promote deep comprehension in pupils. Both perspectives complement one another, providing unique perspectives for understanding and improving teaching practice. Effective teaching requires a dynamic interaction between teachers' thinking abilities and instructional activities, with the overriding goal of facilitating student learning and development. This complex activity demands the application of knowledge from multiple domains to enhance students' learning (Park & Chen, 2012). Secondary school students acquire science knowledge through experiential learning (Nilsson & van Driel, 2011). Aydin and Boz's (2013) study revealed that teaching secondary school students, especially in areas like math and science, requires teachers to possess skills of pedagogical content knowledge (PCK). Teachers must consider crucial factors in students' understanding and success, emphasizing the need to enrich their knowledge and skills.

The science education community in general and chemistry education in particular lack consensus on what constitutes knowledge for teaching Chemistry (Luft et al., 2015). Learning to teach Chemistry extends beyond acquiring subject content knowledge, as emphasized by Ball et al. (2008). They asserted that practicing science and mathematics teachers, especially Chemistry teachers, require specific content knowledge (CK) and PCK to enhance conceptual understanding, academic achievement, and motivation in teaching. The foundational work of Shulman (1986, 1987) on the PCK and Gess-Newsome (2015) on the teachers' professional knowledge and skill (TPK & S) sets the stage for understanding the basic interplay of content and pedagogical knowledge crucial for effective teaching. The integration of TSPCK, as articulated by Mavhunga (2012), provides a focused lens on topic-specific knowledge components essential for teaching chemistry. The TSPCK construct emphasizes the transformation of content knowledge into specific topics, incorporating key elements such as learner prior knowledge with misconceptions, curricular saliency, identification of teachable elements, use of representations, and application of conceptual teaching techniques (Mavhunga, 2012).

The theoretical underpinnings draw from constructivist, cognitive developmental theory, and achievement goal theory, highlighting the active role of learners in constructing knowledge, progressing through cognitive stages, and the influence of beliefs and motivation on academic success. Social cognitive theory further emphasizes the impact of social interactions, self-efficacy, and peer learning on academic achievement (Lee & Kang, 2023; Yusuf, 2011; Lopez, 1999). In addition, the incorporation of social constructivist theory and self-determination theory aligns with the motivation aspect of the study. Social constructivist theory underscores the role of collaborative learning experiences facilitated by TSPCK-based instruction in constructing knowledge, while self-determination theory emphasizes autonomy, competence, and relatedness as crucial factors in motivation (Zhang, 2021). TSPCK-based instruction is seen as providing opportunities for student autonomy, developing competence, and fostering connections with peers in the learning of chemistry.

The theoretical framework of both PCK and teachers' professional knowledge designed by Shulman (1986, 1987) and Gess-Newsome (2015) gives the basis for investigating the effectiveness of TSPCK-based instruction in enhancing conceptual understanding, achievement, and motivation of students in the specific domains (chemical kinetics and equilibrium concepts). The integration of these theories and models creates a robust foundation for the study, guiding the design and implementation of interventions aimed at improving the quality of chemistry education (Akkus, et al., 2003). The exploration of "Knowledge that Matters when teaching Chemistry," with a particular emphasis on TSPCK-based instruction, offers a comprehensive and theoretically grounded framework for enhancing conceptual understanding, achievement, and motivation among students in the realm of chemistry education (Akinyemi & Mavhunga, 2021).

2.4. Pedagogical Content Knowledge Construct in Chemistry Education and its Taxonomies

The conceptualization of Pedagogical Content Knowledge (PCK), as delineated by Shulman in 1986 and 1987, underscores the distinctive nature of teachers compared to subject specialists such as Physicists, Biologists, Chemists, and others (Shulman, 1986, 1987). Beyond the evident disparities in the quality and quantity of substantive knowledge, the divergence lies in how this knowledge is structured and utilized. The recognition of PCK as a functional and potent construct, particularly for teacher education, is widely acknowledged (Oh & Kim, 2013).

Nevertheless, the extent to which this concept has been universally implemented in educational institutions worldwide remains ambiguous.

PCK, functioning as a theoretical framework, has proven instrumental in scrutinizing teachers' content knowledge employed in the teaching process (Padilla & Van Driel, 2011). Moreover, it is identified as an essential component in the preparation of Chemistry teachers for effective pedagogy, demonstrating a strong correlation with students' comprehension of subjects taught in the classroom (Mansor et al., 2010). The multifaceted nature of PCK and its components not only enriched teachers' quality of teaching but also provided a fertile ground for Chemistry education researchers to design and explore structures that facilitate continuous improvement in teaching practices (Findlay & Bryce, 2012).

While the significance of PCK is evident, Nezvalova (2011) highlights, a crucial gap in its development of taxonomies. This raises questions about the accuracy of existing taxonomies or the potential lack of understanding regarding the generation of PCK. The unresolved issues surrounding the development of PCK taxonomies necessitate a comprehensive examination, comparing taxonomies at different stages of development and with diverse features. This exploration is essential for clarifying whether any inaccuracies exist in the taxonomies or if there is a fundamental gap in comprehending the genesis of PCK. Consequently, the ongoing discourse on PCK's taxonomy development contributes to its evolution as a pivotal area in educational research, underscoring the intricate dynamics of teacher knowledge and its effective application in the classroom.

Pedagogical Content Knowledge (PCK) emphasizes the vital link between understanding and practical application by allowing students to easily transform theoretical concepts acquired in the classroom into real-world applications. This connection is precisely addressed in a well-designed teacher education program that deliberately blends a solid foundation in subject matter with a deliberate emphasis on pedagogy. The program, based on the concepts of PCK, as noted by Corney and Reid (2007), aims to develop educators who go beyond basic subject matter understanding, becoming skilled and reflective practitioners capable of positively affecting student learning outcomes. A key component of this approach is the intentional use of PCK, as recommended by Lee et al. (2007), to improve students' learning. The program's commitment to fulfilling the particular needs of educators at the commencement of their classroom subject

matter learning is proven by the recognition that students benefit tremendously from personalized PCK to improve their comprehension and application of knowledge.

The essence of the subject is the recognition that a well-thought-out pedagogy is essential to improving the quality of teaching and thereby influencing the way students learn. The argument is consistent with the notion that an educator with advanced content understanding achieves more student gains than a less prepared or experienced counterpart (Park & Oliver, 2008). This remark highlights PCK's tangible impact not only on educators but, more importantly, on students themselves. PCK emerges as a transformative instructional design that embodies a desirable educational concept. It is the knowledge that educators gain over time and through experience, outlining how to teach specific topics in effective ways that improve student conceptual understanding and overall learning outcomes (Van Dijk and Kattmann, 2007). The adoption of PCK into a teacher education program is thus not merely a pedagogical choice but also a strategic investment in the effectiveness and impact of future educators. PCK and its usefulness in advancing chemistry education have been critically evaluated. Here are some important elements to examine as empirical evidence for the role of both PCK and TSPCK-based instruction in chemistry education.

Miller and Gess-Newsome (2005) emphasize the importance of TSPCK in teaching specific concepts and abilities in chemistry education. Their review, which focuses on critical topics such as acid-base reactions and chemical bonding, underlines the importance of educators having a thorough understanding of pedagogical content knowledge in order to effectively transmit complex ideas and skills to students. The article is a good resource for individuals interested in the significance of PCK in chemistry education (Miller & Gess-Newsome, 2005). Guskey's (2002) research investigates the relationship between subject matter knowledge and teaching experience in shaping PCK. He contends that teachers with a strong understanding of chemistry and extensive teaching experience are more likely to build successful PCK, which improves both teaching and student learning results. This viewpoint illuminates the dynamic interaction between instructors' subject matter expertise and instructional experience in developing effective PCK (Guskey, 2002).

Moore and Gess-Newsome (2009) add to the discourse by emphasizing the importance of professional development in molding teachers' PCK. Their research demonstrates that

professional development options, such as seminars and mentoring programs, are critical in providing educators with the information and skills they need to teach chemistry effectively. This study provides practical insights into how targeted professional development might help instructors acquire strong PCK (Moore & Gess-Newsome, 2009). The National Research Council's comprehensive approach highlights the transformative power of PCK-based instruction in K–12 scientific education (NRC, 2012). Their findings show that PCK-based instruction not only increases student involvement but also improves understanding of complicated ideas. This study demonstrates the larger influence of PCK on student learning outcomes, offering a convincing case for the incorporation of pedagogical content knowledge into science education in general and chemistry education specifically. In conclusion, this collection of relevant study findings emphasizes the importance of PCK in developing good chemistry education.

There are different perspectives in relation to PCK taxonomies. For instance, in their taxonomy, Wong and Evans (2017) take into account the unique requirements of social studies, science, language, math, and the arts. A customized PCK that fits each subject area's particular concepts, abilities, and pedagogical techniques is necessary, highlighting the fact that good teaching is subject-specific. Wong and Evans (2017) categorized PCK by student and various types of teaching, which include English language learners, students with special needs, and gifted and talented students. Each type of student diversity demands a tailored PCK that is modified to the unique pedagogical strategies and subject matter expertise required for effective teaching in different student groups. The study conducted by Koehler and Mishra (2009), classified PCK based on grade levels, including elementary, middle, and high school. Acknowledging the unique impediments and possibilities present at every grade level, this classification of PCK highlights how PCK may be designed to meet the unique requirements of various learning phases, enabling focused instructional approaches.

PCK is categorized according to instructional strategies, such as project-based learning, direct instruction, and collaborative learning, under a different taxonomy put forward by Lee and Shakrani (2011). This viewpoint emphasizes how important it is to customize PCK to the unique needs of each teaching strategy by acknowledging the variety of pedagogical tactics and topic knowledge connected with each approach.

A taxonomy centered on technology integration is presented by Hampton (2013) and includes digital tools, online resources, and classroom technology use. This classification highlights how the educational landscape is changing and how important it is for teachers to create PCK that is in line with the unique pedagogical approaches and subject-matter expertise linked to a variety of technology tools.

Hmelo-Silver (2004) contributes to the taxonomic landscape by classifying PCK based on learning outcomes and assessment modalities. This viewpoint acknowledges the distinct educational practices and material knowledge required for outcomes like critical thinking and teamwork, as well as the various assessment kinds (formative, summative, and authentic assessments). This technique ensures that PCK is adapted to the individual requirements of different learning objectives and assessment methodologies. Krajcik and Czerniak (2014) provide a taxonomy based on curriculum frameworks such as Understanding by Design (UbD) and Backwards Design. This classification emphasizes the alignment of PCK with specific curricular standards, emphasizing the importance of educators tailoring their knowledge to the unique needs of various curriculum frameworks.

Veal and Makinster (1999) present a taxonomy that categorizes pedagogical content knowledge (PCK) into three major dimensions: general PCK, domain-specific PCK, and topic-specific PCK, providing a foundational framework for understanding the nuanced nature of teachers' knowledge and pedagogical practices within specific disciplines. In this thorough examination, the taxonomic framework serves as a structured lens through which to comprehend the diverse character of PCK. Differentiating between general, domain-specific, and topic-specific PCK provides educators and researchers with a nuanced perspective, allowing for targeted inquiries into the complexities of pedagogical content knowledge within distinct disciplinary contexts. This taxonomy establishes the framework for future research efforts aimed at understanding the complexity of PCK and its transformative effect in education.

Veal and Makinster's (1999) taxonomy begins with generic PCK, capturing a larger knowledge of instructors' pedagogical strategies in areas such as science (Nezvalová, 2011). The conceptualizations of general PCK reveal multiple facets, presenting teacher PCK as both clear and, in some cases, mysterious. While these conceptual models provide insights into PCK structures, they are too broad to be directly utilized in circumstances where PCK is exclusive to a

particular chemical concept. Moving deeper into the taxonomy, domain-specific PCK focuses on specialized topic matter within a given area, such as science. Notably, this model has resonance in science disciplines such as biology (Juttner & Neuhaus, 2012) and chemistry (Tepner & Witner, 2011). PCK component descriptions in domain-specific contexts include factors such as science curriculum, scientific knowledge, and science orientation (Jing-Jing, 2014). However, for the current study, this PCK model, which is rich in science-specific components, requires adaptation because the focus is on the topic-specific nature of PCK, with an emphasis on the transformation of content knowledge (CK).

A growing consensus among educators is that PCK is essentially topic-specific (Abell, 2008; Aydin et al., 2014). This is consistent with Mthethwa-Kunene et al. (2015), who argue that PCK is a combination of topic-specific content knowledge, pedagogical knowledge, and awareness of students' preconceptions and learning difficulties (p. 1145). The emphasis here is on a thorough examination of PCK in relation to a specific chemical concept, with a special emphasis on the transformation of content knowledge during the teaching process. Furthermore, Nezvalova (2011) investigated the theoretical premise that competency in topic-specific PCK can reflect a teacher's solid understanding and ability in both general and domain-specific PCK. The next section gives emphasis to the topic specific PCK based instruction in learning science in general and chemistry education in particular.

2.5. Topic Specific Pedagogical Content Knowledge as Instructional approach

Shulman's (1987) notion "completed concepts must be revised in some way if they are to be taught" is the basis for this study (p. 8). The capacity of teachers to redesign instruction based on pedagogical content knowledge (PCK), with the purpose of making concepts in the subtopic understandable to students, in a single topic is the key to this argument. Having sufficient Content Knowledge (CK) is extremely important in order to apply proper pedagogical transformation skills (Oh & Kim, 2013). In this regard, Aydin et al. (2014) indicated that "teachers entirely transfer their subject matter knowledge (SMK) into PCK for teaching diverse topics within a comparable discipline" (p. 658). A teacher is required to be aware of the relevance of remodeling subject matter information in order to improve learning (Geddi, 1993; Gess-Newsome, 2015). This argument has formed the foundation for PCK investigations that leads to the widely held topic-specific nature/belief nowadays (Rollnick & Mavhunga, 2014).

The TSPCK framework posits that effective technology integration in teaching and learning requires a combination of knowledge in technology, pedagogy, and content. The model consists of three main components: Technological Knowledge (TK), Pedagogical Knowledge (PK), and Content Knowledge (CK). According to Mishra and Koehler (2006), TK refers to the knowledge and skills needed to effectively use technological tools and resources. PK refers to the knowledge and skills required to design and implement effective teaching and learning strategies using technology. CK refers to the knowledge and skills required to teach the subject matter taught. Therefore, this study was utilized these three knowledge and skills (TK, PK and CK) in using TSPCK based instruction in learning chemical kinetics and equilibrium concepts to enhance students' conceptual understanding, achievement and learning motivation.

2.6. Topic Specific Pedagogical Content Knowledge Components in Teaching Chemistry

A comprehensive examination of instructional strategies and representations for teaching Chemistry, as delineated by Marifa et al., (2023), reveals a distinction between subject-specific and topic-specific methodologies. Subject-specific approaches, such as learning cycles, conceptual change strategies, and inquiry-oriented instruction, provide broad instructional frameworks congruent with scientific education goals. In contrast, topic-specific techniques are unique strategies tailored to specific topics within the scientific domain, narrowing the focus to intricacies inherent to teaching particular concepts of Chemistry.

The concept of topic-specific pedagogical content knowledge (TSPCK) explores deeper into the difficulties of teaching particular chemistry topics, addressing challenges, frequent misconceptions, and useful strategies particular to each concept (Makhechane & Mavhunga, 2021; Smith, 2015). For example, TSPCK in chemistry entails knowing how to teach difficult concepts like stoichiometry, chemical bonding, and thermodynamics. It highlights how crucial it is to adjust instruction to each topic's unique characteristics and difficulties.

In another study, Mavhunga and Rollnick (2013) provided a thorough explanation of the TSPCK concept, emphasizing five essential elements: (i) students' preconceptions and prior knowledge; (ii) curriculum saliency; (iii) factors influencing a subject's comprehension ease or difficulty; (iv) representations and analogies; and (v) conceptual teaching strategies. In line with Shulman's (1987) claim that concepts must be transformed in order for instruction to be effective,

Mavhunga (2014) identified these elements as being essential to the conversion of content knowledge (CK) into TSPCK. TSPCK is a transformational pedagogical method that is significant because it allows for the conversion of a particular chemistry topic through the development of a specialized understanding that is derived from the study of content-specific components.

Although PCK covers a wider range of knowledge, including context, students, subject matter, and pedagogical strategies, TSPCK focused on the interaction between CK and the subtleties of topic-specific instruction (Davidowitz & Rollnick, 2011). One of the four knowledge domains, the content knowledge domain, is essential in bridging PCK and TSPCK. This link emphasizes how important subject-specific knowledge is for improving pedagogical strategies, especially when dealing with the difficulties that come with teaching different subjects within a field.

The following subsection explores the explicit elements of TSPCK, explaining how each facet contributes to the conversion of content knowledge for successful topic teaching. This targeted strategy, which emphasizes the specifics of a given subject, highlights the distinctive and specialized character of TSPCK and establishes it as a useful framework for improving instructional practices in the context of particular content areas.

2.6.1. Learner Prior Knowledge

Within TSPCK, the notion of prior knowledge has been deeply ingrained. It refers to students' perceptions and understandings of how well they have understood particular scientific concepts (Hassard & Dias, 2009). Geddis (1993) offers an important viewpoint on prior understanding, defining it as a set of misconceptions that are essential to the subject matter's transformation within the TSPCK framework. This includes the misconceptions that students have about the subject matter they are studying when they enter the classroom.

Geddis (1993) argues that, as an efficient teaching and learning technique, the curriculum should incorporate the prior knowledge of the learners. In noteworthy studies (Hailikari et al., 2008; Liu et al., 2008), researchers created a set of questions that focused on the mole concept, manifestations of substance concentration in aqueous solutions, and chemical changes. A thorough understanding of chemical changes, concentration expressions, and the mole concept is essential for teaching and studying chemical kinetics and equilibrium. According to Gabel

(1999), these concepts are vital because they provide the required basis for understanding more difficult issues in chemical kinetics and equilibrium. Mastery of chemical changes enables students to comprehend how reactions progress, whereas concentration expressions are critical for understanding reaction rates and equilibrium positions (Eilks & Byers, 2009). Furthermore, the mole idea is critical for quantifying reactants and products in chemical processes, which is required for investigating reaction kinetics and equilibrium states (Sanchez & Guerra, 2017). Thus, prior knowledge in these domains facilitates a deeper understanding and successful learning of advanced chemical concepts. Learner prior knowledge is an important aspect of teaching chemical kinetics and chemical equilibrium because it allows the teacher to build on existing knowledge, activate prior knowledge, address misconceptions, use analogies and examples, provide opportunities for practice, use formative assessments, differentiate instruction, use technology, encourage collaboration, and provide feedback to students (Kopcha & Sullivan, 2007). Effective learning and teaching rely on resolving previous knowledge, particularly misunderstandings, which is an important focus of Topic-Specific Pedagogical Content Knowledge (TSPCK) (Magnusson et al., 1999). Recognizing and correcting these misconceptions with targeted TSPCK-based instruction increases comprehension and educational results (Mthethwa-Kunene et al., 2015). Identifying and resolving learners' pre-existing misconceptions allows educators to improve the effectiveness of their educational practices and encourage a more nuanced and accurate comprehension of complicated scientific subjects (Cook, 2006).

2.6.2. Curricular Saliency

Curriculum saliency, as operationally described by Akinyemi and Mavhunga (2021), is the ability to identify the fundamental ideas that connect a topic, which is critical to how teachers approach lesson planning and delivery. In the context of teaching, educators have the issue of completing syllabi while emphasizing vital topics, also known as "big ideas." Vokwana (2013) underlines the necessity of recognizing which issues are critical in this process, emphasizing the transforming power of teachers' knowledge.

Loughran et al. (2012) define big ideas as science concepts that are considered crucial for students' thorough grasp of a subject or issue. As Ball et al. (2008) state, this entails identifying fundamental concepts that students should grasp before proceeding forward. Teachers'

understanding of curricular saliency not only helps them discover necessary concepts in a topic, but also supports them in determining the order in which they should teach them. Mthethwa-Kunene et al. (2015) show that teachers' mastery of the curriculum has a major impact on their PCK, functioning as a knowledge source for content planning and sequencing. The assessment criteria for instructors' classroom activities in terms of curricular saliency in chemistry topics include differentiating the scope of chemistry, sequencing chemistry concepts for effective learning, identifying available curricular resources, and using standards to guide chemistry planning and teaching (Barber, 2020). Big ideas in chemical kinetics include rate of reaction, rate law, rate-influencing factors, and reaction mechanism. Similarly, in chemical equilibrium, important concepts include equilibrium dynamics, equilibrium constants, and Le Chatelier's principle. Big ideas in chemical kinetics include rate of reaction, rate law, rate-influencing factors, and reaction mechanism. Similarly, in chemical equilibrium, important concepts include equilibrium dynamics, equilibrium constants, and Le Chatelier's principle. In this study the big ideas are the specific topics discussed here.

2.6.3. Easy or Difficult Nature of the Subject to Teach

One of the key components of the TSPCK approach is figuring out what makes a given topic easy or difficult to teach. Both teachers and students face difficulties when it comes to the concepts associated with chemical kinetics and equilibrium. According to Vokwana (2013), giving attention to nature of the subject helps educators create conceptual models and instructional strategies that successfully tackle the challenges posed by concepts.

Several factors contribute to the complexity of teaching chemical kinetics and equilibrium. These include the need for threefold representation, mathematical concepts, and advanced teacher knowledge integrating CK and PCK. In chemical kinetics, challenges arise in understanding the concept of order of reaction, rate laws and reaction mechanism. Also, in the concepts of chemical equilibrium difficulties are commonly observed in concepts such as Le Chatelier's principles and dynamic equilibrium. To overcome these challenges, teachers need to possess knowledge about the complexities inherent in each concept, making it essential for them to identify and understand the types and aspects of complexity that hinder accessibility.

Khadim and Al-Asmar (2018) investigated the teaching of chemical kinetics and equilibrium, stressing techniques for improving comprehension. They discovered that concept mapping,

relatable examples (such as the browning of a roast), and visual aids such as graphs all help with learning. TSPCK-based instructional strategy improves conceptual understanding and expands the application of key principles. The difficulties in these concepts are related to mathematical complexity, abstract concepts, and disconnection from everyday circumstances (Al-Shehri & Al-Jarallah, 2019; Khadim & Al-Asmar, 2018). The mathematical equations can be difficult to understand, especially for those who struggle with math. Abstract ideas such as reaction mechanisms and equilibrium constants can be difficult to picture and understand. Furthermore, a lack of applicability to everyday life can impair students' perceptions of the concept's importance. Educators can improve accessibility and engagement by incorporating relevant examples, visual aids, and interactive activities into their instructional methods.

2.6.4. Representations

According to Geddis and Wood (1997), representation-based instruction in TSPCK entails using effective examples, metaphors, analogies, models, simulations, diagrams, and drawings to engage students. Johnstone (1991) suggests three levels of representation within this aspect. In chemistry education, the notions of triple representation and mental representation are closely related but distinct. The three levels of representation are macroscopic, microscopic, and symbolic (Johnstone, 1991; Permatasari et al., 2022). The macroscopic level deals with observable events; the microscopic level delves into the atomic and molecular realms that are not directly apparent; and the symbolic level uses symbols and equations to represent chemical phenomena. These levels serve as external frames, assisting students in understanding the links between different levels of chemistry representation.

However, much of chemical instruction takes place at the abstract (symbolic) level, which presents obstacles since students may struggle to grasp symbols or translate them to other levels of representation (Konidaris et al., 2018). On the other side, mental representation refers to the mental images or models that people build to understand and solve problems (Sinaga, 2022). These mental models are essential for problem-solving in the field of chemistry. An individual's prior knowledge, experiences, and understanding of the subject matter all have an impact on both their physical and mental representations. While triple representation serves as an outward framework, mental representation depicts the interior cognitive processes that students use to

understand and solve problems. Effective chemistry instruction entails enabling linkages between these triple (external) and mental (interior) representations.

Representation is a cornerstone of educational techniques, providing a powerful technique for aiding instruction and problem-solving for both educators and students (Kozma, 2012). As educators develop their teaching strategies, they should carefully consider the various ways representation might be used in lesson planning, practice sessions, and reinforcement activities (Tasker & Dalton, 2006). The integration of various types of representations ranging from powerful examples and metaphors to analogies, models, simulations, diagrams, and illustrations is critical in the field of TSPCK (Geddis and Wood, 1997). Notably, such representations can immediately engage with and address learners' current preconceptions or alternative conceptions, encouraging deeper knowledge and meaningful learning experiences.

Furthermore, Johnstone's (1991) argument for recognizing three levels of representation—macro, micro (sub-micro), and symbolic is critical for conceptualizing teaching chemistry topics. Using analogies, as a representation-based TSPCK strategy, require teachers to demonstrate an understanding of how to explain chemical kinetics and chemical equilibrium ideas using various levels of representation. Hands-on demonstrations, laboratory equipment, models, charts, diagrams, and mathematical equations are all examples of representations used in chemistry education (Carrejo & Marshall, 2007). Shulman (1986) highlights the importance of PCK, stating that effective forms of representation, striking analogies, examples, and methods of portraying and articulating issues help to make them understandable to others.

According to Prain and Tytler (2012), representation not only helps students understand concepts better but also acts as a strong motivator by encouraging critical and constructive thought processes. According to Johnstone (1991), science subjects, including chemistry. Present learning challenges and suggests the effective learning practices, such as using labeled diagrams and visual aids, play a key role in facilitating students understanding of the abstract concepts. This approach also supported by Gilbert and Treagust (2009) that allows students to visualize complex chemistry concepts and enhance their cognitive processing, leading to more effective and durable learning outcomes. This highlights how important representation is to good teaching strategies in science (Mthethwa-Kunene et al., 2015). In conclusion, it is critical to increase the

comprehension of chemistry teachers about the use of representations in both actual teaching and preparation, particularly when it comes to the concepts of chemical kinetics and equilibrium.

2.6.5. Conceptual teaching strategies

The conceptual teaching strategy (CTS) emerges as a comprehensive amalgamation of four integral components: learners' prior knowledge, the complexity of teaching material, curricular significance, and varied representations (Mavhunga, 2012). Conceptual teaching strategies perceived as challenging due to their demand for educators to transcend conventional pedagogical approaches, incorporating a diverse array of conceptual ideas (Malcolm et al., 2019). The intricacy of CTS within the TSPCK framework lies in its inclusion of activities across the four TSPCK components, navigating the interactions between these components, and discerning the most specific teaching strategies from general ones (Kahan, 1999).

Choosing the right teaching strategies, especially when it comes to employing representations, and being aware of students' preconceptions are essential components of effective chemistry instruction. Magnusson et al. (1999) stress that, in order to improve comprehension, teaching strategies should be in line with what students already know. Mthethwa-Kunene et al. (2015) go on to show how effective methods for asking questions, diagrams, analogies, and logical concept sequencing are used by knowledgeable teachers to teach chemical kinetics and equilibrium. This highlights the critical role that carefully selected representations play throughout instruction. This emphasizes how teachers must understand curriculum saliency and skillfully use representations to enhance student learning outcomes.

Conceptual teaching strategy-based instruction signifies an approach accentuating the refinement of conceptual comprehension and problem-solving skills. This method encourages students to engage critically and abstractly with chemistry concepts, moving beyond rote memorization of facts and formulas (Bowell & Kingsbury, 2017). Research affirms that such instruction enhances students' ability to apply chemistry concepts to real-life scenarios and tackle intricate problems (Tipton, 2013). Consequently, developing Chemistry teachers' knowledge of conceptual teaching strategies in chemical kinetics and equilibrium at the 11th-grade level proves beneficial.

Teachers can effectively engage students and promote deeper learning by utilizing a variety of instructional strategies that are suited to these topics. The conceptual teaching instructional

strategy includes inquiry techniques, approaches to chemical phenomena, chemistry discourse tools, and wide student-centered procedures.

Inquiry-based learning encourages students to investigate concepts by asking questions, doing experiments, and solving problems. In the context of chemical kinetics and equilibrium, this method enables students to actively examine reaction rates, equilibrium constants, and factors influencing chemical reactions. Students gain a stronger knowledge of these concepts and are driven to investigate further through hands-on exploration and analysis (Trickey, 2010). Demonstrations and predict-observe-explain procedures are useful for providing concrete examples of chemical kinetics and equilibrium principles in action. Visualizing reactions, tracking changes over time, and describing observed occurrences all help students reinforce their conceptual understanding (Jumiati, 2018). This hands-on approach promotes engagement and interest, which increases motivation to joint deeper into the subject matter for learning.

Effective discourse strategies encourage students to have meaningful discussions and exchange ideas. Educators foster a deeper knowledge of chemical kinetics and equilibrium ideas by allowing students to express themselves, ask questions, and participate in peer-to-peer learning (Hartwig, 2017). Guided conversations and collaborative problem-solving activities encourage students to actively participate and take ownership of their learning. Incorporating student-centered activities like debates, writing exercises, and presentations helps students connect chemical kinetics and equilibrium ideas to real-world applications and scenarios (Dixon, 2017). Students become more motivated and engaged when theoretical information is applied to real-world problems. Furthermore, allowing children to demonstrate their comprehension through diverse mediums creates a sense of accomplishment and pride in their learning journey. In a larger sense, conceptual teaching strategy-based instruction refers to a variety of activities.

2.7. Planning versus Enacting Instruction in Topic Specific Pedagogical Content

Knowledge

Teaching involves the transformative process of CK, wherein educators reason through specific topics in a particular manner. Shulman (1987) highlights that this transformation occurs during the planning stage before actual classroom teaching, emphasizing the integral role of pedagogical reasoning in the teaching process. Akinyemi (2016) echoes this sentiment, emphasizing the key

role of transformation in bridging content and pedagogy for teachers. The importance of developing Chemistry teachers' pedagogical transformation abilities is crucial, considering that the observed classroom teaching outcomes are a result of the planning stage transformation. Espoused PCK serves as a guide for teachers in decision-making during the planning stage, as highlighted by Park and Oliver (2008). It signifies teachers' PCK in the planning context, laying the foundation for actual classroom implementation.

Despite the significance of espoused PCK, Aydeniz and Kirbulut (2011) caution that having it does not guarantee its application in actual teaching. While improving teachers' pedagogical transformation competence during planning is valuable, its impact on teacher effectiveness extends beyond classroom-level implementation. Secondary school teachers continually expand their knowledge of chemical kinetics and chemical equilibrium through planning, execution, and reflection on Chemistry teaching and learning (Nilsson & Loughran, 2012).

The study implements TSPCK-based instruction in both planning and enacting lessons on chemical kinetics and equilibrium. This approach aims to bridge the gap between theoretical planning and observed classroom teaching, enhancing teachers' abilities to effectively transform content knowledge into pedagogically powerful knowledge.

2.8. Interactions of Topic Specific Pedagogical Content Knowledge Components and Their Quality

Teachers are responsible for strategically implementing TSPCK components into classroom teaching. However, Friedrichsen et al. (2011) point out that different PCK models frequently identify separate PCK components without precisely defining their interconnections. According to Aydin et al. (2015), it is not just the accumulation of components that is important, but also their dynamic interactions. The quality of teachers TSPCK is closely related to effective teaching (Rollnick et al. 2008). This quality is assessed by seeing how the components interact and manifest during the educational process. Mthethwa-Kunene et al. (2015) find a critical link between their ability to integrate TSPCK components and their thorough comprehension of each component. They believe that teachers' interactive use of TSPCK components demonstrates high-quality teaching.

Chemistry teachers gain TSPCK expertise through active participation in the teaching and learning process. As a result, students who actively participate in learning activities demonstrate improved reasoning skills on specific topics (Mavhunga & Rollnick, 2013). The observed PCK increase in reasoning was related to teachers' understanding of the interactive use of TSPCK components. The complexities of TSPCK interaction are highlighted by situations where the components and their connections are readily visible (Mavhunga, 2015). This observation is consistent with Park and Chen's (2012) approach, which states that TSPCK is more than just the sum of its separate components. As a result, successful teaching requires extensive planning and material transformation prior to course delivery. This review emphasizes the holistic character of effective teaching, emphasizing the significance of careful preparation and the dynamic interaction of TSPCK components in the teaching-learning process.

2.9. Conceptual Understanding in Chemistry and the Three Levels of Representations

Research indicates that both primary and secondary school teachers encounter challenges when teaching science, particularly complex Chemistry concepts (Jurišević et al., 2008). The task of teaching for conceptual understanding in science is particularly daunting for novice teachers (Nam-Hwa & Howren, 2004). Conceptual understanding in science demands students to arrange and connect knowledge into logical and meaningful concepts, rather than simply remembering facts. The use of TSPCK-based teaching strategies emerges as a valuable approach, aiding students in integrating intuitive notions with scientific concepts and fostering meaningful connections, transcending rote memorization (Nam-Hwa & Howren, 2004, p. 31). The literature suggests that science in general, and Chemistry specifically, can be taught and learned more effectively through diverse instructional strategies, including TSPCK-based approaches (Fahmy & Lagowski, 2011). Over the last decade, a systematic approach to teaching and learning, incorporating TSPCK-based instruction, has gained prominence. Chemistry education involves the acquisition and integration of multiple representations across three levels during the teaching-learning process (Ainsworth, 1999; Johnstone, 1993).

Chemical educators emphasize that true understanding of Chemistry occurs when students can proficiently use representations across the three levels and recognize the interconnectedness among them (Devetak & Glazar, 2010). Developing a mental model that integrates the three levels of chemical knowledge and their interconnections deemed essential for students to

cultivate a robust conceptual understanding of a given chemical topic. This review underscores the pedagogical challenges in teaching science, especially Chemistry, and advocates for the efficacy of TSPCK-based instructional strategies in addressing these challenges and promoting meaningful conceptual learning.

2.10. Academic achievement and socio-emotional aspects

In the realm of Chemistry education, the significance of academic achievement for students' current and future lives is widely acknowledged (Kell et al., 2013). However, an evolving perspective is placing increasing emphasis on social and emotional factors, recognizing their pivotal role in students' well-being and psychological development (Chernyshenko et al., 2018; Frydenberg et al., 2017; Moore et al., 2006). This paradigm shift is evident in recent developments such as the inclusion of social and emotional measures in established assessments like those conducted by the Organization for Economic Co-operation and Development (OECD), exemplified by the Program for International Student Assessment (PISA) (OECD, 2019). According to Chernyshenko et al. (2018), these measures encompass emotional regulation, task performance (including drive, perseverance, and self-control), and compound skills such as metacognition and self-efficacy. In alignment with this evolving perspective, the present issue examines the empirical studies exploring the complexities of these social and emotional factors. Some studies directly related to academic achievement, while others extend their focus beyond, collectively contributing valuable insights to the broader discourse.

Research demonstrates how important psychological aspects are to chemistry learning and motivation. The conventional belief that academic failures alone predict success has been challenged by Kumar and Choudhuri (2017), who place more emphasis on the mediating roles of academic balance and self-concept. Martinez et al. (2019) have demonstrated that psychological capital resources, including efficacy, hope, optimism, and resilience, have a substantial impact on improving student achievement and engagement. These findings support a comprehensive approach that addresses the complexities of academic motivation and performance by highlighting the significance of including both cognitive and socio-emotional components in TSPCK-based instructional strategies.

2.11. Relationship between Conceptual understanding and Achievement in learning Chemistry

Comprehending the complex relationship between conceptual comprehension and academic performance is essential in the field of education. According to Amsel (2015), conceptual understanding is the deep grasp of fundamental ideas, principles, and concepts within a subject. It is a foundational talent for critical thinking and problem-solving because it entails the capacity to make connections between seemingly unrelated pieces of information, identify patterns, and comprehend the overall framework (Junsay, 2016). Conversely, academic achievement, as defined by Johansson (2013), relates to the mastery of particular information and skills in a given subject and is determined by grades, test results, or other evaluations. Memorization and application of facts, formulas, and processes are common components of academic achievement (Kim Yoo Jeong, 2017). To put it simply, academic achievement is centered around showcasing mastery of particular skills and knowledge, while conceptual understanding concentrates on comprehending the underlying concepts and principles (Sparfeldt & Schwabe, 2024).

Various theoretical underpinnings have further elaborated on the dichotomy between academic achievement and conceptual understanding, illuminating the complex nature of learning. Higher grades and improved assessment performance are correlated with deeper conceptual knowledge (Farage, 2021). It offers a strong basis on which to apply knowledge, solve problems, and engage in critical thinking. Therefore, deeper comprehension and ultimately higher success are produced by effective teaching strategies that prioritize conceptual knowledge, such as inquiry-based learning and cooperative learning like topic-specific PCK-based instruction (Dejene & Belachew, 2023; Younger, 2020).

2.12. Motivation in Learning Chemistry

An extensive investigation into motivation in high school chemistry instruction highlights the complex and hidden elements of this multifaceted problem (Nurhayani et al., 2018). Researchers have studied the motivation from many angles, providing light on several common themes and conclusions in the extant literature. One critical issue under consideration is the distinction between intrinsic and extrinsic motivation. Intrinsic motivation comes from within the individual, whereas extrinsic motivation is motivated by external influences like grades or prizes

(Olanmi, 2016). Numerous studies have examined the impact of both types of motivation on students' involvement and overall achievement in the field of chemistry education (Grajcevcic & Shala, 2021; King & Datu, 2017). The literature suggests a direct correlation between students' motivation and their understanding of how chemistry connects to real-world scenarios or future aspirations (Eckhardt, 2018). When students discern the applicability of chemistry to their lives, their motivation to master the subject invariably heightened (Yadigaroglu et al., 2021).

The influential role of teachers in shaping students' motivation constitutes a significant focal point in the research (Bhattacharjee & Roy, 2012). Teacher enthusiasm, effective communication of subject matter, and the establishment of a supportive and inclusive learning environment have all scrutinized as crucial factors influencing student motivation in the context of chemistry education (Palmer, 2020; Lazarides et al., 2018). The impact of the learning environment, both within the classroom and the broader school setting, emerges as another critical consideration (Cicuto & Torres, 2016). Factors such as the availability of resources, the quality of laboratory facilities, and the overall culture of the school community are identified as contributors to students' motivation to actively engage in chemistry concept (Kember et al., 2010).

Moreover, the integration of technology and innovative teaching methods has been a subject of exploration (Hassan & Salihu, 2020). Studies suggest that virtual labs, interactive simulations, and other technology-enhanced learning tools can play a pivotal role in positively influencing students' interest and motivation to examine the complexities of chemistry (Munene et al., 2023). Cultural and gender differences constitute an additional layer of complexity in understanding motivation in learning chemistry (Veloo et al., 2015). The literature underscores the need for educators to comprehend and address these variations, emphasizing the importance of inclusive and culturally responsive teaching practices to foster motivation among diverse student populations (Rüschepöhler & Markic, 2020). In the ensuing subsections, PCK/TSPCK-based instruction and motivation; and motivation subscales in relation to TSPCK-based instruction in chemistry are discussed.

2.12.1. Topic Specific Pedagogical Content Knowledge-based instruction and Motivation in Learning Chemistry

The impact of PCK/TSPCK-based instruction on high school students' motivation to learn chemistry has received substantial attention in the continuous attempt to improve pedagogical approaches and student learning (Magwilang, 2016). A detailed critical review of existing literature reveals an advanced knowledge of the multifaceted link between PCK, instructional strategies, and student motivation (Olahanmi et al., 2016).

PCK, recognized as the fusion of content and pedagogical knowledge, emerges as a foundational element in effective teaching (Keller et al., 2017). The literature consistently emphasizes the crucial need for teachers to possess a profound grasp of the subject matter and the ability to convey that knowledge in ways that are accessible and meaningful for diverse learners. Studies exploring the nexus of PCK and topic-specific PCK consistently reveal a positive correlation with student motivation (Akinyemi & Mavhunga, 2021). Teachers armed with a sophisticated understanding of both content and effective teaching methods well positioned to design instructional experiences that attract students' interest and foster a profound sense of the subject's relevance and importance.

PCK-based instruction frequently integrates interactive and inquiry-based teaching methods (Aulls et al., 2015). The literature suggests that these approaches not only deepen students' comprehension of chemistry concepts but also contribute substantively to increased motivation. Strategies such as hands-on experiments, collaborative learning experiences, and problem-solving activities are identified as particularly effective in engaging students actively in the learning process (Kampamba, 2023). A pivotal facet of leveraging PCK for intensified student motivation lies in teacher professional development (Yang et al., 2020). The literature underscores the ongoing need for training and support mechanisms that assist educators in developing and refining their PCK (Faikhamta et al., 2020). This ensures that teachers can proficiently implement topic-specific instructional strategies resonant with the unique characteristics of high school students. PCK-based instruction is often associated with the promotion of student-centered learning environments (Wiener et al., 2018). When students actively participate in the learning process, are encouraged to pose questions, and provided opportunities for independent exploration their motivation is more likely to flourish (Cicuto &

Torres, 2016). While the prevailing literature generally attests to the positive impact of PCK and TSPCK-based instruction on high school students' motivation in learning chemistry, it concurrently underscores the imperative role for continued research and distinctive exploration (Miheo & Mavhunga, 2020). Moreover, examining the effect of sustained TSPCK based instruction and its influence on students' motivation would significantly contribute to the depth of insights in the chemistry education fields.

2.12.2. Motivation subscales in learning chemistry and TSPCK-based Instruction

Comprehending the function of motivation in learning environments is essential to improve teaching strategies, especially when it comes to difficult topics like chemical kinetics and equilibrium. The main motivational sub-scales examined in this review include intrinsic motivation, self-efficacy, self-determination, mark motivation, and career motivation. Examining these motivational components within the framework of TSPCK-based instruction aims to highlight how these factors contribute to improved conceptual understanding, academic achievement, and overall student motivation.

Intrinsic Motivation

The notion of intrinsic motivation in learning, defined as an individual's desire to engage in learning for the sheer enjoyment, fascination, or relevance to their psychological needs, has been extensively explored in academic literature (Froiland et al., 2012). Students' engagement is driven by intrinsic motivation, which stems from their inborn interest and pleasure in the subject matter (Deci & Ryan, 2000). Research consistently indicates that heightened intrinsic motivation correlates with increased effort and task performance (Augustyniak et al., 2016). Moreover, students exhibiting higher levels of intrinsic motivation tend to demonstrate superior conceptual learning, enhanced memory retention, and overall academic success (Augustyniak et al., 2016). This connection to intrinsic motivation extends to a deeper immersion in the subject matter, leading to optimal outcomes for these students (Augustyniak et al., 2016). Studies have demonstrated that intrinsically motivated students are more persistent, emphasizing the significance of intrinsic motivation in learning (Hanus & Fox, 2015). Intrinsic motivation has a significant impact on academic achievement, learning perseverance, and productivity (Froiland et al. 2012). Intrinsically motivated students show a genuine interest in undertaking difficult

assignments and exhibit positive classroom behaviors, ultimately leading to better academic performance (Walker et al., 2006).

The significance of intrinsic motivation extends to long-term achievements, conceptual understanding, and reduced anxiety during academic tasks, mastery goals, voluntary persistence in educational tasks, and various other facets of academic success and psychological well-being (Froiland & Oros, 2014; Blizak, 2017; Csikszentmihalyi & Nakamura, 2014; Cerasoli & Ford, 2014; Froiland, 2015; Upadyaya & Salmela-Aro, 2013). Indirectly, intrinsic motivation exerts its most profound influence on achievement through classroom or behavioral engagement, with some researchers equating intrinsic motivation to emotional engagement, predicting subsequent behavioral engagement (Froiland et al., 2021). In the field of learning chemistry, intrinsic motivation emerges as an important element. Research suggests that using TSPCK-based instruction, which emphasizes real-world applications, hands-on experimentation, and practical relevance, increases students' genuine interest in the subject (Bruce, 2020; Çaylak, 2017). The literature constantly supports a well-designed curriculum that is connected with students' interests and experiences in order to create and maintain intrinsic motivation during the learning process. This is consistent with the premises of self-determination theory, which regards intrinsic motivation as the highest level of autonomous motivation. Promoting intrinsic motivation encourages students to actively participate in disciplines such as math and science (Froiland, 2014; Froiland & Oros, 2014).

Self-Efficacy

Schwarzer (2014) defined self-efficacy as a student's beliefs and convictions about their ability to acquire specific knowledge or abilities. Self-efficacy influences students' belief in their potential to succeed (Bandura, 1997). According to the literature, students with high self-efficacy demonstrate proactive, competitive, and innovative behaviors, which contribute to better learning outcomes (Shi et al. 2018). The nature of self-efficacy emerges as a significant factor, impacting students in diverse ways. Tiyuri et al. (2018) propose that students with elevated self-efficacy find it easier to make decisions and choices, fostering an environment where self-confidence thrives. Conversely, students with low self-efficacy tend to shy away from challenging activities, as noted by Toharudin et al. (2019). The influence of self-efficacy, according to Bandura (1987)

extends beyond the academic realm, constituting a fundamental element of self-concept and playing a vital role in the timely completion of learning tasks.

Teachers, as integral facilitators of the learning process, assume a critical role in nurturing student self-efficacy. Flores (2015) underscores the importance of teachers' expertise and planning in this regard. Effective strategies employed by teachers can significantly impact students' self-efficacy, but the quality of teaching is paramount in achieving this outcome. Establishing positive reciprocal connections between teachers and students, along with teachers possessing high self-efficacy, becomes instrumental in the cultivation of students' self-efficacy (Flores, 2015). The use of conceptual mapping strategies is highlighted as a valuable tool for teachers to enhance students' efficacy in learning (Bressington et al., 2018). Furthermore, the review explores self-learning as a means to encourage self-efficacy, emphasizing the role of technology in facilitating independent learning experiences (Stajkovic et al., 2018). The intricate relationship between self-efficacy and the learning process is expounded upon, with high self-efficacy alleviating stress and low self-efficacy exacerbating the burden associated with learning tasks. This review posits that TSPCK-based instruction exerts a profound impact on students' self-efficacy. Tailoring instructional strategies to the unique characteristics of chemistry enables students to foster a belief in their ability to comprehend and master complex concepts (Tal et al., 2021). However, the literature acknowledges that self-efficacy beliefs are influenced not only by instructional strategies but also by teacher support and the overall learning environment (Burić & Kim, 2020). This underscores the need for a comprehensive approach to enhancing self-efficacy in the realm of learning chemistry, incorporating instructional methods, teacher-student dynamics, and the creation of positive learning environments.

Self-Determination

Wehmeyer et al. (2012) define self-determination as one's motivation to improve oneself as a person and learner. This study investigates the varied consequences of self-determination for students' learning experiences, focusing on motivation, self-esteem, and academic self-efficacy. Self-determination, as defined by the Self-Determination Theory (SDT), is an important aspect in the school environment, especially when learning complicated subjects like chemical kinetics and equilibrium. SDT focuses on three core psychological needs: autonomy, competence, and

relatedness (Deci and Ryan, 2000). Self-determination shows students' sense of autonomy and control over their learning (Bandura, 1997).

Self-determination is a key factor determining students' engagement, conceptual understanding, and achievement, mostly in challenging chemistry concepts like chemical kinetics and equilibrium. Research indicates that students with a sense of autonomy in their learning process are more engaged with the subject matter (Reeve, 2012). This engagement is crucial for understanding the complex ideas in chemical kinetics and equilibrium, which require independent research, critical thinking, and problem-solving.

Bandura (1997) emphasizes that confidence in one's skills promotes determination and mastery, characters essential for navigating the complexities of reaction rates and equilibrium constants. Similarly, Zimmerman (2000) links perceived expertise with improved academic performance and a greater motivation to continue through difficult tasks, enhancing both motivation and conceptual understanding in chemistry. The need for relatedness also plays a significant role in fostering motivation and engagement. Baumeister and Leary (1995) emphasizes the importance of feeling connected to others, an aspect that is enhanced in collaborative learning environments and through supportive teacher-student relationships. These conditions are vibrant for creating a positive and interactive learning experience, particularly when exploring abstract concepts such as dynamic equilibrium and reaction mechanisms (Wentzel, 1998).

While self-determination and self-esteem are distinct constructs, both influence learning outcomes. Deci et al. (1991) argue that self-determined students, driven by intrinsic motivation, reveal higher levels of engagement and determination, which are crucial for mastering the complexities of concepts. Pintrich and Schunk (2002) support this by perceiving that intrinsic motivation enhances problem-solving and conceptual comprehension. Self-determination positively impacts conceptual understanding in chemistry, particularly in complex topics like chemical kinetics and equilibrium. Students with strong self-determination exhibit intrinsic motivation, effective goal-setting, and self-regulation, which are crucial for mastering these challenging subjects (Ryan & Deci, 2000). This internal drive boosts persistence through difficulties, allowing students to address misconceptions and engage profoundly with abstract concepts. Similarly, self-esteem plays a supportive role by fostering confidence, resilience, and active engagement in learning (Baumeister et al., 2003). High self-esteem enhances students'

willingness to seek help, participate in discussions, and insist, creating a positive feedback loop that strengthens comprehension and academic performance in chemistry.

However, a lack of self-determination or low self-esteem can impede conceptual understanding in learning. Understanding the distinct yet interconnected roles of self-determination and self-esteem allows educators to design strategies that develop these behaviors, creating a supportive environment that enhances motivation, engagement, and achievement in mastering complex chemistry concepts.

Mark Motivation

Mark motivation refers to the motivation to learn a subject to earn good scores or achieve high test scores (Çiğdemoğlu, 2012). Mark motivation relates to the motivation to achieve excellent results in school (Schunk, Pintrich, & Meece, 2008). This type of motivation can lead to a lack of engagement and a shallow understanding of the subject matter, which can ultimately hinder academic performance (Ahmad, Yakob, Bunyamin, Winarno, & Akmal, 2021). The complex interplay between mark motivation and learning results, particularly in the field of chemistry education, serves as a focus point for educational research and teaching practice. This critical analysis investigates the intricate relationship between mark motivation and students' conceptual comprehension and academic accomplishment, shedding light on the significance of TSPCK education in this complicated dynamic (Maryani & Martaningsih, 2015). Mark motivation, which encompasses students' desire to achieve excellent academic grades, overlaps with the cognitive and affective components of learning, having a significant impact on educational outcomes (Faizah & Wati, 2021). When placed within the context of TSPCK training, which tailors pedagogical tactics to specific chemical concepts, the relationship between mark motivation and learning results becomes even more convoluted.

Empirical studies on the relationship between mark motivation, conceptual knowledge, and academic accomplishment in the context of TSPCK instruction reveal a complex set of findings. While some research indicates a positive association between mark motivation and learning results, others show a more nuanced relationship influenced by a variety of contextual circumstances (Smith & Stein, 2018). Mark motivation has been shown in studies to have a favorable impact on engagement, perseverance, and academic success (Jones & Wang, 2019).

When combined with specific teaching approaches informed by topic-specific PCK, students may be more receptive to learning, resulting in improved conceptual comprehension and academic performance.

The interaction between mark motivation and learning results is not without difficulties. Students' motivational orientations vary depending on a variety of circumstances, including intrinsic interests, perceived importance of the subject matter, and external incentives (Brown & Lee, 2020). Furthermore, the alignment between students' ambitions for excellent marks and their inherent curiosity and knowledge of chemical ideas requires careful study in order to reduce the possibility of superficial learning outcomes. Understanding the relationship between mark motivation, learning outcomes, and topic-specific PCK instruction requires a deep understanding of motivational dynamics and instructional design (García & Martinez, 2017). Educators are responsible for creating an environment conducive to intrinsic motivation, encouraging students' genuine curiosity and passion for chemistry, and sparingly utilizing extrinsic motivators. Furthermore, the use of new pedagogical practices guided by TSPCK provides potential to effectively synergize mark motivation and learning outcomes (Choi & Kim, 2021). By adapting teaching approaches to specific chemical concepts and students' various learning needs, educators can encourage deeper conceptual understanding and long-term academic accomplishment.

As chemistry education evolves, the interaction between mark motivation, learning outcomes, and TSPCK instruction remains open for investigation and development. The goal of this research is to close a knowledge gap regarding motivation, achievement, and conceptual comprehension in educational settings by combining pedagogical theory, educational psychology, and curriculum design viewpoints. With a more thorough understanding of these variables, this method will help to improve educational practices and enhance the learning experiences of students by allowing for deeper insights into the effects of methods of instruction on results (Nguyen & Smith, 2020). Educators are also encouraged to use evidence-based strategies, foster an intrinsic motivation culture, and constantly refine teaching approaches to improve students' learning outcomes. Combining mark motivation, conceptual comprehension, and academic accomplishment with TSPCK instruction can improve chemistry education's efficacy and relevance in preparing students for future challenges.

Career Motivation

A person's internal, complex desire that is influenced by a variety of external circumstances or variables is known as career motivation. It affects the choices and actions people take with their professional trajectories. London (1983) asserts that this motivation is a dynamic reaction to the environment as well as a personal quality that directs how people approach their goals and professional development. It shows up in the decisions they make, the work they do, and their entire professional path. Career motivation links learning outcomes to future job aspirations (Schunk et al., 2008). Career motivation plays a crucial role in enhancing conceptual understanding and achievement in chemistry learning (Hagos & Andargie, 2022). Research shows that when students are motivated to pursue a career in chemistry, they are more likely to engage in deep learning strategies, such as actively seeking out challenging problems to solve, persistently working to develop their understanding, and reflecting on their learning experiences (Zohar & Dori, 2003). These deep learning strategies, in turn, lead to improved conceptual understanding and better academic performance (Hattie & Donoghue, 2016). Furthermore, research has shown that career motivation can enhance students' persistence and motivation to learn chemistry, even when faced with challenges and obstacles (Pintrich, 2000). This persistence and motivation can lead to improved academic performance and increased success in chemistry concepts (Eccles & Wigfield, 2002).

The impact of career motivation on conceptual understanding and achievement in chemistry learning is a multifaceted topic. Motivation can influence students' ability to grasp complex concepts in chemistry, which often requires connecting different levels of understanding—sub-microscopic, macroscopic, and symbolic (Rahmawati, Hartanto, Falani, & Iriyadi, 2022). Studies suggest that students with higher career motivation levels tend to achieve better academically in chemistry, as motivation can enhance engagement and effort (Sirhan, 2007). Interactive tools like PhET simulations, Ed-puzzle interactive lessons and three level representations can aid in improving students' conceptual understanding, although they may need further enhancements to address specific misconceptions (Rahmawati et al., 2022).

2.13. Difficulties in Learning/Teaching Chemical Kinetics and Equilibrium

Chemical kinetics and chemical equilibrium are both complex topics in chemistry that students often find challenging (Cakmakci & Aydogdu, 2011). Chemical kinetics is an anchoring concept or “big idea” at high school-level chemistry curriculum. It ties observable phenomena with theoretical aspects of chemistry that are modeled mathematically (Teo et al., 2014). Chemical kinetics is a branch of Chemistry that deals with the rate of reaction of reactants converted into products or the rate at which the product is formed and the study of reaction mechanisms. However, it is difficult for students to grasp chemical kinetics concepts because it involves understanding phenomena at the macroscopic, microscopic, and symbolic levels. It requires a good understanding of mathematics (Bain & Towns, 2016). Chemical kinetics concepts are difficult for learners to understand since they involve the application of mathematical concepts such as differential and integration (Lemmer, 2013). These concepts are important fundamental aspect of chemical reactions necessary for understanding some other Chemistry topics (Lemmer, 2013). Lemmer's (2013) study found that knowing chemical kinetics concepts leads to a better grasp of chemical equilibrium. The learners' comprehension of the order of reaction, changes in concentration and time, and so on leads to an understanding of the law of mass action, equilibrium constants, the relationship between K_C and K_P , and equilibrium constant determination. Chemical kinetics introduces the majority of chemistry topics, and a thorough comprehension of these concepts is required to understand chemistry and its mathematical concepts (Lemmer, 2013, p. 244).

The difficulty level of chemical equilibrium for high school students in chemistry learning can vary based on several factors, including the curriculum, instructional methods, and individual student backgrounds. Chemical equilibrium is a fundamental concept in chemistry that involves understanding the dynamic balance between reactants and products in a chemical reaction (Chang, 2017). For many high school students, chemical equilibrium can pose a moderate to high level of difficulty due to its abstract nature and the need to grasp concepts such as equilibrium constants, reaction rates, Le Chatelier's principle, and the factors that affect equilibrium position. Additionally, students may encounter mathematical calculations involving equilibrium constants and concentrations, adding another layer of complexity (Russell & Moller, 2013). The difficulty level may also be influenced by the depth of coverage and the extent to

which students are expected to apply their understanding to solve problems and analyze real-world scenarios (Taber, 2013). In some curricula, chemical equilibrium is introduced as a basic concept, while in others, it is explored in greater detail with more advanced applications.

Furthermore, students' prior knowledge and exposure to related concepts, such as stoichiometry, chemical kinetics, and thermodynamics, can impact their ability to comprehend chemical equilibrium. Educators may need to scaffold instruction and provide ample opportunities for practice and application to support students in mastering this challenging topic. Chemistry teachers often struggle to convert their subject knowledge into effective Pedagogical Content Knowledge (PCK) due to limited classroom teaching experience (Aydeniz & Kirbulut, 2011). The study that focused on acid base concepts also looks at the impact of a teacher's ability to teach students how to use the Arrhenius model (Kurt & Ayas, 2012). The thoughts and reasons that influence the actions of a teacher in classrooms are observable in the transformation stage (Shulman, 1987), a stage needed before the actual delivery of the lesson. Developing PCK in chemistry teachers is done by teaching them the components that make up PCK (Shulman, 1987, p. 547). This process requires that they first develop pedagogical reasoning skills about topics in their subject of specialization because of their limited teaching opportunities. Teachers' PCK helps in their good mastery of teaching concepts and thus makes them specialists in topics (Mavhunga, 2014). This is the target of using TSPCK-based instruction, which consists of five knowledge components and a way of transforming subject matter knowledge into PCK (Rollnick & Mavhunga, 2016).

2.14. Conceptual Framework

Topic-specific Pedagogical Content Knowledge (TSPCK) represents the personalized expertise and instructional approaches that educators use to effectively impart unique subject information within a given area (Hill et al., 2008). In chemistry education, TSPCK-based instruction focuses on tailoring instructional methods and content delivery to improve students' understanding of complex concepts like chemical kinetics and chemical equilibrium. This instructional framework incorporates specialized pedagogical strategies that have been rigorously designed to address the unique challenges associated with teaching chemical kinetics and chemical equilibrium. It emphasizes the identification of common student misconceptions, the careful selection of appropriate teaching approaches and materials, and the use of precise instructional strategies to

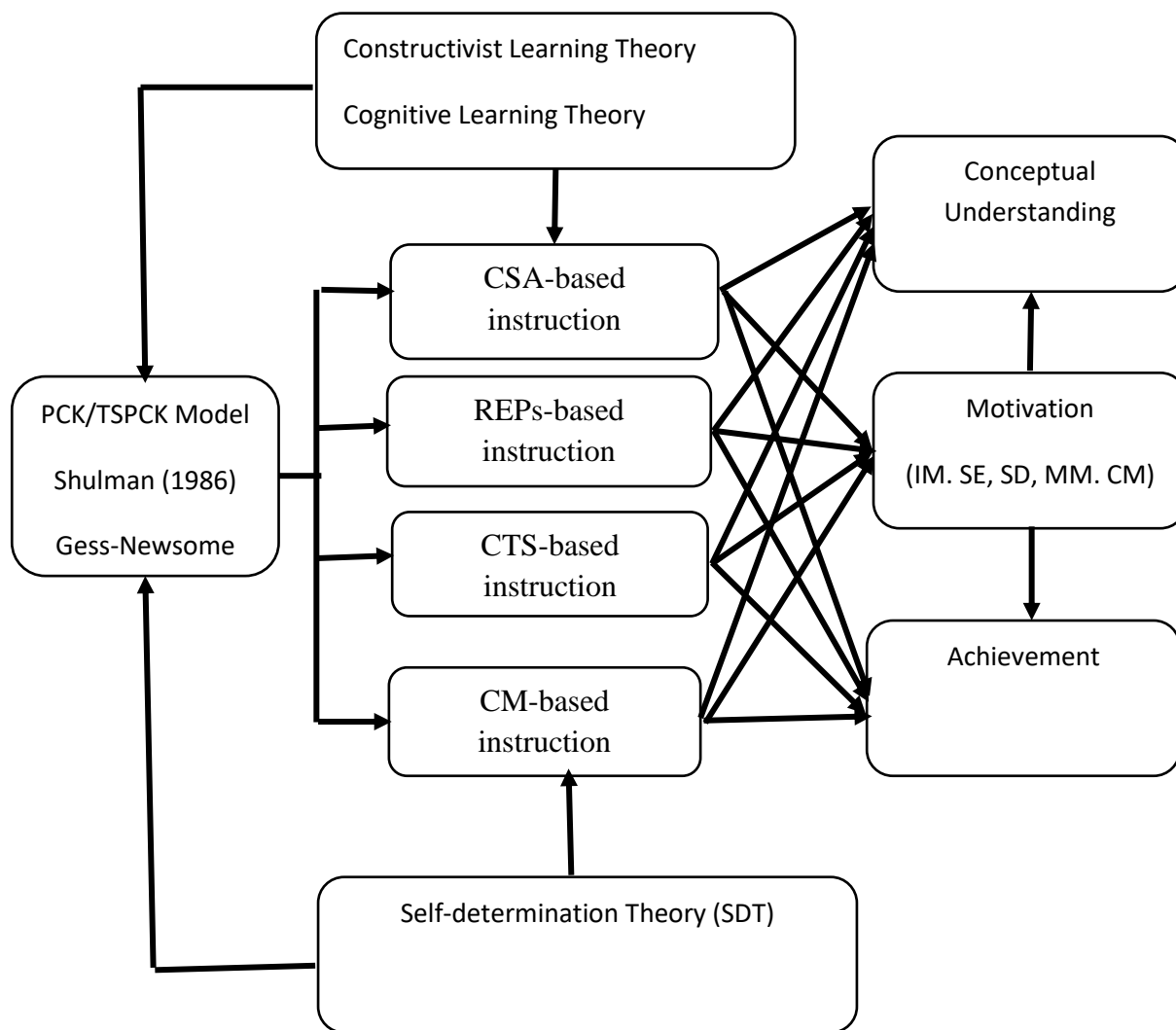
encourage profound conceptual understanding (Treagust, 1988). The introduction of TSPCK-based instruction is expected to improve students' depth of comprehension. By addressing frequent misconceptions and implementing effective instructional tactics, students are expected to develop a more precise and thorough understanding of fundamental concepts in chemical kinetics and chemical equilibrium. This method may include promoting conceptual clarity, connecting abstract ideas to real-world occurrences, and offering opportunities for active participation and inquiry-based learning.

The breadth and depth of learning, as well as the effectiveness of the instructional approaches used, affect students' overall understanding of chemical kinetics and chemical equilibrium. TSPCK-based instruction aims to improve students' overall conceptual understanding by scaffolding learning experiences that build on prior information, correct misconceptions, and develop critical thinking skills. This may require using conceptual models, visual aids, simulations, and hands-on laboratory tasks to help students understand complex chemical principles. Besides, the effect of TSPCK-based instruction on student achievement in chemical kinetics and chemical equilibrium can be measured in a variety of ways. It is anticipated that effective implementation of TSPCK instruction will result in improved academic performance.

Furthermore, achievement outcomes may be reflected in students' ability to apply their knowledge of chemical kinetics and chemical equilibrium to assess and solve real-world chemistry problems. TSPCK-based instruction has the potential to improve students' motivation and engagement when learning chemical kinetics and chemical equilibrium. TSPCK instruction can boost intrinsic motivation and foster a positive learning environment by providing relevant, exciting, and connected learning experiences that align with students' interests and aspirations. Motivational dividends may include increased curiosity, tenacity, and strengthened self-efficacy beliefs related to learning chemistry ideas. The conceptual framework shown below emphasizes the possible effects of TSPCK-based instruction on students' conceptual understanding, achievement, and motivation in studying chemical kinetics and chemical equilibrium.

Complex concepts like chemical kinetics and equilibrium were effectively taught using constructivist and cognitive learning theories that place an emphasis on deep understanding, engagement, and the integration of prior knowledge. By using techniques like scaffolding, multiple representations, and curricular saliency to emphasize important linkages, constructivism

promotes the application of Topic-Specific Pedagogical Content Knowledge (TSPCK) (Rollnick & Mavunga, 2014). Concurrently, Self-Determination Theory (SDT) promotes engagement and determination by strengthening motivation through intrinsic motivation, self-efficacy, self-determination, mark motivation, and career motivation (Deci & Ryan, 2000). Chemical kinetics and equilibrium are better understood and performed better when SDT and TSPCK are combined to provide a cognitively and emotionally supportive environment (Pintrich & Schunk, 2002; Mavhunga, 2020).



Key: CSA-curriculum saliency, REPs- representations, CTS- conceptual teaching strategies, CM-Conventional based teaching

Figure 1: Conceptual Framework of the Study

This conceptual framework examines how TSPCK-based instruction affects students' learning outcomes in chemical kinetics and equilibrium by combining constructivist and cognitive learning theories with self-determination theory (SDT). Constructivist theories of active, engaged, scaffolded learning and cognitive theory's focus on mental structures are in line with the independent variable, TSPCK-based instruction, which includes curriculum saliency, representation, and a conceptual teaching approach. With subscales such as intrinsic motivation, self-efficacy, self-determination, mark motivation, and career motivation moderating the link between instruction and students' learning outcomes, SDT provides a basis for comprehending motivation. When compared to the traditional approach, it is expected that the dependent variables, such as conceptual understanding, academic achievement, and motivation, was improved under TSPCK-based instruction, underscoring its potential to provide meaningful learning experiences in chemistry education.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1. Introduction

This chapter presents research paradigms, research design, methods, samples and sampling techniques, data gathering instruments, data analysis and interpretation, and ethical issues.

3.2. Research Paradigm

This study was guided by the pragmatic paradigm. The pragmatic research paradigm in quasi-experimental research design is gaining popularity due to its versatility in addressing complex research questions. Quasi-experimental research offers an alternative to conventional experimental designs, allowing researchers to evaluate interventions' effectiveness in real-world settings when randomized controlled trials are not feasible or ethical (Kaushik & Walsh, 2019). The pragmatic paradigm is characterized by its flexibility and adaptability, allowing researchers to use various methods for data collection and analysis. The pragmatic research paradigm prioritizes practicality and utility over theoretical purity, encouraging researchers to use existing data sources and focus on findings applicable in real-world settings (Dahler-Larsen, 2023; Creswell, 2014). Quasi-experimental researches with a nonequivalent control group design studies often use a pragmatic worldview (Pitts, Prost, & Winters, 2005).

3.3. Research Method and Design

3.3.1. Research Method

Mixed method research approach is employed in this study. Mixed method refers to a developing methodology of research that progresses the systematic integration, or mixing, of quantitative and qualitative data within a single investigation (Wisdom & Creswell, 2013). Both quantitative and qualitative research methodologies were used in this study. When employing a quantitative approach, data must be converted into numerical form and analyzed using quantitative analytic methods (Azorín & Cameron, 2010). Whereas, qualitative method involves collecting data in textual or narrative form and analyze by employing qualitative data analysis techniques (Creswell, 2013).

Choosing mixed methods in this study was based on two main reasons. First, it is based on the underlying principle that investigating an issue holistically from different perspectives requires different research methods. In support of that, Frels and Onwuegbuzie (2013) argued that the fundamental premise of mixed methods is that the integration of the two methods gives a better understanding of the research problems and complex phenomena than the individual approach does alone.

Second, the mixed methods are further recognized to have active roles in studies that explore social-related issues and the significance of intervention programs in addressing TSPCK construct (Luft et al., 2011). Maries and Singh (2013) referred to such student learning as a social activity. Thus, secondary school students learn to develop conceptual understanding, enhance their achievement and learning motivation as they engage in the process of learning. According to Smith and Banilower (2015), the link between motivation, achievement, and understanding of concepts as assessed by TSPCK is a multifaceted, complicated construct distinctive to each topic. Investigating conceptual understanding and its level of understanding, achievement and motivation of secondary school students (grade 11) through TSPCK-based strategies is a social issue as the learning- teaching process is supported by interaction between students and their peers, and students and teachers.

This study used an embedded mixed method. An embedded mixed method is a method that combines both qualitative and quantitative data to assess the effectiveness of an intervention or treatment. The advantages of embedded mixed methods include increased validity (Creswell & Creswell, 2017), richer understanding (Johnson & Onwuegbuzie, 2004), improved generalizability (Teddlie & Tashakkori, 2003), enhanced flexibility (Murphy & Dempster, 2018), and increased credibility (Maxwell, 2013). However, there are challenges associated with this approach, such as increased complexity, data integration, and time-consuming nature. Besides, the combination of qualitative and quantitative data can lead to a more complex study, as the two types of data may require different analytical techniques and may not fit together seamlessly. Collecting and analyzing both qualitative and quantitative data can be time-consuming as indicated here above. The qualitative data enriched the quantitative findings in this study.

3.3.2. Research Design

Research questions of this study largely demanded quantitative research approach but qualitative data was collected to get insights about the degree of implementation and level of complexity of chemistry. Since the dominant research questions were answered by quantitative research approach, an embedded mixed method study with non-equivalent groups' pretest-posttest quasi-experimental design was employed in the study. The quasi-experimental research design involved three treatment groups (Curricular Saliency-based, Representation-based, and Conceptual teaching strategy-based instruction) and one comparison group in this study. Table 3.1 below depicts the nonequivalent control group design with pretest and posttest.

Table 3.1: The nonequivalent control group design with pretest and posttest

Group	Pre-test	Treatment	Post-test
Intervention group 1	O ₁	X ₁	O ₂
Intervention group 2	O ₁	X ₂	O ₂
Intervention group 3	O ₁	X ₃	O ₂
Comparison Group	O ₁	---	O ₂

In the table 3.1 above, O₁ represents the pre-test, O₂ represents the posttest, X₁ represents teaching both chemical kinetics and equilibrium concepts through identifying big ideas and sequencing them (curricular saliency-based instruction), X₂ represents teaching through representations (macro, micro, and symbolic through diagram, graphs and animations), and X₃ represents conceptual teaching strategy (chem-craft, ed-puzzle, and animations).

3.4. Research Population, Sample, and Sampling Techniques

The study was conducted on secondary schools in Addis Ababa City administration. In this connection, the target population of this study was grade 11 students enrolled in Yeka Sub-city of Addis Ababa city administration during 2021/2022 academic/school year. The study sample comprised 159 grade 11 students at four different secondary schools in Yeka Sub-city. A multistage sampling technique was used in this investigation. The process started with a simple selection at random to select one of the eleven sub-cities under the city government of Addis

Ababa. Yeka Sub-city was selected as the study's focus area by this random selection technique. Second, secondary schools in the Yeka Sub-city were chosen using a whole/comprehensive sampling technique (Krejcie & Morgan, 1970). All the public secondary schools (A, B, C, D) of Yeka Sub-city with grade 11 students were included in this study. Third, grade 11 was chosen purposively as the study focused on chemical Kinetics and equilibrium. Fourth, one section was chosen purposively from each secondary school in the Yeka Sub-city. Purposive selection of one section was based on the teacher's teaching experience and qualification as this was important for the intervention. There was no randomization of participants and intact classes were taken from the four schools for this study.

3.5. Variables of the Study

3.5.1. Independent Variables

In this study, the independent variables that caused the dependent variables to change or vary were the TSPCK-based instructions (curriculum saliency-base instruction, representations-based instruction and conceptual teaching strategies-based instruction) in learning chemical kinetics and equilibrium concepts. Gender was also the independent variables in this study.

3.5.2. Dependent Variables

In this investigation, the dependent variables were conceptual understanding, achievement and motivation on the learning of chemical kinetics and equilibrium concepts.

3.6. Treatments

In this study, the researcher took nine weeks to cover all chemical kinetics and equilibrium concepts. The first week was used for introduction of the dissertation objectives for the students, conducting one day training for teachers and making necessary preparations for the intervention. ICT experts were in the training with teachers to support the implementer teachers in downloading videos, interactive simulation and how to select appropriate lesson from youtube, school administrators participated in the training to know the nature of trainings given for teachers for future use in their respective schools.

The contents of the training given to the teachers included how to teach chemical kinetics and chemical equilibrium using curricular saliency-based instruction, Representation-based instruction, and conceptual teaching strategy-based instruction. During the training the topics of intervention were related with real-life of the students to help teachers do the same thing during the intervention. Also selected videos, animation and interactive simulations were used. The training was prepared based on the hands-on activities on some selected chemical kinetics and equilibrium concepts. The remaining eight weeks were used for the intervention. Details of the treatments in the TSPCK-based intervention groups and conventional instruction-based group are given below.

3.6.1. Curriculum Saliency-based Instruction

In the curricular saliency based instruction, the implementer teacher and the students were doing the following activities. These were

Identifying big ideas and sequencing them (organizing chemistry concepts for learning)

The teacher arranged the students in to the groups of 4-6 members and gave them to identify which concept of chemical kinetics and chemical equilibrium are big ideas, subordinate ideas and which comes to first to learn by using the objective of the lesson on their textbook at their home. Also there were discussions with the students about the selection of the big ideas and the order of the sequence using literature and the intended objective of each lessons.

Relating chemical kinetics and equilibrium concepts with real-life of the students

The teacher taught using interactive discussion on each big ideas of the selected topics (chemical kinetics and equilibrium). In this part of the activity, the teacher raised some application of chemical kinetics in how reactions took place in human bodies when the take medicines. In relation to chemical equilibrium, the flow of cars from bus station indicated the dynamic nature of the equilibrium concept. These gave opportunities for students to ask other real-life applications of chemical kinetics and equilibrium.

Identification of prior knowledge and misconceptions on chemical kinetics and equilibrium

In this part, students were asked questions that related to the prior knowledge and misconceptions in chemical kinetics and equilibrium concepts. The teacher gave concluding remarks and immediate feedbacks on the interaction of the students in every topic.

3.6.2. Representations-based instruction

Representation-based instruction includes teaching chemical kinetics and equilibrium concepts at the macro, micro, and symbolic levels of understanding. At the macro level, chemical kinetics and equilibrium concepts were taught through laboratory and hands-on activities. Also, videos, animations, and interactive simulations from the internet were used to get a microscopic and symbolic understanding of chemical kinetics and equilibrium concepts. After observing the selected video, animation, or interactive simulation, the teacher asked students to reflect on each one and classify the level of understanding as micro or symbolic. Furthermore, the represented topics were relevant to the students' real-life experiences. Finally, the teacher addressed questions, gave final remarks, and provided quick feedback on the students' misconceptions.

3.6.3. Conceptual Teaching Strategies-based Instruction

In the conceptual teaching strategy-based instruction, the following activities were considered in all chemical kinetics and equilibrium concepts. First, the teacher identified the prior knowledge, and misconceptions focusing on what makes the topics of chemical kinetics and equilibrium easy or difficult to learn based on the existing literature. Then, the teacher used ed-puzzle educational platform (e-learning instructional approach) on the chemical kinetics and equilibrium concepts. Moreover, students were allowed to watch video/interactive simulation and engaged in interactive questions through discussions. Peers and teachers were involved in the discussion. According to BouJaoude and Barakat's (2003) framework, students' understanding levels in this intervention group were categorized using their responses on the Edpuzzle platform. Their scores were categorized as low (less than two out of five), medium (2.1 to 3.5), and high (3.6 to 5.0) out of five. The teacher gave concluding remarks and immediate feedbacks on the concepts on daily basis.

3.6.4. Conventional Instruction

In the conventional instruction, the teacher taught the chemical kinetics and equilibrium concepts for eight weeks without employing the TSPCK-based instructions. The chemistry teacher followed a teacher-dominated approach. The teacher largely depended on explaining concepts from the textbook.

3.7. Instruments of Data Collection

In the current study, data were collected using both quantitative and qualitative instruments. The quantitative data gathering instruments of the study were conceptual understanding test, chemistry achievement test, and Chemistry motivation questionnaire. The qualitative data-gathering instrument for the current study were semi-structured interviews and classroom observation checklists. The test and questionnaires assisted in examining the effect of the TSPCK instruction (Curricular saliency, representation, and conceptual teaching strategy) to get quantitative data, whilst semi-structured interviews and observation checklists helped in identifying participant opinions on the quality of the intervention as a qualitative data sources on the intervention.

3.7.1. Chemical Kinetics and Equilibrium Conceptual Understanding Test (CKECUT)

In this study, two-tier diagnostic test was developed based on Treagust's (1988) methods by the researchers. Development process was conducted on three phases (define content areas, determination of grade 11 students alternative conceptions, development and validation of instruments) and steps for chemical kinetics and equilibrium concepts.

Phase 1: define the content area

The initial step in this phase was to identify the content boundaries and learning objectives in accordance with the research's general purpose. This procedure entailed determining the precise topics to be covered as well as the study's aims, ensuring that both the content and objectives were directly connected to the research question and desired outcomes. Regarding chemical kinetics concepts, rate of reaction, factors affecting rate of reaction, rate law and its reaction orders, theories of rate of reaction and reaction mechanism were selected. Furthermore, in the case of chemical equilibrium concepts, equilibrium dynamism, equilibrium constants and expression and Le Chatlier's principle were defined content areas for this study.

Phase 2: Determination of grade 11 students' alternative conceptions

In this phase, alternative conceptions were identified from literature sources and students semi-structure interview. Later 40 multiple-choice content knowledge items and 40 multiple-choice reasoning items with free response parts were constructed. The free-response items were administered to 61 students (grade 12 students) who were taught chemical kinetics and equilibrium concepts one semester before the intervention. The study did not include these students.

Phase 3: Development and validation of the instrument

In the final step, a two-tier conceptual understanding diagnostic test was designed, with the first tier being content knowledge (the first tier) and the second tier being the reasons for the first tier. The first layer includes selected principles such as chemical kinetics and equilibrium. The second category featured reasoning-based issues with three or more options, one of which was the expected response. Distractors of the second tier included inaccurate explanations and scientifically unsuitable beliefs held by students, as found through literature reviews and student interviews (Proksa et al., 2018; Holme et al., 2015). Finally, 30 first-tier concept-based multiple-choice items and 30 reason-based multiple-choice items were created, validated, and prepared for the study (see Appendix A). The developed understanding test items were administered as pretest and posttest in this study.

3.7.2. Chemistry Achievement Test

The researcher prepared 40 items multiple-choice Chemistry Achievement Test (CAT) on the chemical kinetics and equilibrium concepts. The items from chemical kinetics included rate of reaction, theories of rate of reaction, rate laws and order of reaction, and reaction mechanism. Similarly, the items from chemical equilibrium included dynamic equilibrium, equilibrium expression, factors affecting chemical equilibrium, and Le Chatlier's principle. The developed CAT items were administered as pretest and posttest in this study (see Appendix B).

3.7.3. Chemistry Motivation Questionnaires

Chemistry Motivation Questionnaires were adapted to assess grade 11 students' motivation towards chemistry and administered to collect data on motivation components. The tools used in this study were developed by Glynn et al. (2011), based on their rigorous research and theoretical

framework. These motivation scales have five independent sub components, namely, intrinsic motivation, self-efficacy, self-determination, mark motivation, and career motivation (see Appendix C). These Likert scale motivation scale questionnaires have five rating scales (1 = **Strongly Disagree**; 2 = **Disagree**; 3 = **undecided**; 4 = **Agree**; 5 = **strongly agree**). The motivation items were administered as pretest and posttest in this study.

3.7.4. Semi-structured interview

A semi-structured interview (Appendix E) which included misconceptions of chemical kinetics and equilibrium concepts, the role of using strategies of identifying big ideas, representations and conceptual teaching strategy was designed. and used for assessing conceptual understanding and the level of motivation of the grade 11 students. The semi-structured questions centered on how grade 11 students perceived the TSPCK-based instruction's intervention, which were curricular saliency, representation, and conceptual teaching strategy. Four questions were developed for the semi-structured interview based on earlier research (Hamed & Aljanazrah, 2020, Kapici,et al. , 2020, Hinkhouse, 2013). Students in the intervention groups were questioned about how the TSPCK-based instruction was different from the other constructivist learning approaches, as well as about its advantages and disadvantages, individual preferences, degree of engagement, how it helped their understanding of the concept and comments for further improvement. Teachers and grade 11 students were interviewed with three questions about the differences between the TSPCK and conventional instruction, their advantages and disadvantages, and one question focused on identifying students' misconceptions. The interviews were conducted with two participants from each intervention groups and comparison group. A total of six students (3 females, 3 males) and three teacher (all are males) from each of the study groups were interviewed. Twelve participants were interviewed from three treatment groups and one comparison group. The researcher took notes as the participants responded to the specific questions posed. Interviews were carried out to find out what students and chemistry teachers thought about the TSPCK based instruction and its effectiveness used in the chemistry learning. This information provided the researcher with a comprehensive picture of teachers and students' opinion on the curricular saliency, representations, and conceptual teaching strategy in learning chemical kinetics and equilibrium concepts. The developed semi-structured interview items were administered as posttest in this study.

3.7.5. Classroom observation checklist

In this study, observation checklist is adapted and used as a data collection tool. The treatment groups were observed while they were at work during selected teaching sessions in different stages: beginning, intermediate, and final. Teaching sessions for each intervention group and conventional group with its respective activities were selected for observation. The checklist was designed to enable the researcher to observe how grade 11 students and the implementer teacher educator in both the treatment groups and conventional group are actually engaged in the process. The classroom observation checklist was adopted from a literature source (Gleason et al., 2015). This was done after getting permission from them through email confirmation. It consisted of 16 items, which were broadly classified into two. These are students' motivation and engagement activities (items 1-5, items 12-15) and teachers' facilitation (items 4, 6-11, 13 and item 16) (see Appendix F). Observations were done three times in each intervention group and conventional group during the eight week's intervention. .

3.8. Validity and Reliability of the Instruments

Validity and reliability are the two most important and fundamental features in the evaluation of any instrument for good research (Ary et al., 2009). In this study, both the content and face validity of conceptual understanding test, chemistry achievement tests and chemistry motivation questionnaires were checked. The chemical kinetics and equilibrium conceptual understanding test, Chemistry achievement tests and motivation questionnaires were reviewed and examined for face and content validity by two supervisors, two chemistry education PhD candidates, and four experienced senior secondary school chemistry teachers who had been teaching the subject for more than 15 years. The suggestions and views of the specialists were carefully taken into account when making improvements.

For validation of the instructional materials, specialists in measurement and evaluation were given the instructional materials prepared based on the TSPCK-based instruction. The assessment by these specialists enabled the researcher to gather suggestions that were used to improve the instructional materials and items.

Moreover, two experts in chemistry education looked at the content validity of the semi-structured teacher and students interview form. Necessary revisions were made based on the educators' recommendations. The question included five open-ended questions designed to elicit

the teacher's thoughts and students learning based on TSPCK based instruction. Besides, two chemistry education professionals assessed the content validity of the classroom observation form. The classroom observation form had 16 items categorized as the motivation and engagement of students, and the teacher facilitative role that were used to monitor classroom activities and interactions using TSPCK based instructional approaches. The internal consistency reliability was checked for all the quantitative tools after the pilot test. Pilot study results were reported in the next section.

3.9. Pilot study

It is a good idea to test out data collection tools and methods before starting a study. A pilot study plays an important role in this respect. Researchers need to conduct a pilot study to evaluate research instruments (Shaw & Gould, 2001). The tools as well as the TSPCK-based instructional approaches were piloted before the main study.

3.9.1 Piloting conceptual understanding test

Conceptual understanding test was piloted on group of students which are not part of the main study. The pilot study had a sample size of 61 grade 12 students from Addis Ababa secondary schools. The test consisted of 80 items: 40 concept-based questions assessing knowledge of reaction rates, factors affecting reaction rates, dynamic equilibrium, and Le Chatelier's principle; and 40 reason-based questions. To ensure accuracy, the test was administered in a controlled atmosphere where the invigilators are accessible for procedural questions. During piloting errors and misunderstandings were found and corrected. Also item difficulty indexes were computed. The item difficulty index (symbolized by the letter P) expresses how difficult the item is, with a number ranging from 0.0 to 1.0, with higher values indicating easier items and lower scores indicating more difficult ones (Boopathiraj & Chellamani, 2013). According to Gajjar et al. (2014), the suggested p-value for item difficulty is between 0.3 and 0.7. That is, items with p-values of less than 0.3 and more than 0.7 are judged as difficult and easy, respectively.

Based on the above-mentioned item difficulty index guidelines, chemical kinetics and equilibrium conceptual tests have an item difficulty range of 0.40 to 0.625 for concept-based items and 0.40 to 0.71 for reason-based items. Thirty questions out of 40 questions were at a reasonable difficulty level. However, ten items (1, 9, 13, 14, 17, 19, 24, 27, 34, and 36) were

rejected because they had high difficulty indexes and very low discrimination power (symbolized by letter D) (Appendix A). The D-value ranges from -1 to +1, and item discrimination indicates how well the item differentiates between low- and high-scoring students. Items with a D-value approaching +1 discriminate better, while those with a D-value close zero discriminate less. Seven items with D-values of 0.20 to 0.29 were reviewed, according to Melumad and Nissim (2009), while ten items with D-values of less than 0.20 were deleted. The chemical kinetics and equilibrium conceptual tests also have a discrimination index ranging from 0.24 to 0.58. Using the Kuder-Richardson formula (KR-20), chemical kinetics and equilibrium conceptual understanding test had a reliability coefficient estimate of 0.80. The pilot study helped in improving the conceptual understanding test items.

3.9.2. Piloting Chemistry Achievement Test

Chemistry Achievement test was piloted on group of students which are not part of the main study. The pilot study included 61 students in grade 12 at Addis Ababa administrative City. The achievement test was composed of 40 items that focused on key concepts in chemical kinetics and equilibrium. The questions covered themes including reaction rates, factors influencing reaction rates, dynamic equilibrium, and Le Chatelier's principle. Students were given sufficient time to finish the test, with invigilators available to answer any procedural questions. The item difficulty of chemical kinetics and equilibrium achievement tests ranges from 0.41 to 0.63. Twenty-eight of the thirty questions were within a reasonable difficulty range, while two appeared to be poor items and were reviewed (See Appendix B). Also, 28 of the 30 items discriminated fairly well between high and low-achieving students, but two of them appeared to be poor discriminators against students due to their low discrimination index, and items 27 and 28 were reviewed (Appendix A). The chemical kinetics and equilibrium achievement test discrimination index ranges between 0.32 and 0.45. Chemical kinetics and equilibrium achievement tests had a KR-20 value, of 0.79 that indicated the achievement test have high internal consistence. The pilot study helped in improving the chemistry achievement test items.

3.9.3. Piloting Chemistry Motivation Questionnaires

Understanding students' motivation to learn chemistry is critical for devising effective teaching strategies. Motivation items were piloted on group of students which are not part of the main study. The pilot study included 61 students in grade 12 at Addis Ababa administrative City. The

motivation questionnaire included items aimed at examining components of students' motivation (intrinsic motivation, self-efficacy, self-determination, mark motivation, and career motivation). Intrinsic motivation towards chemistry learning (five items), self-efficacy in learning chemistry (five items), self-determination for studying chemistry (five items), mark motivation (five items), and career motivation (five items) were the components of the chemistry motivation questionnaire. Cronbach's alpha was used to calculate the reliability coefficient of motivation items, which was averagely determined to be 0.83. Intrinsic motivation, self-efficacy, self-determination, mark motivation, and career motivation components have reliability coefficients of 0.85, 0.89, 0.81, 0.85, and 0.76, respectively. According to Frankel and Wallen (2000), a reliability coefficient of 0.70 or above is suggested for use in research studies. The pilot study helped in improving the chemistry motivation items. In this study, both the test items and the chemistry motivation questionnaire had reliability coefficients of over 0.70. Therefore, the tools were appropriate for the study.

3.9.4. Piloting the TSPCK Instructional-Approaches

3.9.4.1. Piloting of Curriculum saliency based Instructional approach

The piloting of a curriculum saliency-based instructional approach aimed to enhance student learning by prioritizing essential content and skills, structuring them effectively, and connecting them to real-life examples. Identifying big ideas and subordinate ideas was a crucial first step. For chemical kinetics and equilibrium, the big ideas include understanding reaction rates, activation energy, rate laws, dynamic equilibrium, and Le Chatelier's Principle. Subordinate ideas support these foundations and include the role of catalysts, reaction mechanisms, the effects of concentration, temperature, and pressure, and the equilibrium constant (K).

Pilot testing of Curricular Saliency-based instruction was carried out with 50 grade 11 students who were not part of the main study for one week or three periods in the same school. This was done deliberately to improve the problems observed during piloting and run the intervention effectively. The instructive sequence followed a logical flow, beginning with an introduction to reaction rates and continuing through activation energy and catalysts, rate laws and reaction mechanisms, dynamic equilibrium, and Le Chatelier's Principle. Real-life examples were used to demonstrate the relevance of these concepts, including reaction rates in drug effectiveness,

catalysts in industrial processes like ammonia production, temperature effects on food preservation, dynamic equilibrium in biological systems like respiration, and the environmental impact of CO₂ levels on oceanic equilibrium. This technique was intended to improve students' conceptual knowledge and application of chemical concepts.

The implementation of this approach involved several steps. Planning and preparation include curriculum analysis to identify essential content and developing resources such as instructional materials and real-life examples. Training sessions were conducted to familiarize teachers with the saliency-based approach and new materials. Instructional design involved creating detailed lesson plans that prioritize big ideas, integrating subordinate ideas logically, and incorporating active learning strategies and real-life applications to enhance engagement. Monitoring and support included providing continuous support to teachers through regular check-ins, peer collaboration, and establishing mechanisms for collecting feedback from both teachers and students. Piloting curriculum saliency-based approach helped to improve the intervention during the main study.

3.9.4.2. Piloting of representations-based Instructional approach

Teaching chemical kinetics and equilibrium using representation-based instruction entails classifying ideas into macroscopic, microscopic, and symbolic levels and making use of interactive simulations, videos, and visual aids. Students used concrete experiments and data visualization at the macroscopic level to see and characterize chemical interactions. At the microscopic level, students investigated molecular interactions and reaction mechanisms using simulations and animations. At the symbolic level, the focus was on equilibrium constants and rate laws while teaching students how to depict reactions using equations and symbols. A variety of media were incorporated into lessons to accommodate various learning preferences; promote active learning through debate and problem-solving; and evaluate students' comprehension. Various processes were involved in the piloting stage of representation-based instruction to teach chemical kinetics and equilibrium. First, teachers created and presented lessons using interactive simulations, videos, and visual aids that are organized around the macroscopic, microscopic, and symbolic levels of knowledge. Second, through the use of techniques like observation, surveys, and pre- and post-assessments, data were gathered during instruction regarding student involvement, comprehension, and interaction with the contents. Thirdly, teachers examined this

data to evaluate the pilot method's efficacy and pinpointed its advantages, disadvantages, and areas for improvement. A one-week pilot of representation-based instruction with 45 grade 11 students who did not participate in the main study focused on chemical kinetics and equilibrium concepts. This was done intentionally to improve the problems discovered during piloting and to operate the intervention effectively. We employed laboratory activities to develop macro-level knowledge, videos and simulations for the micro-level, and mathematical expressions and formulae for the symbolic level. The pilot, which took place over three periods, attempted to improve conceptual comprehension by refining this multirepresentational instruction. Piloting representations-based approach helped to improve the intervention during the main study.

3.9.4.3. Piloting of Conceptual Teaching strategy-based Instructional approach

To teach chemical kinetics and equilibrium concepts, a conceptual teaching strategy based on Ed-Puzzle, interactive simulations, and interactive questions within video lessons was employed at piloting phase. This involved a number of subject-specific strategic steps. First, teachers created lessons that are in line with the conceptual knowledge of chemical kinetics and equilibrium. They accomplished this by simplifying complex ideas into manageable chunks and minimized common misconceptions that are often associated with these areas of study.

Teachers built interactive video classes with properly placed questions and assessments by integrating technology tools like Ed-Puzzle. They elicited student participation and evaluated students' understanding. In addition, interactive models were utilized to enable practical investigation of chemical kinetics and equilibrium phenomena. Through actual interaction with abstract concepts, these simulations helped students gain a deeper comprehension of the underlying principles. Data were examined to determine the teaching strategy's efficacy and to pinpoint its strong points and potential areas for improvement. Teachers evaluated the effects of technology-enhanced conceptual teaching approaches by using this systematic methodology that is specifically designed for chemical kinetics and equilibrium concepts. A one-week pilot of conceptual teaching strategy-based instruction with 42 grade 11 students focusing on chemical kinetics and equilibrium, with Edpuzzle, interactive questions, and concept summaries to excel understanding. This was done deliberately to improve the problems observed during piloting and run the intervention effectively. The pilot, which took place over three periods, improved the

strategy's effectiveness in developing conceptual clarity. Piloting conceptual teaching strategy-based approach helped to improve the intervention during the main study.

3.10. Procedure of Data Collection

3.10.1. Procedures of Conceptual Understanding Test Administration

The conceptual Understanding test was prepared by the researcher based on the procedures of development suggested in the literature (Treagust, 1988). The administration of this instrument was done with the help of chemistry teachers. The intervention groups and comparison groups were given the Understanding test as a pre-test before the start of the treatment. After the intervention, the researcher with the help of chemistry teachers administered post-tests to the three intervention groups and one comparison group. The researcher, then, scored the responses to the understanding test and generated data.

3.10.2. Procedures of Achievement Test administration

The achievement test was prepared by the researcher. The administration of this instrument was done with the help of chemistry teachers. The intervention and comparison groups were given achievement test as a pre-test before the start of the treatment. After the intervention, the researcher with the help of chemistry teachers administered post-tests to the three intervention groups and one comparison group. The researcher, then, scored the responses to achievement test and generated quantitative data.

3.10.3. Procedures of Motivation Questionnaire administration

The Chemistry Motivation Questionnaire (CMQ) was adapted from literature (Glynn et al., 2011). The administration of this instrument was done also with the help of chemistry teachers. The intervention and comparison groups were given CMQ as a pre-test before the start of the treatment. After the intervention, the researcher with the help of chemistry teachers administered post-tests to the three intervention groups and one comparison group. The researcher then scored the responses to CMQ and generated quantitative data.

3.10.4. Procedures of Interview administration

Interview items were developed by the researcher. The interview guide was created prior to the intervention. To accomplish the study's objectives, six grade 11 students and three teachers were specifically chosen for the interview, representing three different achievement levels: low, middle, and high achievers. Following selection, the researcher gave the participants an orientation. Participants consented to participate and then the researcher interviewed them. During the interview process, based on the consent obtained, audio appliance was used for recording. Participants were probed to get more ideas during the interview process. Then, qualitative data were generated for analyses.

3.11. Method of Data Analysis

McMillan and Schumacher (2014) described data analysis as the process a researcher uses to reduce data for interpretation. Cohen et al. (2018) stipulate that data analysis involves organising, accounting for and explaining the data. Also, Bertram and Christiansen (2020) posit that data analysis is the process of reducing large amounts of collected data to make sense of it. Hence, this study employed quantitative and qualitative data analysis methods to interpret the data collected.

3.11.1. Quantitative Data Analysis

In the present study, pre- and post-test analyses of conceptual understanding, chemistry achievement, and motivation were carried out. Descriptive and inferential statistics were used during analysis after normality check. Parametric statistics were used for the analysis in this study, after checking the assumptions. Parametric tests that were used to examine the effect of the TSPCK based instruction on the conceptual understanding, achievement and motivation in this study are ANOVA, MANOVA, follow-up ANOVA and multiple linear regressions. Furthermore, multiple linear regressions were used to determine whether the motivation subscales have influenced conceptual understanding and achievement, and to check whether the pretest-posttest mean difference was statistically significant or not. Furthermore, the researcher computed the mean gains and normalized learning gains for each group by comparing pre- and post-test scores.

3.11.2. Qualitative Data Analysis

Semi-structured interviews with a selected set of participants were conducted to capture the implementation of the interventions and examine the effect of the TSPCK-based instruction modes and students' misconceptions on both chemical kinetics and equilibrium concepts. The researcher first coded and classified the qualitative data collected from grade 11 students and chemistry teachers with semi-structured interviews. Then, the responses of the students, who participated, as well as the chemistry teachers who taught them, were categorized into themes. To determine the interviewee's overall opinions, each interview theme containing captured texts was carefully examined in thematic analysis. When discussing the study's findings, these overall views and comparisons served as a foundation. The data obtained through the classroom observation checklist were also compared between treatment and comparison groups. Finally, the results were combined to fully address the research questions and provide a more robust and meaningful picture of the issue under investigation, which is the effect of TSPCK-based instruction on the variables examined in this particular study.

3.12. Ethical Issues and Considerations

All the processes of research highlighted in this study began and ended with ethical considerations. Creswell and Creswell (2017) pointed out that empirical research in education inevitably carries ethical issues, because it involves collecting data from people, and about people. Educational researchers claim that ethical issues and considerations encompass the whole process of research (Cohen et al., 2007). Thus, efforts were made in terms of taking care of ethical issues from selecting and designing methods to reporting and dissemination of findings. Quasi-experimental research designs are essential in evaluating the effectiveness of interventions, programs, and policies in various fields. However, these designs raise unique ethical considerations that researchers must address to ensure the integrity and validity of their findings. This study has highlighted the key ethical considerations in quasi-experimental research design, including informed consent, confidentiality and anonymity, avoidance of harm, respect for cultural diversity, avoidance of coercion, beneficence, and responsible use of resources.

3.12.1 Cooperation Letter

The researcher has taken a letter of cooperation on February 16, 2022 Ref No: SMED/344/2022-14 from the Department of Science and Mathematics Education of Addis Ababa University. Then, by having this letter of cooperation, the researcher submitted the letter to the Addis Ababa administrative city educational office and the selected secondary schools to get permission. Finally, the researcher discussed with four selected chemistry teachers and their students. The researcher informed the objective of this study and its importance to the students, teachers, and the school community.

3.12.2 Informed Consent

Informed consent is an extremely important ethical concept in research, and participants in this study must provide informed consent. The researcher has ensured that participants understood the purpose of the study, the potential risks and benefits, and their rights as participants (Creswell, 2014). Subsequently, grade 11 students were informed orally to participate in the study and they consented to participate voluntarily. The form explained the purpose of the research study, its benefits, and the confidentiality and anonymity of the data collected. It also indicated that the students were free to withdraw at any stage without any negative effect on them and this was strictly adhered to in this study (see Appendix J).

3.12.3 Confidentiality and Anonymity

This often involved the collection of sensitive information. Researchers must ensure that participants' confidentiality and anonymity were maintained. This was achieved by using pseudonyms, de-identifying data, and ensuring that data are stored securely (Borgman, 2015). In this study, the researcher used code in the interviews (A, B, C, D, E, F) for the students and teachers (T01, T02 and T03), and gave identification code for all participants in the pre-test and posttest scores.

3.12.4 Avoidance of harm and respect for cultural Diversity

The researcher has taken steps to avoid causing any harm to participants in this study. This included ensuring that the intervention groups were engaged, interviewed without any

frustration, and thinking about the impact of pretest and posttest scores on their subject scores. Furthermore, the study often involved participants from diverse backgrounds, and the researcher respected the diversity of participants'/differences (gender, language, etc.).

3.12.5 Avoidance of Coercion, Beneficence, and Use of Resources

Participation in this study was voluntary and based on the participants' willingness to take part. The researcher has avoided coercing or manipulating participants in any way. This includes avoiding any form of pressure or incentive to participate (Creswell, 2014). In addition, the researcher of this study had a responsibility to ensure that the study benefits society or the participants. This includes ensuring that the intervention is being tested effectively and that the study contributes to the existing knowledge base (Kothari, 2018). This study responsibly used the school resources and the researcher of this study ensured that the study was conducted efficiently and cost-effectively (Borgman, 2015).

CHAPTER FOUR: RESULT AND DISCUSSIONS

Introduction

In this chapter, the findings in relation to the dissertation entitled “Topic Specific Pedagogical Content Knowledge-Based Instruction and Grade 11 students’ Chemistry Learning” are presented and discussed. The quantitative and qualitative data analyses techniques were employed in answering the research questions indicated in Chapter one.

4.1. Demographic Characteristics of the Respondents

A sample of 159 grade 11 students, and 4 chemistry teachers participated in the study. The demographic data presented in table 4.1 below presents the number of grade 11 students in terms of sex and achiever levels in each study group. The data showed that male and female ratios as well as the achiever level ratios were unequally distributed in the settings. Based on demographic characteristics, variables were compared. Additionally, participants in the four groups were of similar age, with an average of 17 years ($M = 17.04$, $SD = 0.989$), and they all shared the same learning environment in the Addis Ababa administrative city.

Table 4.1: Demographic characteristics of the respondents

Study Group	Number	Sex		Achiever levels			Age			Total
		M	F	Low	Medium	High	15-17	18-20	>20	
CSA Group	Count	19	19	11	18	9	26	11	1	38
	%	50	50	28.9	47.4	23.7	68.4	29.0	2.6	100
REPs Group	Count	16	20	9	22	5	25	11	0	36
	%	44.4	55.6	25	61.1	13.9	69.4	30.6	0	100
CTS Group	Count	16	19	4	18	13	27	8	0	35
	%	45.7	54.3	11.4	51.4	57.2	77.1	22.9	0	100
CM Group	Count	29	21	12	26	12	37	13	0	50
	%	58	42	34	52	34	74.0	26.0	0	100

CSA= Curricular Saliency based teaching, REPs= Representation based teaching, CTS= Conceptual teaching strategy based teaching, CM= conventional method of teaching

As indicated in Table 4.1, there were 159 participants in four secondary schools, with 80 (50.3%) males and 79 (49.7%) females. Though entire classes were employed for the study, the average number of participants in each class was 39.8, which corresponded to the standard of 40 pupils in each class. From participants of the study, 36 (22.6%) were low achievers, 84 (52.8%) were medium achievers, and 39 (24.5%) were high achievers. The achiever level classification was based on the result of first semester chemistry average scores. This demonstrated that there were more middle achiever levels in each group than low and high achiever levels.

4. 2 Analysis of Quantitative Data

Quantitative data analysis involves examining numerical data or data that can be converted into numbers without losing its essence, often to quantify differences between groups, correlations between variables, and to test hypotheses in a scientifically rigorous way (Pallant & Manual, 2007). This approach contrasts with qualitative data analysis, which explores individuals' perceptions of events or situations. In this investigation, the variables and tools are detailed in Table 4.2. Three dependent variables (DVs) were utilized: the Chemical Kinetics and Equilibrium conceptual understanding, Chemistry achievement, and Chemistry Motivation. Additionally, there were three independent variables (IVs): treatment with four ordinal levels (CSA group, REPs group, CTS group, and Conventional Method (CM) group), gender with two ordinal levels (male, female).

Table 4.2: Variables and instrument of the study

Variables	Type	Measuring instrument	Measurement
Conceptual understanding	DV	CKECUT	Scale
Achievement	DV	CAT	Scale
Motivation	DV	CMQ	Scale
Treatments/Groups	IV	CSA/REP/CTS/CM	Ordinal
Gender	IV	Male/Female	Ordinal

4.3. Analysis of Pre-test and Post test Scores of the Dependent Variables

Research Question One: Are there significant mean score differences between intervention and comparison groups in posttest scores of conceptual understanding, achievement and motivation?

- a. Are there significant mean score differences between intervention and comparison groups On the conceptual understanding in learning chemical kinetics and equilibrium?
- b. Are there significant mean score differences between intervention and comparison groups On the achievement in learning chemical kinetics and equilibrium?
- c. Are there significant mean score differences between intervention and comparison groups On motivation and motivation sub-scales in learning chemical kinetics and equilibrium?

4.3.1. Analysis of Pre-test Scores of the Dependent Variables

The researcher examined the impacts of TSPCK based instruction on students' conceptual understanding, achievement and motivation. The results of the pre-test and posttest tests were analyzed based on the study's four quantitative research questions. The findings from the baseline data (analyses of pre-test results) were presented in the first part of the analysis section, and the results from the post-intervention quantitative data were presented in the second part.

The assumption at the start of this study was that the intervention groups would be comparable. As a result, the researcher tried to analyze the baselines of the intervention and comparison groups prior to implementing the instruction as described by Wiersma and Jurs (2005). The pretest mean scores for the three interventions and one-comparison groups were compared using one-way ANOVA based on data acquired from pre-conceptual understanding test, the pre-chemistry achievement test, and the pre-motivation test. In Table 4.3 and Table 4.4, the statistical findings of each group were analyzed and reported. After all assumptions (independence of observation, homogeneity of variances, normality and absence of outliers), the researcher used one-way ANOVA because there are four independent groups and three dependent variables. Therefore, we did ANOVAs on each three dependent variables for pre-test scores on conceptual understanding, achievement and motivations in learning chemical kinetics and equilibrium.

Table 4.3: Descriptive Statistics of the Students' Pre-Test Scores in Conceptual understanding test, achievement test and Motivation survey of the Groups

Dependent Variables	Groups	N	M	SD
Pre-test Conceptual Understanding	CSA	38	43.86	13.17
	REPs	36	47.64	9.79
	CTS	35	48.00	13.52
	CM	50	44.59	7.77
Pretest Achievement	CSA	38	45.70	13.88
	REPs	36	50.83	8.96
	CTS	35	50.19	14.06
	CM	50	45.86	11.98
Pretest-Motivation	CSA	38	3.57	.584
	REPs	36	3.40	.389
	CTS	35	3.44	.322
	CM	50	3.58	.545

Table 4.3 displays the descriptive statistics of each group. The CTS group (M = 48.00, SD=13.52) scored higher in pre-conceptual understanding than the CSA group (M = 47.64, SD=9.79), CM group (M= 44.59, SD=7.77), and CSA group (M = 43.86, SD= 13.17). Moreover, the REPs group (M = 50.83, SD=8.96) scored higher in pre-achievement than the CTS group (M = 50.19, SD=14.06), CM group (M= 45.86, SD=11.98), and CSA group (M = 45.70, SD= 13.88). Besides, the CM group (M = 3.58, SD=0.545) scored higher in pre-motivation than the CSA group (M = 3.57, SD=0.584), CTS group (M= 3.44, SD=0.322), and REPs group (M = 3.40, SD= 0.389). To check whether these differences were statistically significant or not, ANOVA test was employed (Table 4.4).

Table 4.4: One-Way ANOVA results for Pre-Test Scores of the dependent variables

DV	Category	SS	df	MS	F	Sig.
Pre-CU	Between Groups	506.84	3	168.95	1.382	.250
	Within Groups	18944.49	155	122.22		
	Total	19451.33	158			
Pre-Ach	Between Groups	883.23	3	294.41	1.926	.128
	Within Groups	23693.634	155	152.86		
	Total	24576.867	158			
Pre-Mot	Between Groups	1.01	3	.335	1.444	.232
	Within Groups	36.01	155	.232		
	Total	37.02	158			

Table 4.4 shows whether the groups were the same at baseline or not. The results revealed that Pre-conceptual understanding ($F(3,155) = 1.382, p = .250$), Pre-achievement ($F(3,155) = 1.926, p = .128$), and pre-motivation ($F(3,155) = 1.444, p = .232$) scores of the groups were not significant. This implies that all groups were the same at the beginning or baseline. The result suggests that at the entry-level, the four groups are almost similar in conceptual understanding, achievement, and motivation.

4.3.2 Analysis of Posttest results of the Dependent Variables

The conceptual understanding test, the chemistry achievement test and chemistry motivation questionnaires scores on the post-test for the four groups were also analyzed using SPSS. A one-way ANOVA was used to compare the means of these four groups, namely the curricular Saliency based instruction (CSA) group, the representation based instruction (REPs) group, Conceptual teaching strategy-based instruction (CTS) group and the Conventional Method (CM) group. The posttest means of the CSA group, the REPs group, CTS group and the CM group were compared to determine the most successful strategy for increasing students' conceptual understanding, achievement and motivation in studying chemical kinetics and equilibrium concepts.

Although One-way ANOVA results showed a statistically significant difference in mean scores between groups, it did not identify which specific group differed, as there were more than two

groups. To determine these differences, post hoc multiple comparison was performed. In the next sub-sections, the groups' mean scores were compared based on the post-test results.

4.3.2.1 Effect TSPCK-based Instruction on the Conceptual Understanding of the Students

To investigate the effect of the treatment on students' conceptual understanding the researcher checked the assumptions (independence of observation, absence of outliers, homogeneity of variances and normality) of one-way ANOVA and used it for analysis. The participants were separated into four groups: CSA (Curricular Saliency based), REPs (Representation based), CTS (Conceptual teaching Strategy-based), and CM (Conventional Method). The outcome variable was normally distributed (Appendix L) and unequal variances were assumed based on Levene's test results ($F(3, 155) = 4.420, p=.005$). This means that the one-way ANOVA assumption was not violated. As a consequence, based on the conceptual understanding test scores, the posttest grand mean, mean, and standard deviation of the four groups were analyzed, and the findings are given in Tables below.

Table 4.5: Descriptive Statistics of Groups for Conceptual Understanding Posttest Scores

Groups	N	M	SD
CSA	38	54.34	14.39
REPs	36	62.64	13.26
CTS	35	62.52	15.44
CM	50	45.90	9.32

As can be observed from Table 4.5, the REPs group (M=62.64, SD=13.26) scored higher in post-conceptual understanding than the CTS group (M=62.52, SD=15.44), CSA group (M=54.34, SD=14.39), and CM group (M=45.90, SD=9.32). The data showed that the posttest mean conceptual understanding scores of the intervention groups (REPs, CTS and CSA) are higher than the conventional method. To check whether these differences were statistically significant or not, ANOVA test was employed (Table 4.6).

Table 4.6: ANOVA results

DV	Categories	SS	df	MS	F	Sig.	Partial eta ²
Conceptual understanding	Between Groups	8082.15	3	2694.05	15.823	.000	.239
	Within Groups	26390.96	155	170.26			
	Total	34473.11	158				

The ANOVA analysis result (Table 4.6) showed a significant effect of the treatment on posttest scores ($F(3,155) = 15.823$, $p < .0001$, $\eta^2 = .239$), indicating a larger effect size (Cohen, 1988) guidelines as it is greater than 0.14. The results revealed that there was a statistically significant difference between the treatment and comparison groups in terms of conceptual understanding posttest mean scores. This effect size suggests that approximately 24% of the variance in conceptual understanding scores is attributed to the intervention. This indicates that the TSPCK-based instructional strategies or intervention explains a substantial portion of the variance in students conceptual understanding in learning chemical kinetics and equilibrium concepts. This implies that the TSPCK-based instruction (CSA, REPs and CTS) has a significant and meaningful impact on students conceptual understanding. In order to know which groups has a statistically significant from one another, the Games Howell multiple comparison post hoc analysis was made due to the Levene test result ($p = .005$).

Table 4.7: Games Howell multiple comparison among the groups on the posttest conceptual understanding score.

DV	(I) Groups	(J) Groups	MD (I-J)	SE	Sig.	95% CI		
						LB	UB	
Conceptual understanding		REPs	-8.30	3.21	.056	-16.75	.154	
		CSA						
		CTS	-7.90	3.53	.123	-17.18	1.39	
		CM	8.45*	2.68	.013	1.36	15.53	
		CSA	8.30	3.21	.056	-.154	16.75	
		REPs	CTS	.404	3.45	.999	-8.68	9.49
			CM	16.75*	2.57	.000	9.94	23.55
			CSA	7.90	3.53	.123	-1.39	17.18
		CTS	REPs	-.404	3.45	.999	-9.49	8.68
			CM	16.34*	2.95	.000	8.49	24.19
			CSA	-8.45*	2.68	.013	-15.53	-1.36
		CM	REPs	-16.75*	2.57	.000	-23.55	-9.94
		CTS	-16.34*	2.95	.000	-24.19	-8.49	

*. The mean difference is significant at the 0.05 level. LB: lower bound, UB: Upper bound

The Games-Howell test results (Table 4.7) showed a statistically significant mean difference in post-conceptual understanding results between CSA and CM groups (MD=8.45, $p = .013$); REPs and CM groups (MD=16.75, $p < .0001$); and CTS and CM groups (MD= 16.34, $p < .0001$). The p values indicated the existence of significance difference between all intervention and comparison groups. The mean differences are significant between intervention and comparison groups but no significant difference exists between intervention groups.

Table 4.8: Mean gain and normalized learning gain of conceptual understanding between intervention and comparison groups

DV	Groups	N	M-Pre-CU	M-post-CU	M-gain	L-Gain
Conceptual understanding	CSA	38	43.86	54.35	10.49	0.27
	REPs	36	47.64	62.64	15.00	0.42
	CTS	35	48.00	62.24	14.24	0.40
	CM	50	44.59	45.90	1.31	0.03

Table 4.8 shows the mean gain of the intervention and comparison groups on the conceptual understanding of chemical kinetics and chemical equilibrium concepts. These data revealed that the representation-based instruction and conceptual teaching strategy-based instruction have higher mean gain and normalized learning gain as compared to curricular saliency-based instruction and comparison groups. This indicated that representation based instruction improved by 42% and conceptual teaching strategy based instruction enhanced by 40% on the conceptual understanding of grade 11 students in learning the chemical kinetics and chemical equilibrium concepts from the baseline. On the other hand, curricular saliency-based instruction outperformed by 27% in normalized learning gains than the comparison group. This indicates that both Representation and conceptual teaching strategy-based instruction are moderately effective instruction with noticeable range and Curricular saliency based instruction showing the low gain as compared to the two TSPCK-based instruction which reflectes low effectiveness instruction with minimal learning improvement (Hake, 1998, Rodrigues et al., 2018). In general, the TSPCK-based instruction (three intervention groups) improved the conceptual understanding of grade 11 students after interventions.

In addition to the inferential statistics, the levels of conceptual understanding (no understanding, partial understanding, misconceptions) were decreased after TSPCK-based instruction was

employed. As a result, the level of sound understanding improved in all three intervention groups in favoring both the representation and conceptual teaching instruction-based instruction. In the next section, the researcher analyzed the level of conceptual understanding between intervention groups and conventional method as follows:

Table 4.9: Level of conceptual understanding among the groups on chemical kinetics and chemical equilibrium

Contents	Level of CU	CSA(N=38)		REPs (N=36)		CTS (N=35)		CM (N=50)	
		Pre-test (%)	Posttest (%)	Pretest (%)	Posttest (%)	Pretest (%)	Posttest (%)	Pretest (%)	Posttest (%)
CK'	NU	26.3	7.9	30.8	11.5	28.6	11.4	30.0	26.7
	PU	18.4	13.2	26.9	15.4	25.7	14.3	21.7	18.3
	MS	26.3	10.5	30.8	15.4	34.3	17.1	33.3	28.3
CE	SU	28.9	68.4	11.5	57.7	11.4	57.1	15.0	26.7
	NU	31.6	18.4	26.9	7.7	25.7	15.2	23.3	28.3
	PU	21.1	10.5	30.8	19.2	22.9	12.1	26.7	18.3
	MS	23.7	13.2	34.6	7.7	37.1	21.2	36.7	28.3
	SU	23.7	57.9	7.7	65.4	14.3	51.5	13.3	25.0

CSA: curricular Saliency based instruction, REPs: Representation-based instruction, CTS: conceptual teaching strategy based instruction, CM: Conventional method of teaching

Table 4.9 illustrates the conceptual understanding levels among the treatment groups (CSA, REPs, CTS) and the comparison (CM) group. In the CSA group, conceptual understanding decreased in NU (26.3% to 7.9%), PU (18.4% to 13.2%), and MS (26.3% to 10.5%). However, students' sound understanding of chemical kinetics increased significantly, from 28.9% to 68.4%. Similarly, in the REPs group, NU decreased from 30.8% to 11.5%, PU from 26.9% to 15.4%, and MS from 30.8% to 15.4%, with sound understanding rising from 11.5% to 57.7%. The CTS group saw reductions in NU (28.6% to 11.4%), PU (25.7% to 14.3%), and MS (34.3% to 17.1%), with sound understanding increasing from 11.4% to 57.1%. The CM group showed a smaller decrease in NU (30.0% to 26.7%), PU (21.7% to 18.3%), and MS (33.3% to 28.3%), with sound understanding increasing from 15% to 26.7%.

Additionally, the CSA-based instruction improved student understanding by 39.5% in chemical kinetics and 34.2% in chemical equilibrium. REPs-based instruction resulted in a 46.2% increase in chemical kinetics and a 57.7% increase in chemical equilibrium. CTS-based instruction yielded mean increases of 45.7% in chemical kinetics and 37.2% in chemical equilibrium. In contrast, the CM group showed minimal improvement (11.7% in both topics). Overall, TSPCK-based instructions (CSA, REPs, and CTS) resulted in greater improvements in conceptual understanding of chemical kinetics compared to chemical equilibrium, outperforming conventional instruction.

The level of conceptual understanding was higher in all treatment groups (CSA, REPs, and CTS) compared to the conventional teaching group. This indicates that the treatment groups effectively enhanced the understanding of grade 11 students in chemical kinetics and chemical equilibrium. Among the treatment groups, the REPs-based instruction outperformed the others, as well as the conventional method, in improving students' understanding of both concepts. This success can be attributed to the use of threefold representations (macro, micro, and symbolic levels) in the REPs group, which made learning more meaningful.

The CTS-based instruction, which incorporated web-based tools (such as Edpuzzle and Chem-Craft) and interactive questions, also contributed to an increase in students' sound understanding. Similarly, CSA-based instruction, which connected chemical kinetics and equilibrium to students' daily lives and focused on big ideas, further enhanced their understanding compared to conventional teaching methods. The trends observed in the sound understanding levels across the intervention and comparison groups are summarized as follows in figure 2.

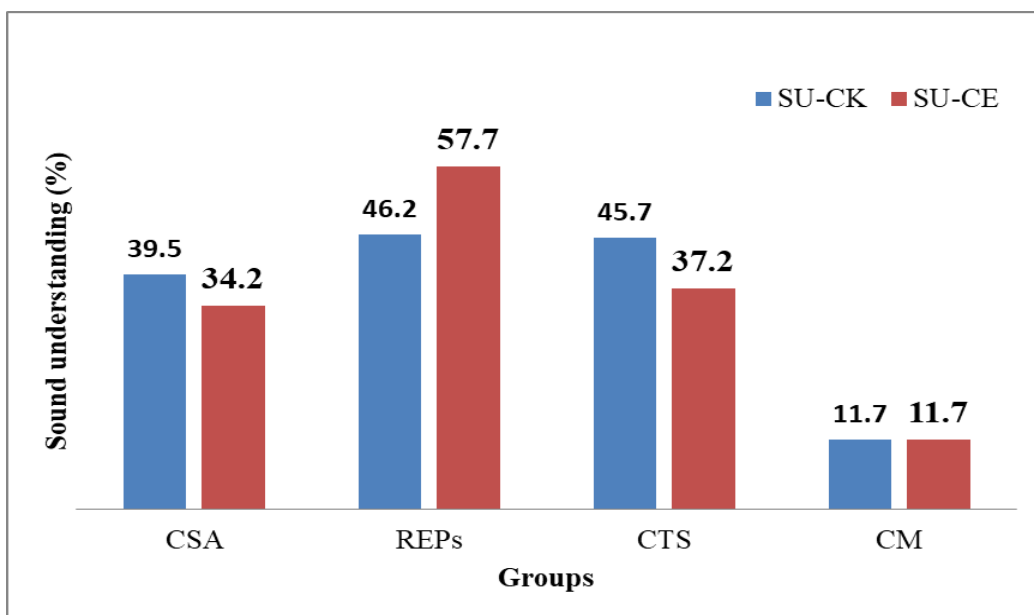


Figure 2: level of sound understanding by intervention and comparison groups on chemical Kinetics and chemical equilibrium concepts

Figure 2 depicts that the level of sound understanding of students in the chemical kinetics and chemical equilibrium concepts. As mentioned on the figure 2 above, the level of sound understanding has enhanced in chemical kinetics by 39.5% and equilibrium concepts by 34.2% in CSA based instruction. The representation-based instruction also enhanced the level of sound understanding of the students by 46.2% and 57.7% in chemical kinetics and equilibrium concepts respectively. Similarly, the CTS based instruction also increased the level of sound understanding of grade 11 students by 45.7% and 37.2% respectively in chemical kinetics concepts. However, the conventional teaching method groups had no change in the level of sound understanding of the students in both chemistry topics.

Discussion on Results of Conceptual Understanding

This part of the study discusses findings in relation to conceptual understanding. Review work in this dissertation has shown that the understanding of learners changes meaningfully when different innovative approaches are employed in chemistry education. In this work, an attempt was made whether the literature-related findings are in agreement with the results of the kinetics and equilibrium concepts or not. ANOVA analysis and follow up Games-Howell test results indicated that statistically significant mean differences in post-conceptual understanding results

between CSA and CM groups; REPs and CM groups; and CTS and CM groups. A statistically significant difference between all intervention and comparison groups was reported. The mean differences are not significant between intervention groups. TSPCK-based instruction (three intervention groups) improved the conceptual understanding of grade 11 students after interventions.

For instance, representation-based instruction is a novel teaching method that stresses the use of visual and concrete representations to convey chemistry topics. This strategy is founded on the assumption that students learn more effectively when they can perceive and manipulate abstract concepts. Chemistry concepts are grouped into macro, micro, and symbolic levels. In contrast, traditional teaching methods rely mainly on lectures and textbooks to deliver information.

Several studies have compared representation-based instruction with traditional teaching methodologies in chemistry, demonstrating significant advantages. Representation-based instruction regularly leads to superior understanding and also improves problem-solving skills of chemistry concepts, as demonstrated by Hmelo-Silver (2004). Kozan (2013) observed that students who used representation-based strategies were better at addressing complicated problems. Finally, representation-based instruction increases chemistry concept retention, as demonstrated by BouJaoude (2010), who discovered that learners retained more information about chemical reactions than their traditionally taught classmates.

The study demonstrates the superior effectiveness of TSPCK-based instructional approaches such as representation-based, conceptual teaching strategy-based, and curricular saliency-based in enhancing students' conceptual understanding of chemical kinetics and equilibrium compared to conventional teaching methods. Among these, representation-based and conceptual teaching strategy-based methods showed the most significant improvement in students' comprehension and engagement. Representation-based instruction excels in simplifying abstract concepts through visual aids and interactive tools, aligning with findings by Kozan (2013) and Tipton (2013), who emphasize its role in fostering a deeper understanding. Similarly, conceptual teaching strategy-based instruction outperformed others by focusing on structured problem-solving and conceptual frameworks, creating a highly interactive learning environment. These findings underscore the effectiveness of TSPCK-based approaches in addressing the challenges of abstract and complex chemistry topics.

Curricular Saliency-based instruction, while slightly less effective than the other TSPCK methods, demonstrated significant advantages over conventional approaches. By linking chemical concepts to real-world applications, it boosted students' motivation, interest, and retention. This aligns with studies by Hmelo-Silver (2004), Kim (2013), and Lee (2015), which highlight its role in promoting meaningful learning outcomes and engagement. Although curricular saliency focuses more on relevance than deep conceptual mastery, its ability to connect students' learning to practical scenarios enhances comprehension and application of chemical concepts. Together, these findings confirm that TSPCK-based instruction offers a holistic approach to improving conceptual understanding, engagement, and learning outcomes in chemistry education.

Regarding the conceptual teaching strategy- based instruction, the finding of this study revealed that this strategy enhanced the conceptual understanding of the students even higher than the curricular saliency based instruction and conventional method of teaching chemistry concepts. This enhanced understanding in learning chemical kinetics and equilibrium obtained as a result of using technology supported ed-puzzle educational platform that made the student engaged and interactive in their learning. The finding of this study was supported by Tipton (2013) that confirmed that conceptual teaching strategy based-instruction promote comprehension and problem solving rather than the memorizing of facts and formulas. This strategy promotes critical and abstract thinking, which may improve students' capacity to solve complicated problems and apply chemical concepts in real-world scenarios

In this study, conceptual teaching strategy-based instruction in chemistry focuses on developing students' conceptual knowledge and problem-solving skills, resulting in better learning outcomes and performance. This study utilized the ed-puzzle e-learning platform, a computer-assisted instructional technique, to engage students in the learning process, make them interactive between lessons, and deliver closing remarks at the end of each concepts. This finding was also consistent with the study conducted by Goldsmith (2008) and Kozan (2012) that indicated in their study that students who receive conceptual teaching strategy based instruction outperform than those who receive conventional instruction on chemical concept examinations and particularly useful for improving high school students' understanding of chemical reactions . Research conducted by Zohar (2010) indicated that both conceptual teaching strategy-based

instruction and curriculum saliency-based instruction have been demonstrated to enhance student performance in chemistry, the former was more successful in fostering a thorough comprehension of difficult chemical concepts. Zohar's (2010) study findings are consistent with this study findings. On the other hands, the conventional methods of instruction frequently place more emphasis on memory than on conceptual understanding and problem-solving abilities, which can result in inadequate learning outcomes and a lack of comprehension of chemical concepts (Sweller, 1999).

Even though many studies findings are consistent with the findings of this study, there are inconsistent findings reported by different researchers. Studies have indicated that alternate approaches to teaching chemistry, like conceptual teaching methodologies and curriculum saliency-based instruction, might not be as successful as conventional method of teaching. According to these studies, using these different approaches resulted in decreased in achievement, and conceptual knowledge (Tipton & Goldsmith, 2006; Yoon & Lee, 2015).

According to a review in the Journal of Science Teacher Education, while conceptual teaching practices in chemistry can improve conceptual comprehension, they may also reduce focus on procedural skills and student motivation (Cetin-Dindar & Geban, 2017). These findings do not represent all the research on these strategies, indicating that more research is required to completely understand their effects. The exact context and application of these strategies are critical for interpreting the outcomes, as they may have unexpected negative effects such as poorer achievement and motivation.

Constructivist teaching approaches, such as problem-based learning (PBL), greatly improve students' conceptual understanding and problem-solving abilities as compared to conventional methods. Hmelo-Silver (2004) and others found that PBL improves mental models and comprehension of complicated chemistry topics such as chemical bonds and chemical reactions. Similarly, Tipton and Goldsmith (2006) and Kozan and Gurses (2013) discovered that conceptual instructional strategies that emphasize understanding and utilization outperform procedural knowledge, resulting in improved grasp and application of chemical concepts. Studies also emphasize the importance of curricular saliency and representation-based teaching strategies (macro, micro, and symbolic levels) in improving conceptual understanding and problem-solving

abilities, but difficulties arise when students are unfamiliar with interactive multimedia tools (Rollnick & Mavunga, 2014).

Gender-based differences in conceptual understanding were also observed, with female students outperforming male students in certain contexts, such as using submicroscopic media animations (Mashami & Gunawan, 2018; Gunawan et al., 2018b). Despite some variations, topic-specific PCK-based instruction consistently decreased misunderstandings while improving students' understanding of chemical kinetics and equilibrium. Research on several chemical topics confirms the usefulness of PCK-based strategies in developing deeper knowledge, as evidenced in research on acid-base chemistry and quantum mechanics (Miller & Goldsmith, 2012; Lawson & Wong, 2013). Overall, combining TSPCK-based approaches with multimedia tools has tremendous promise to improve conceptual learning in chemistry.

There are inconsistent studies to this study. For instance, a study conducted by Bell and Lederman (2012) discovered that students' comprehension of thermodynamic concepts with conventional instruction was not significantly affected by TSPCK-based thermodynamics instruction. According to the study conducted by Rollnick and Mavhunga (2014), due to lack of technology and computer using skills, TSPCK-based instruction may actually cause students' conceptual grasp of chemistry concepts to decline. According to a study conducted by Gabel and Crawford (2013), students' capacity to apply chemical concepts to practical contexts decreased as a result of TSPCK-based instruction in chemical reactions as compared to conventional teaching strategies.

Some studies have revealed that the efficiency of TSPCK-based instruction can be influenced by factors such as teacher training and support, instructional material quality, and students' prior knowledge and experience. For example, Kozan and Gurses (2013) discovered that TSPCK-based instruction was more effective when teachers were given additional training and assistance.

Overall, the research reveals that topic-specific PCK-based instruction can help students enhance their conceptual grasp of chemistry concepts, although the effectiveness varies depending on a number of parameters. More research is required to fully comprehend the conditions under which

TSPCK-based instruction is most successful and to find the best ways for implementing TSPCK-based instruction in chemistry.

4.3. 2.2 Effect of TSPCK-based Instruction on the Achievement Posttest Scores of Students

In the next analysis, the researcher focused on the achievement of grade 11 students on the effectiveness of TSPCK based instructions (CSA, REPs and CTS) in comparison with the comparison groups on the chemical kinetics and equilibrium concepts

Table 4.10: Descriptive statistic of the groups for achievement posttest scores

Dependent Variable	Groups	N	Mean	SD
Posttest-Achievement	CSA	38	54.73	14.58
	REPs	36	61.56	15.02
	CTS	35	62.66	16.92
	CM	50	47.06	11.01
	Total	159	55.61	15.54

Table 4.10 above depicts the descriptive statistics of groups. As can be observed from Table 4.10, the CTS group (M=62.66, SD= 16.92) scored higher in post-achievement test than the REPs group (M=61.56, SD= 15.02), CSA group (M=54.34, SD=14.39), and CM group (M=47.06, SD= 11.01). The data showed that the posttest mean achievement scores of the intervention groups (CTS, REPs and CSA) are higher than the conventional method. To check whether these differences were statistically significant or not, ANOVA test was employed (Table 4.11).

Table 4.11: ANOVA result

DV	Category	SS	df	MS	F	Sig.	Partial eta ²
Post-Ach	Between Groups	6695.76	3	2231.92	11.004	.000	.176
	Within Groups	31438.62	155	202.83			
	Total	38134.38	158				

The ANOVA analysis result (Table 4.11) showed a significant effect of the treatment on posttest scores ($F(3,155) = 11.004, p < .0001, \eta^2 = .176$), indicating a large effect size (Cohen, 1988). This effect size indicates that 18% of the variance in achievement scores is explained by the intervention. This indicates that the interventions explain a substantial portion of the variance in students' chemistry achievement on learning chemical kinetics and equilibrium concepts. This implies that the TSPCK based instructional strategies (CSA, REPs and CTS) have a significant and meaningful impact on students' chemistry achievement scores in learning chemical kinetics and equilibrium concepts. However, it did not tell us which groups were statistically significantly different from one another. Therefore, the overall F values are significant and the Levene's test was significant. Thus, the Games-Howell post hoc multiple comparison was used in the next table as follows.

Table 4.12: Games-Howell multiple comparison among the groups on the posttest achievement scores

DV	(I) Groups	(J) Groups	MD (I-J)	SE	Sig.	95% CI	
						LB	UB
Achievement		REPs	-6.83	3.44	.204	-15.89	2.23
		CSA					
		CTS	-7.93	3.71	.152	-17.71	1.85
		CM	7.67*	2.83	.042	.201	15.13
		CSA	6.83	3.44	.204	-2.23	15.89
		REPs					
		CTS	-1.10	3.80	.992	-11.11	8.91
		CM	14.50*	2.95	.000	6.71	22.28
		CSA	7.93	3.71	.152	-1.85	17.71
		CTS					
		REPs	1.10	3.80	.992	-8.91	11.11
		CM	15.60*	3.26	.000	6.96	24.23
	CSA	-7.67*	2.83	.042	-15.13	-2.01	
	CM						
	REPs	-14.50*	2.95	.000	-22.28	-6.71	
	CTS	-15.60*	3.25	.000	-24.23	-6.96	

*. The mean difference is significant at the 0.05 level.

The Games-Howell test results (Table 4.12) showed a statistically significant mean difference in post-achievement test results between CSA and CM groups ($MD=7.67, p = .042$); REPs and CM

groups (MD=14.50, $p < .0001$); and CTS and CM groups (MD= 15.60, $p < .0001$). The p values indicated the existence of significance difference between all intervention and comparison groups. The mean differences are significant between intervention and comparison groups but no significant difference exists between intervention groups. From this Games-Howell multiple comparison posttest result, CSA, REPs, and CTS improved the academic achievement of grade 11 students on the concepts of chemical kinetics and chemical equilibrium. These changes in the posttest achievement scores of the students were also confirmed on the mean gains and normalized learning gains as shown in the table 4.13 below.

Table 4.13: mean gain and normalized learning gain of academic achievement of intervention and comparison groups in the pre-test and posttest scores

DV	Groups	N	Pre-Ach	post-Ach	M-gain	L-Gain
Achievement	CSA	38	45.70	54.73	9.03	0.24
	REPs	36	50.83	61.56	10.73	0.33
	CTS	35	50.19	62.66	12.47	0.38
	CM	50	45.86	47.06	1.20	0.03

Table 4.13 shows that the mean gain and normalized learning gains of the intervention and comparison groups on the academic achievement of kinetics and chemical equilibrium concepts. That data revealed that the representation based instruction and conceptual teaching strategy-based instruction have higher mean gain and normalized learning gain as compared to curricular saliency-based instruction and comparison groups. This indicated conceptual teaching strategy based instruction improved the achievement scores of grade 11 students on the chemical kinetics and chemical equilibrium concepts followed by representation-based instruction. On the other hand, curricular saliency-based instructional group students also outperform the students in the comparison group. In general, the TSPCK-based instruction improved the students' academic

achievement after the interventions in the treatment groups. The normalized learning gain in academic achievement of CSA, REPS, CTS and CM were 24%, 33%, 38% and 3% respectively. This implies that the conceptual teaching strategy based instruction increased the academic performance of the students by 38% and the representation based instructional strategy increased by 33% when compared with the conventional instructional strategy. Furthermore, the curricular saliency-based instructional group outperformed the conventional instructional strategy group with a mean gain of 24%. Generally, the academic achievement normalized learning gain of grade 11 students in Addis Ababa secondary schools increased on the range of medium gain due to TSPCK-based instruction. This suggests moderately effective TSPCK-based instruction with noticeable but not exceptional improvement (Hake, 1998; R; Rodriguez et al., 2018). The values of normalized learning in table 4.13 revealed that the learning gains obtained also supported with the effect size of topic specific PCK based instruction.

Discussion on the Achievement of the students in Groups

Conceptual teaching strategy (CTS)-based instruction enabled pupils to learn and achieve more. It was discovered to be more successful in students' achievement than REP-based and CSA-based instruction for teaching complex chemical concepts. CTS-based instruction had the highest posttest achievement mean scores, followed by REPs-based instruction, CSA-based instruction, and then the conventional group. This was similar to self-discovery in that everything taught in the course could be implemented efficiently without assistance. As a consequence, in terms of teaching chemical kinetic and chemical equilibrium concepts, the conceptual teaching strategy-based instructional mode outperformed both the REPS-based and conventional modes. This confirms Carless's (2005) findings that CTS-based learning implementation leads to cognitive enhancement in science students who employ computer-assisted lesson preparation.

Besides, REPS-based and CTS-based approaches were more effective than conventional approach for teaching chemical topics. Students learn faster and more efficiently when they participate in particular exercises during representation-based and CTS-based approaches, which broadens their knowledge and boosts their self-determination. In REPS-based approach, the treatment of chemistry concepts in three understanding levels (macro, micro, and symbolic) improved student knowledge and achievement (Johnstone, 1991). The treatment of concepts at these three levels facilitates students' comprehension of difficult chemical concepts. Computer-based multimedia training, as one approach of representation based instruction, can also help

with conceptual comprehension skills (Masami et al., 2014; Guzel & Adadan, 2013). This computer supported representation-based instruction, however, may mislead students who are unaccustomed to computer use when comparing animated notions to real-world concepts (Rollnick & Mavhunga, 2014). Overall, understanding the three levels of representations in chemistry helps improve teaching approaches and students' understanding of complicated chemical ideas (Hausein et al., 2019; Hermansyah et al., 2019).

This study found that TSPCK-based instructional strategies (CSA, REPS, and CTS) significantly enhanced students' understanding of chemical kinetics and equilibrium concepts as compared to conventional teaching methods. These strategies improved students' academic performance by focusing on understanding and problem-solving skills. The findings are consistent with research by Manurung and Mihardi (2018) and Dasilva et al. (2019), who found that interactive multimedia and technology-assisted TSPCK promote conceptual understanding and critical thinking. Virtual labs and multimedia tools, such as submicroscopic media animations, have been shown to enhance learning by making it more dynamic, engaging, and effective, while also reinforcing higher-order thinking abilities and academic achievement.

Contrary to Bodner and Herron's (2004) arguments that conceptual understanding has no impact on problem solving, this study confirms the usefulness of interactive multimedia in facilitating deeper learning. Incorporating macroscopic, submicroscopic, and symbolic representations into multimedia tools greatly improved problem-solving abilities and academic achievement. However, the conflicting findings in other studies indicated the need for more research with larger, more diverse samples to investigate the broader impact of TSPCK-based instruction and interactive multimedia on students' learning outcomes in a variety of circumstances.

4.3.2. 3. Effect of TSPCK-based Instruction on the Motivation Posttest Scores of Students

Table 4.14: Descriptive statistics of groups

DV	Groups	N	Mean	SD
Motivation	CSA	38	4.12	.326
	REPs	36	4.35	.353
	CTS	35	3.76	.363
	CM	50	3.70	.485
	Total	159	3.96	.474

Table 4.14 above depicts the descriptive statistics of groups. As can be seen from Table 4.14, the REPs group (M=4.35, SD= 0.353) scored higher in post-motivation score than the CSA group (M=4.12, SD= .326), CTS group (M=3.76, SD= .363), and CM group (M=3.70, SD= .485). The data showed that the posttest mean motivation scores of the intervention groups (REPs, CSA and CTS) are higher than the conventional method. To check whether these differences were statistically significant or not, ANOVA test was employed (Table 4.15). Table 4.14 above depicts that the descriptive statistics of posttest scores of motivation between intervention and comparison groups. The mean score of achievement scores of CSA motivation posttest score (N= 38), REPs (N= 36), CTS (N= 35) and CM (N=50).

Table 4.15: ANOVA Results

DV	Category	SS	df	MS	F	Sig.	Partial eta ²
Motivation	Between Groups	11.261	3	3.754	23.924	.000	.316
	Within Groups	24.321	155	.157			
	Total	35.582	158				

The ANOVA analysis result (Table 4.15) showed a significant effect of the treatment on posttest scores ($F(3,155) = 23.924, p < .0001, \eta^2 = .316$), indicating a very large effect size. This value revealed that a very large effect size than the conceptual understanding and achievement as it is much greater than 0.14. It suggests that the intervention explained 32% of the variance in

motivation scores. This showed that the TSPCK based instruction or factors being studied has a substantial influence on students' motivation to learn chemical kinetics and equilibrium concepts. This implies that the teaching approaches (TSPCK-based instructions) have a significant and powerful impact on students' motivation, suggesting it is highly effective in fostering intrinsic motivation, self-efficacy, self-determination, mark motivation and career motivation in the chemistry subject. However, it did not tell us which groups were statistically significant from one another. Therefore, the overall F values is significant and the Levene's test was not significant. Thus, the Tukey post hoc multiple comparison was used in the next table as follows.

Table 4.16: The Tukey HSD multiple post hoc comparison of posttest motivation in groups

(I) Groups	(J) Groups	Mean Difference		Sig.	95% Confidence Interval	
		(I-J)	S. E		Lower Bound	Upper Bound
CSA	REPs	-.232	.092	.062	-.471	.008
	CTS	.358*	.093	.001	.117	.599
	CM	.420*	.085	.000	.199	.642
REPs	CSA	.232	.092	.062	-.008	.471
	CTS	.590*	.094	.000	.346	.834
	CM	.652*	.087	.000	.427	.877
CTS	CSA	-.358*	.093	.001	-.599	-.117
	REPs	-.590*	.094	.000	-.834	-.346
	CM	.062	.0873	.893	-.165	.289
CM	CSA	-.420*	.085	.000	-.642	-.199
	REPs	-.652*	.087	.000	-.877	-.427
	CTS	-.062	.087	.893	-.289	.165

*. The mean difference is significant at the 0.05 level.

The Tukey's HSD post hoc multiple comparison results (Table 4.16) showed a statistically significant mean difference in post-motivation score results between CSA and CM groups (MD=0.42, $p < .0001$); CSA and CTS (MD=0.36, $p = .001$); REPs and CM groups (MD=0.65, $p < .0001$); REPs and CTS (MD=0.59, $p < .0001$). The p values indicated the existence of

significance difference between two intervention groups (CSA and REPS) and comparison group, CSA and CTS, and REPs and CTS. But no significant difference exists between CSA and REPs, and CTS and CM. These findings show that, while both CSA and REP-based instruction improved students motivation as compared to their respective CTS-based instruction and CM, there was no obvious benefit of CSA over CTS or CTS over CM in terms of motivation.

Effect of TSPCK-based Instruction on the Motivation Sub-scales Posttest Scores of Students

Table 4.17: Descriptive statistic of the groups on the posttestmotivation Sub-scales

Dependent variables	Groups				
		CSA (N=38)	REPs (N=36)	CTS (N=35)	CM (N=50)
Intrinsic Motivation	M	4.13	4.42	3.85	3.76
	SD	0.43	0.43	0.51	0.54
Self-Efficacy	M	4.03	4.36	3.73	3.62
	SD	0.44	0.43	0.39	0.58
Self-Determination	M	3.94	4.24	3.62	3.39
	SD	0.45	0.40	0.48	0.72
Mark motivation	M	4.50	4.39	4.10	4.23
	SD	0.46	0.48	0.63	0.65
Career Motivation	M	3.96	4.32	3.55	3.49
	SD	0.53	0.58	0.55	0.73

Table 4.17 here above depicts the descriptive statistics of groups. As can be seen from Table 4.17, the REPs group (M=4.42, SD= 0.43) scored higher in post- Intrinsic Motivation score than the CSA group (M=4.13, SD= .43), CTS group (M=3.85, SD= .51), and CM group (M=3.76, SD= .54). The data showed that the posttest mean intrinsic motivation scores of the intervention groups (REPs, CSA and CTS) are higher than the conventional method. As can be seen from the same Table, the REPs group (M=4.36, SD= 0.43) scored higher in post-self-efficacy score than the CSA group (M=4.03, SD= .44), CTS group (M=3.73, SD= .39), and CM group (M=3.62, SD= .58). As can be observed from Table 4.17, the REPs group (M=4.24, SD= 0.40) scored

higher in post- Self-Determination score than the CSA group (M=3.94, SD= .45), CTS group (M=3.62, SD= .48), and CM group (M=3.39, SD= .72). As can be seen from the same Table, the CSA group (M=4.50, SD= 0.46) scored higher in post- Mark motivation score than the REPs group (M=4.39, SD= .48), CM group (M=4.23, SD= .65), and CTS group (M=4.10, SD= .63). As can be observed from Table 4.17, the REPs group (M=4.32, SD= 0.58) scored higher in post-Career Motivation score than the CSA group (M=3.96, SD= .53), CTS group (M=3.55, SD= .55), and CM group (M=3.49, SD= .73). The data showed that the posttest mean intrinsic motivation, self-efficacy, self determination, career motivation scores of the intervention groups (REPs, CSA and CTS) are higher than the conventional method. Also, the data revealed that the posttest mean mark motivation scores of the CSA group, REPs group, and CM group, are higher than the CTS group. This may as a result of redundant interactive questions between the lesson that limited the the level of participation of good achieving students in the CTS-based groups and the implementation of ed-puzzle educational instruction was new for them. To check whether these differences were statistically significant or not, ANOVA test was employed (Table 4.18).

Table 4.18: ANOVA results of motivation components

Dependent variable	Category	SS	df	MS	F	Sig.
Intrinsic motivation	Between Groups	10.511	3	3.504	14.822	.000
	Within Groups	36.640	155	.236		
	Total	47.151	158			
Self-efficacy	Between Groups	13.102	3	4.367	19.210	.000
	Within Groups	35.238	155	.227		
	Total	48.339	158			
Self-determination	Between Groups	17.090	3	5.697	19.099	.000
	Within Groups	46.233	155	.298		
	Total	63.323	158			
Mark motivation	Between Groups	3.397	3	1.132	3.494	.017
	Within Groups	50.233	155	.324		
	Total	53.630	158			
Career motivation	Between Groups	17.844	3	5.948	15.766	.000
	Within Groups	58.475	155	.377		
	Total	76.319	158			

The ANOVA analysis result (Table 4.18) showed a significant effect of the treatment on posttest intrinsic motivation ($F(3,155) = 14.822, p < .0001$), posttest self-efficacy ($F(3,155) = 19.210,$

p<.0001), posttest self-determination (F (3,155) =19.099, p= .000), posttest mark motivation (F (3,155) =3.494, p= .017), and career motivation scores (F (3,155) =15.766, p< .0001). To know which groups has a statistically significant from one another we introduced the Turkey and Games Howell multiple comparison post hoc analysis were used based on the Levene test statistics respectively.

Table 4.19: Tukey’s multiple comparisons post hoc test among the groups on the posttestmotivation component scores

Dependent Variable	(I)	(J)	MD		Sig.	95% CI	
	Groups	Groups	(I-J)	SE		LB	UB
	<hr/>						
Intrinsic Motivation		REPs	-0.285	0.113	0.061	-0.58	0.01
		CTS	0.280	0.114	0.070	-0.02	0.58
	CSA	CM	.372*	0.105	0.003	0.10	0.64
		CTS	.565*	0.115	0.000	0.27	0.87
	REPs	CM	.657*	0.106	0.000	0.38	0.93
		CTS	0.091	0.107	0.829	-0.19	0.37
<hr/>							
Self-Efficacy		REPs	-0.324*	0.111	0.021	-0.61	-0.04
		CTS	.306*	0.112	0.034	0.02	0.60
	CSA	CM	.412*	0.103	0.001	0.15	0.68
		CTS	.629*	0.113	0.000	0.34	0.92
	REPs	CM	.736*	0.104	0.000	0.47	1.01
		CTS	0.106	0.105	0.746	-0.17	0.38
<hr/>							
Career Motivation		REPs	-0.364	0.143	0.056	-0.74	0.01
		CTS	.409*	0.144	0.026	0.04	0.78
	CSA	CM	.470*	0.132	0.003	0.13	0.81
		CTS	.774*	0.146	0.000	0.40	1.15
	REPs	CM	.834*	0.134	0.000	0.49	1.18
		CTS	0.061	0.135	0.970	-0.29	0.41

* The mean difference is significant at the 0.05 level.

The Tukey's HSD post hoc multiple comparison results (Table 4.19) showed a statistically significant mean difference in post- Intrinsic Motivation score results between CSA and CM groups (MD=.372, $p=, 003$); REPs and CTS groups (MD=.565, $p<.0001$); and REPs and CM (MD=.657, $p=.000$). But no statistically significance difference exists between REPs and CTS (MD= -.285, $p=.061$), CSA and CTS (MD=0.280, $p=.070$) and CTS and CM group (MD=.091, $p=.829$). This indicated that CTS-based instruction was equally important in enhancing the intrinsic motivation of the students of the comparison group. The p values indicated the existence of significance difference between CSA and CM groups, REPs and CTS groups, and REPs and CM. However, no significant difference exists between REPs and CTS groups, CSA and CTS groups, and CTS and CM groups. The Tukey's HSD post hoc multiple comparison results, also showed a statistically significant mean difference in post-self-efficacy score results between CSA and CM groups (MD=.412, $p=, 001$); REPs and CM groups (MD=.736, $p=.000$); CSA and REPs (MD= -.324, $p=.021$), and CSA and CTS (MD=.306, $p=.034$). But no statistically significance difference exists between CTS and CM group (MD=.106, $p=.746$). The p values indicated the existence of significance difference between CSA and CM groups; REPs and CM groups; CSA and REPs, and CSA and CTS groups. However, no significant difference exists between CTS and CM groups. This might be due to the nature of questions asked during CTS-based instruction. Moreover, the Tukey's HSD post hoc multiple comparison results showed a statistically significant mean difference in post-career motivation score results between CSA and CM groups (MD=.470, $p=, 003$); REPs and CM groups (MD=.834, $p<.0001$); REPs and CTS (MD=.774, $p<.0001$), and CSA and CTS (MD=.409, $p=.026$). Yet no statistically significance difference exists between CSA and REPs (MD= -.364, $p=.056$), and CTS and CM (MD=0.061, $p=.970$). The p values indicated the significant difference between CSA and CM groups, REPs and CM groups, REPs and CTS, and CSA and CTS. However, no significant difference exists between CSA and REPs, and CTS and CM groups.

One can concluded that, in three motivation subscales (intrinsic motivation, self-efficacy and career motivation), the TSPCK-based instruction guided by CSA and REPs approaches made a statistically significance difference in the mean scores of groups as compared to the conventional method of teaching.

Table 4.20: Games-Howell multiple comparison among the groups on the posttest of motivation component scores

DV	(I)	(J)	MD (I-J)	SE	Sig.	95% CI	
						LB	UB
Self-determination	CSA	REPs	-.2968*	.0983	.018	-.555	-.038
		CTS	.3192*	.1086	.023	.033	.605
		CM	.5541*	.1254	.000	.225	.883
	REPs	CSA	.2968*	.0983	.018	.038	.555
		CTS	.6160*	.1043	.000	.341	.891
		CM	.8509*	.1217	.000	.532	1.170
	CTS	CSA	-.3192*	.1086	.023	-.605	-.033
		REPs	-.6160*	.1043	.000	-.891	-.341
		CM	.2349	.1301	.278	-.106	.576
	CM	CSA	-.5541*	.1254	.000	-.883	-.225
		REPs	-.8509*	.1217	.000	-1.170	-.532
		CTS	-.2349	.1301	.278	-.576	.106
Mark motivation	CSA	REPs	.1058	.1098	.770	-.183	.395
		CTS	.3976*	.1301	.017	.054	.741
		CM	.2627	.1191	.130	-.049	.575
	REPs	CSA	-.1058	.1098	.770	-.395	.183
		CTS	.2917	.1328	.135	-.059	.642
		CM	.1569	.1220	.574	-.163	.477
	CTS	CSA	-.3976*	.1301	.017	-.741	-.054
		REPs	-.2917	.1328	.135	-.642	.059
		CM	-.1349	.1405	.773	-.504	.234
	CM	CSA	-.2627	.1191	.130	-.575	.049
		REPs	-.1569	.1220	.574	-.477	.163
		CTS	.1349	.1405	.773	-.234	.504

*. The mean difference is significant at the 0.05 level.

The Games-Howell test results (Table 4.20) showed a statistically significant mean difference in post-self-determination results between CSA and CM groups (MD=0.554, p= .000); CSA and

REPs (MD= -0.297, p= .018); and CSA and CTS (MD=0.319, p= .023). Yet no statistically significance difference exists between CTS and CM groups (MD= 0.235, p= .278). The p values indicated the significant difference between CSA and CM groups, CSA and REPs, and CSA and CTS. However, no significant difference exists between CTS and CM groups. This revealed that an interesting result that students equally self determined in the learning of chemical kinetics and equilibrium concepts in both Cm and CTS groups. Besides, the Games-Howell test results showed a statistically significant mean difference in post-mark motivation results between CSA and CTS groups (MD=0.398, p= .017). This implies that both group students (CSA and CTS) motivated differently because CSA focused on the learning based on identifying big ideas and related it with real life of the students whereas, CTS strategy focused on ed-puzzle educational platform and interactive questions. But no statistically significance difference exists between CSA and REPs (MD= 0.106, p= .770); CSA and CM (MD=0.263, p= .130), REPS and CTS (MD= 0.292, p= .135), and REPs and CM groups (MD= 0.157, p= .574). This revealed that the intervention groups (REPs and CTS) and comparison (CM) are equally motivated in scoring a good mark scores on the chemical kinetics and equilibrium concepts. This implies that students were equally motivated in having a good mark in representation, conceptual teaching strategy and conventional method of teaching chemistry concepts.

Table 4.21: mean gain and normalized learning gain of motivation of intervention and comparison groups in the pre-test and posttest scores

DV	Groups	N	M-Pre-Mot	M-post-Mot	M-gain	L-Gain
Motivation	CSA	38	71.48	82.36	10.88	0.41
	REPs	36	68.00	87.00	19.00	0.63
	CTS	35	68.86	75.2	6.34	0.22
	CM	50	71.64	73.96	2.32	0.09

Table 4.21 shows that the mean gain and normalized learning gains of the intervention and comparison groups on the motivation of learning kinetics and chemical equilibrium concepts. That data revealed that the representation based instruction and curricular saliency-based instruction have higher mean gain and normalized learning gain as compared to conceptual teaching strategy-based instruction and comparison groups. This indicated that representation-based instruction improved the motivation of grade 11 students on the chemical kinetics and chemical equilibrium concepts followed by curricular saliency-based -based instruction. On the other hand, conceptual teaching strategy-based instructions also outperform the learning motivation than the comparison group. In general, the TSPCK based instruction improved the motivation of grade 11 students after the researcher made an intervention on the treatment groups. Table 4.21 also revealed that the normalized learning gain in motivation of CSA, REPS, CTS and CM were 0.41, 0.63, 0.22 and 0.09 respectively. This implies that the representation-based instruction increased the motivation of students by 63% and the curricular saliency-based -based instruction also improved by 41% motivation of the students in learning chemical kinetics and equilibrium than conceptual teaching strategy-based instructions and the conventional instructional teaching strategy. Furthermore, the conceptual teaching strategy based instruction outperforms 22% than the conventional method of teaching chemical kinetics and chemical equilibrium concepts. This implies that the motivation of both representation and curricular saliency-based instruction improved in medium learning gain and suggested moderately effective TSPCK-based instruction with noticeable improvement and conceptual teaching strategy-based instruction with low learning gain as compared to both representation and conceptual teaching instruction with minimal improvement (Hake, 1998, Rodriguez et al., 2018). Generally, the motivation of grade 11 students in Addis Ababa secondary schools increased due to the implementation of TSPCK-based instruction on the posttest scores.

Discussion on the Motivation of Groups

It has been discovered that topic-specific pedagogical content knowledge (TSPCK)-based instructions, such as conceptual teaching strategy (CTS), curriculum saliency (CSA), and representations (REPs), positively affect students' motivation to study chemical kinetics and equilibrium concepts. Rather than focusing only on memorization of formulas and processes, research indicates that these instructional strategies can help students gain a deeper knowledge of the subject matter by stressing the conceptual frameworks and relationships between concepts

(Kind, 2015). In his study Kind (2015) discovered the effectiveness of TSPCK in teaching, stressing how, deep knowledge of specific topics can improve students engagement and motivation. Further more, students may become more motivated and engaged as a result of being able to recognize the significance and relevance of the subject matter they are studying when using TSPCK based instruction (Kucuk & Kucuk, 2016). For instance, CSA can assist students in structuring their comprehension of intricate chemical processes and reactions and in creating links between various ideas. The concepts can be visually represented by REPs, which increases their accessibility and comprehension. In order to help students understand the subject matter and comprehend how it all fits together, CTS can assist them in creating cohesive and logical sequences of thoughts (Yoon & Lee, 2017). In addition, the integration of technological tools like interactive models and simulations can improve the efficacy of these teaching tactics and offer students a more dynamic and engaging educational experience.

Students who learn best visually or through hands-on activities may find this very inspiring (Kozan & Gurses, 2014). Overall, by offering a more interesting, participatory, and significant learning experience, topic-specific PCK-based instructions like CSA, REPs, and CTS might increase students' willingness to understand chemical kinetics and equilibrium concepts. The significance of pedagogical content knowledge (PCK) in chemistry education has been emphasized in recent reviews of the research as it pertains to enhancing student learning outcomes. In addition to the pedagogical tools and procedures instructors employ to teach the content, PCK refers to the knowledge and comprehension teachers have about the subject matter they teach (Shulman, 1986).

Because they adapt their teaching strategies to meet the needs of each individual student, high-PCK-level chemistry teachers successfully engage their students and foster their success (Smith & Thompson, 2017). Studies show that when it comes to predicting student accomplishment, PCK outperforms other teacher attributes, including subject expertise (Brown & Smith, 2018). Furthermore, professional development is a means to refine PCK. A PCK-focused curriculum enhanced instructors' lesson design and execution, according to Davis & Sumara (2016). Kim (2020) demonstrated that instructors in these programs used creative tactics and had higher levels of self-efficacy.

Recent studies have highlighted the pivotal role of TSPCK within the broader framework of Pedagogical Content Knowledge (PCK) in enhancing students' motivation and engagement in

chemistry education. Consistent findings emphasize that PCK plays a crucial role in advancing inclusive and equitable practices in teaching chemistry.

A critical aspect of the study on PCK's impact in chemistry education involved the use of a mixed-methods research design, integrating both quantitative and qualitative data to provide a high level understanding of PCK's role. This methodological approach aligns with contemporary trends in educational research, as highlighted by Creswell (2014), which advocate for the use of diverse methodologies to explore multifaceted phenomena. These findings collectively confirm that TSPCK, as a component of PCK, is not only vital for enhancing students' motivation but also for promoting equity and inclusion in chemistry classrooms. However, inconsistent findings in the literature highlight challenges such as variability in the implementation of PCK-based strategies and the need for more context-specific research. Addressing these gaps through targeted professional development and sustained research efforts can further unlock the transformative potential of PCK in fostering motivation and achievement in chemistry education.

While foundational research (Loucks-Horsley et al., 1986; Guskey, 2002) classifies PCK as a critical predictor of student achievement, some recent studies challenge this view, finding no significant connection between PCK and academic performance. This discrepancy may derive from variations in study design, sample characteristics, or contextual factors influencing the outcomes. Furthermore, the effect of PCK on student motivation and engagement was not directly assessed in certain studies, contrary to findings from Watts (2006), which established a positive correlation between PCK and these variables. The omission of moderating factors such as teaching context, educator experience, and subject expertise further highlights gaps in the literature, departing from earlier understandings (Guskey, 2002; Loucks-Horsley et al., 1986).

A growing body of evidence emphasizes the importance of motivation-related subscales including self-determination, intrinsic motivation, and self-efficacy in enhancing students' conceptual understanding and achievement in chemistry. Othman and Leng (2011) affirm that self-determined learners, driven by their passions and goals, achieve deeper conceptual understanding. Similarly, TSPCK-based instruction fosters self-determination by aligning teaching strategies with students' interests and real-world applications (Dübbers & Schmidt-Daffy, 2021; Vokwana, 2013).

Recent research has demonstrated the importance of motivation subscales intrinsic motivation, self-efficacy, self-determination, mark motivation, and career motivation in increasing students' understanding of concepts and achievement in chemistry when employing TSPCK-based instruction. Self-determination theory (Deci & Ryan, 2000) emphasizes the significance of building autonomy, competence, and relatedness in order to increase intrinsic motivation, a fundamental motivator of academic achievement. Project-based learning, and peer collaboration (Hsieh et al., 2019) are strategies that improve engagement and understanding by connecting learning experiences with students' values and aspirations. TSPCK-based instructions incorporates these motivating subscales, which not only help students grasp complicated concepts like chemical kinetics and equilibrium, but also instills confidence and real-world application skills.

Motivation serves as both a mediator and a result of good TSPCK-based training. Research (e.g., Mintzes et al., 2014) shows that increased motivation through TSPCK improves learning outcomes, engagement, and achievement. Self-determination principles combined with TSPCK strategies, like active learning, formative assessments, and specific teaching, lead to meaningful learning experiences that are tailored to students' needs. While some studies find discrepancies in PCK's direct influence on academic achievement, they emphasize the need for more study into the interaction of motivational variables with TSPCK. A comprehensive strategy that combines theories of motivation and effective instructional strategies may utilize the potential of TSPCK-based instruction, making chemistry education more successful across a variety of learning environments.

4.4. Effect of TSPCK-based Instruction on the Gender in Learning Outcomes

Research Question Two: Do groups and gender have interaction effects on conceptual understanding, achievement and motivation?

To answer the research question here above posttest mean scores of conceptual understanding, achievement and motivation were considered with respect to the groups (intervention and comparison) and gender. The appropriate statistic for this question is two-way ANOVA or factorial ANOVA. This statistic was used when there are two different independent variables within a groups design. The assumptions for conducting two-way ANOVA (Appendix M) were thoroughly evaluated and checked to be met. Independence of observations was ensured

through proper random sampling and experimental design, with no overlap between groups. Normality was assumed using shapro-Wilk tes and Q-Q plots, both of which indicated that the data were approximately normally distributed with each groups. Homogeneity of variances were verified using levene’s test, which was not significant ($p>.05$), confirming equal variances across the groups. Additivity was supported as interaction effect was not significant ($p>.05$), indicating no violation of the assumption. These results validate the use of two-way ANOVA for analyzing the data and ensure the reliability of its statistical parameter.

4.4.1. Conceptual Understanding of Males and Females in the Groups (Mean-wise comparison)

The conceptual understanding scores of males and female grade 11 students with in the groups were analyzed based on the mean scores and their significance was analyzed by two way ANOVA table 4.22 and table 4.23 as follows.

Table 4.22: Mean, standard Deviation and N for conceptual understanding as a function of gender and group

Group	Males			Females			Total	
	N	M	SD	N	M	SD	M	SD
CSA	19	52.28	14.67	19	56.41	14.19	54.34	14.38
REPs	16	59.89	14.21	20	64.84	12.37	62.64	13.26
CTS	16	59.59	14.95	19	65.00	15.82	62.53	15.44
CM	29	45.92	9.01	21	45.87	9.96	45.90	9.32
Total	80	52.96	13.98	79	57.81	15.20	55.37	14.76

The descriptive statistics table here above (Table 4.22) shows the means and standard deviations for conceptual understanding separately for male and female students and the groups. As can be observed from table 4.22 the mean posttest scores of conceptual understanding of male students in CSA (M=52.28, SD=14.67), REPs (M=59.89, SD=14.21), CTS (M=59.59, SD=14.95), CM (M=45.92, SD=9.01). Similarly the conceptual understanding of female students in CSA (M=56.40, SD=14.19), REPs (M=64.84, SD=12.37), CTS (M=65.00, SD=15.82), CM (M=45.87, SD=9.96). This descriptive statistics table indicated that the mean scores of female

students in all three intervention groups were higher mean scores in conceptual understanding than the male students in both the intervention and comparison groups.

4.4.2. Interaction Effects between Groups and Gender on the Posttest Conceptual Understanding

Table 4.23: ANOVA for conceptual understanding as a function of gender and groups

Source	Type III SS	df	MS	F	Sig.	Partial Eta Squared
Corrected Model	8856.787 ^a	7	1265.255	7.480	.000	.257
Intercept	487531.754	1	487531.754	2882.028	.000	.950
Groups	7821.053	3	2607.018	15.411	.000	.234
Gender	502.376	1	502.376	2.970	.087	.019
Group * Gender	205.751	3	68.584	.405	.749	.008
Error	25543.575	151	169.163			

a. R Squared = .257 (Adjusted R Squared = .223)

The ANOVA table (Table 4. 23) shows that there was not a significant interaction between gender and groups on the conceptual understanding scores ($F(3,151)=.405$, $P=0.749$). There was also not a significant main effect of gender on conceptual understanding, $F(1,151) = 2.970$, $p=.087$. The partial eta squared and eta values for gender was about .019 and .14, respectively which, according to Cohen (1988), is a smaller effect. Furthermore, there was a significant main effect of the groups on conceptual understanding ($F(3,151) = 15.411$, $p=0.000$). The partial eta squared and partial eta values for the group was about .234 and .48 which was a larger effect. This implies that 23.2% of the variances in conceptual understanding can be predicted from the intervention groups. Similarly, 1.9% of the variances in conceptual understanding can also be predicted from gender. Even though the descriptive statistics indicated the female students had higher conceptual understanding than male students, the change is not significant. This implies that the TSPCK-based instruction did not differentiate the conceptual understanding of male and female students rather it gave equal opportunities in learning chemical kinetics and equilibrium.

The difference in the mean scores of male and female students on the conceptual understanding was shown in the figure 9 below.

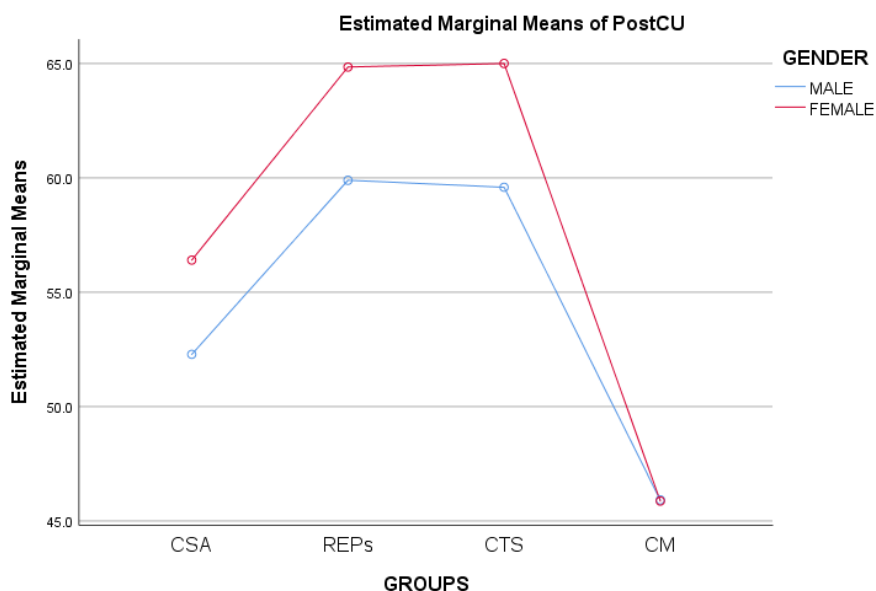


Figure 3: Estimated marginal means between males and female students on the posttest conceptual understanding

The results of this study are consistent with previous research highlighting the importance of multiple representations in improving conceptual understanding of complex chemistry topics such as chemical kinetics and equilibrium (Treagust et al., 2003). The combination of macro, micro, and symbolic representations, as well as technology-enhanced tools like animated video lessons and Edpuzzle, encourages active participation and supports cognitive theories such as Mayer's (2005) multimedia learning theory. These multimodal approaches have shown promise in addressing difficult concepts and encouraging deeper learning.

However, the study discovered no significant interaction effect between gender and TSPCK-based instruction on students' conceptual understanding, achievement, and motivation, which contradicts some research indicating that technology-integrated pedagogies can reduce gender disparities (Stoet & Geary, 2018). This inconsistency could be due to contextual factors like students' prior exposure to instructional strategies or cultural influences. Nonetheless, the findings support the value of innovative methods such as REPs and CTS, which promote meaningful engagement and are consistent with constructivist learning theories (Johnstone,

1991; Taber, 2013), while also highlighting the need for additional research on the factors influencing equitable performance in diverse student populations.

4.4.3. Achievement of Males and Females in the Groups

The achievement scores of males and females grade 11 students in the groups were analyzed based on the mean scores, and their significance was analyzed by two-way ANOVA in tables 4.24 and 4.25, as follows.

Table 4.24: Mean, standard Deviation and N for achievement as a function of gender and group

Group	Males			Females			Total	
	N	M	SD	N	M	SD	M	SD
CSA	19	53.50	15.54	19	55.96	13.98	54.73	14.58
REPs	16	58.11	15.10	20	64.32	14.74	61.56	15.02
CTS	16	59.36	17.20	19	65.44	16.52	62.66	16.92
CM	29	45.74	10.79	21	48.89	11.32	47.06	11.01
Total	80	52.78	15.10	79	58.48	15.54	55.61	15.54

Table 4.24 shows the means and standard deviations for posttest achievement scores separately for male and female students and the groups. As can be observed from table 4.30 the mean posttest scores of achievement of male students in CSA (M=53.50, SD=15.54), REPs (M=58.11, SD=15.10), CTS (M=59.36, SD=17.20), CM (M=45.74, SD=10.79). Similarly the achievement scores of female students in CSA (M=55.96, SD=13.98), REPs (M=64.32, SD=14.74), CTS (M=65.44, SD=16.52), CM (M=48.89, SD=11.32). This showed that the mean scores in achievement of female students in all the three intervention groups were higher in achievement mean scores than the male students in both the intervention and comparison groups.

4.4.4. Interaction Effects Between Groups and Gender on Posttest Achievement Scores

Table 4.25: Analysis of variances for achievement as a function of gender and groups

Variables and Source	Type III			F	Sig.	Partial Eta ²
	SS	df	MS			
Achievement						
Group	6100.42	3	2033.472	10.035	.000	.166
Gender	771.38	1	771.378	3.807	.053	.025
Group * Gender	108.65	3	36.218	.179	.911	.004
Error	30596.83	151	202.628			

a. R Squared = .198 (Adjusted R Squared = .160)

Table 4. 25 shows that there was not a significant interaction (gender* groups) between gender and groups on the achievement scores ($F(3, 151)=179, p=.911$) in learning chemical kinetics and equilibrium concepts. In addition , there was not a significant main effect of gender on achievement ($F(1,151) =3.807, p=.053$). The partial eta squared and eta values for gender was about .025 and .23 respectively which is a medium effect according to Cohen (1988). Furthermore, there was a significant main effect of the groups on achievement scores ($F(3,151) =10.035, p<0.0001$). The partial eta squared and eta values for the group was about .166 and .407 which was considered as a larger effect according to Cohen (1988). This implies that 16.6% of the variances in achievement can be predicted from the interventions. similarly, 2.5% of the variances in achievement scores can also be predicted from gender. In addition, the adjusted R^2 revealed that the percent of variance in achievement predicable from both gender and groups was 16.0%. The difference in the mean scores of male and female students on the achievement was shown in the figure 4 below.

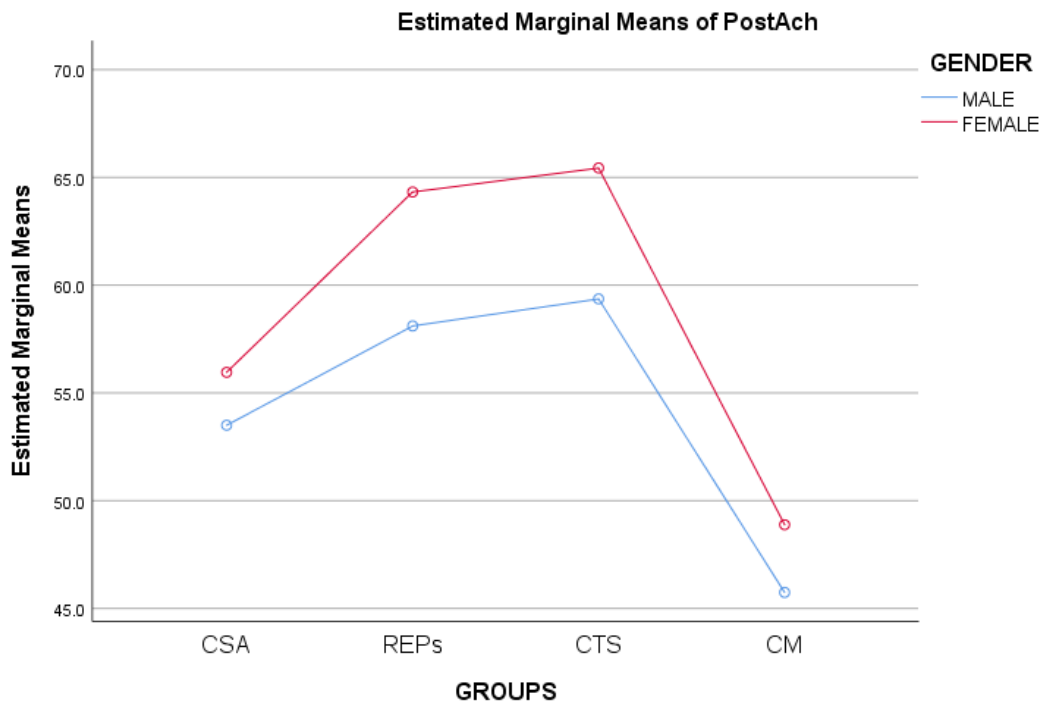


Figure 4: Estimated marginal means between males and female students on the posttest achievement

The findings reveal that the estimated marginal means of posttest achievement scores between male and female students varied across the instructional groups. Minimal gender-based differences were observed in the CM and CSA groups, whereas larger marginalized mean differences were evident in the REPs and CTS groups. The higher differences in the REPs and CTS groups suggest that strategies incorporating the three levels of representation (macro, micro, symbolic), animated video lessons, and the Edpuzzle educational platform significantly enhanced achievement for both male and female students. The CSA group also demonstrated a moderate marginalized mean difference, indicating its effectiveness in improving achievement in learning chemical kinetics and equilibrium compared to the conventional method.

These findings are consistent with previous research emphasizing the effectiveness of multimodal instructional strategies in improving student achievement. Studies indicate that integrating macro, micro, and symbolic representations helps learners grasp abstract chemistry concepts, leading to enhanced performance (Treagust et al., 2003). Similarly, technology-based approaches like animated videos and interactive platforms such as Edpuzzle are widely

recognized for fostering engagement and achievement in science education (Mayer, 2005; Brame, 2016).

However, the higher gender disparity observed in the REPs and CTS groups contrasts with studies suggesting that innovative, technology-driven pedagogies often reduce achievement gaps between male and female students (Stoet & Geary, 2018). This discrepancy could be attributed to contextual factors, such as variations in how these strategies were implemented or differences in students' prior familiarity with the tools. Overall, the findings affirm the value of innovative instructional approaches in improving learning outcomes while highlighting the need for further research to understand and address gender-related achievement differences.

4.4.5. Motivation of Males and Females in the Groups

Table 4.26: Mean, standard Deviation and N for motivation as a function of gender and group

Group	Males			Females			Total	
	N	M	SD	N	M	SD	M	SD
CSA	19	4.14	.353	19	4.10	.281	4.12	.326
REPs	16	4.14	.367	20	4.52	.243	4.35	.353
CTS	16	3.70	.418	19	3.81	.312	3.76	.353
CM	29	3.64	.510	21	3.78	.447	3.70	.485
Total	80	3.87	.491	79	4.05	.443	3.96	.474

Table 4.26 shows the means and standard deviations for motivation separately for male and female students and the groups. As can be observed from table 4.25 the mean posttest scores of motivation of male students in CSA (M=4.14, SD=.353), REPs (M=4.14, SD=.367), CTS (M=3.70, SD=.418), CM (M=3.64, SD=.510). Similarly the motivation of female students in CSA (M=4.10, SD=.281), REPs (M=4.52, SD=.243), CTS (M=3.81, SD=.312), CM (M=3.78, SD=.447). From this data one can conclude that the mean scores in the achievement of female students in the intervention groups except in CSA group were higher than the mean scores of male students in both the intervention and comparison groups.

4.4.6. Interaction Effects Between Groups and Gender on Posttest Motivation Scores

Table 4.27: Analysis of variances for motivation as a function of gender and groups

Source	Type III SS	df	MS	F	Sig.	Partial Eta ²
Groups	10.320	3	3.440	22.854	.000	.312
Gender	.833	1	.833	5.534	.020	.035
Groups * Gender	.779	3	.260	1.726	.164	.033
Error	22.728	151	.151			

a. R Squared = .361 (Adjusted R Squared = .332)

Table 4. 27 shows that there was not a significant interaction (gender* groups) between gender and groups on the motivation scores ($F(3,151)=1.726, p=.164$). However, there was a significant main effect of gender on motivation ($F(1,151)=5.534, p=.020$). The partial eta squared and eta values for gender were about 0.035 and .19, which, according to Cohen (1988), is a smaller effect. This indicated that male and female students have difference in motivation in using TSPCK based instruction. Furthermore, there was a significant main effect of the groups on motivation scores ($F(3,151)=22.854, p=0.000$). The partial eta squared values for the group was about .312 and .558 which was a very larger effect. This implies that 31.2% of the variances in motivation can be predicted from the interventions. Similarly, 3.5% of the variances in motivation scores can also be predicted from gender. In addition, the adjusted R^2 revealed that the percent of variance in motivation predicable from both gender and groups was 33.2%. The difference in the mean scores of male and female students on the motivation was shown in the figure 5 below.

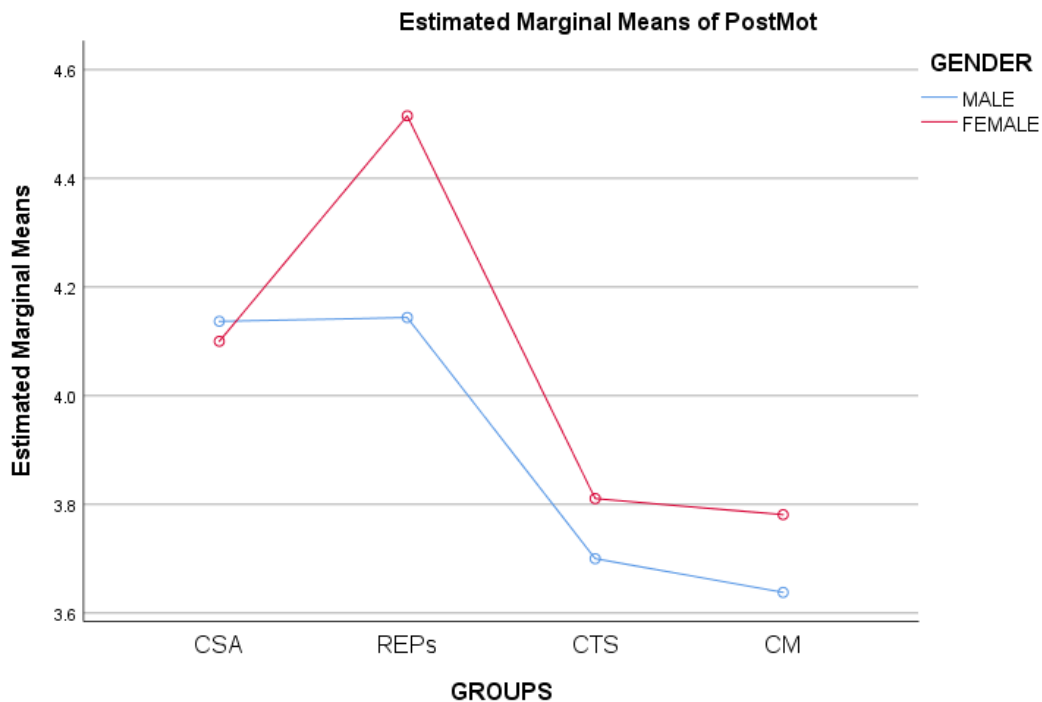


Figure 5: Estimated marginal means between males and female students on the posttest achievement

Figure 5 shows that the estimated marginal of posttest motivation scores between male and female students in the four groups. The graph showed that male and female students in the CM and CTS groups have smaller marginalized mean differences. However, there was a higher estimated marginalized mean difference between male and female students in REPs group. In the CSA-based group, females had lower motivation than male students. The higher marginalized mean difference shown in REPs indicated that it was an appropriate instructional strategy for enhancing motivation. This implies that classifying chemistry concepts in to three level of representations (macro, micro, symbolic) favored female students in having higher motivation in learning chemical kinetics and equilibrium concepts. Although, the findings do not show gender friendly nature it could be said effective as it fevored the female students, which is not common in most studies. Furthermore, the CSA-based instruction group has smaller differ estimated marginalized mean difference between male and female students in motivation scores on learning chemical kinetics and equilibrium concepts.

4.5. Effect of TSPCK-based Instruction on Combined Dependent Variables

Research Question Three: Are there significant mean score differences between Intervention and comparison groups on a linear combination of conceptual understanding, achievement and motivation in learning chemical kinetics and equilibrium?

Multivariate analysis of variance (MANOVA) is used to determine the significance of different groupings on more than two independent variables as ANOVA compares a single dependent variable. The only difference between the ANOVA and MANOVA processes is that MANOVA can handle several dependent variables, whereas ANOVA can only handle one. These many dependent variables are frequently made up of diverse measurements of the same object (Aron & Aron, 1999), although this is not always the case. At the very least, the dependent variables should be linear and have a consistent conceptual meaning (Stevens, 2012). MANOVA has many dependent variables, which is an evident advantage over ANOVA. An ANOVA determines if mean differences in single dependent variables among groups are significant or likely to have happened by chance. When dealing with several dependent variables in a multivariate context, however, we must treat them all together. MANOVA provides a number of benefits over its univariate predecessor (Tabachnick & Fidell, 1996). First, monitoring several dependent variables rather than just one considerably increases the likelihood of detecting what truly changes as a result of different treatments and any interactions. A second advantage is that, in some cases, MANOVA can uncover differences that are not seen in independent ANOVAs (Tabachnick & Fidell, 1996; Stevens, 2012). Third, the use of several univariate analyses resulted in a significantly higher total Type I error rate. Finally, doing several univariate tests overlooks some critical information. Remember that if you have numerous dependent variables in your study, they should all be correlated. As a result, the study's third research question was to determine if the combined three dependent variables of conceptual understanding achievement and motivation scores on studying chemical kinetics and equilibrium concepts showed significant mean differences between the groups. The researcher used a one-way MANOVA to assess the effects of intervention groups on the combined dependent variables.

To avoid inflating the Type 1 error rate in the follow-up ANOVAs and post-hoc comparisons, a MANOVA was first run on the means. Prior to doing the MANOVA, a Pearson correlation between the dependent variables was conducted to evaluate the MANOVA assumption that the

dependent variables would be moderately associated with each other (.20–.60; Meyers et al., 2006). The dependent variable (conceptual understanding, achievement and motivation) scores showed a significant pattern of correlations, indicating that a MANOVA was acceptable (Appendix M). Second, the multivariate normality distribution was examined; the means of each dependent variable in each cell, as well as all linear combinations of dependent variables, were found to be normal. In this study, the variances (the Levene’s test) and the M values were violated the homogeneity of variances and covariances. Since MANOVA robust or tolerable if the sample size of near to equal (when the larger sample is less than 1.5 times the smaller sample size). Therefore, the covariance matrices between the groups were assumed to be unequal for the purposes of the MANOVA as a result, Pillai's Trace was utilized as the test statistic. To check if there is significant difference between Intervention and comparison groups on a linear combination of conceptual understanding, achievement and motivation MANOVA was employed on the post-test scores of groups.

Table 4.28: Mean and standard deviation for post CU, post-Ach and post-Mot by the groups

Groups	Post-CU		Post-Ach		Post-Mot		N
	M	SD	M	SD	M	SD	
CSA	54.34	14.38	54.73	14.58	4.12	.326	38
REPs	62.64	13.26	61.56	15.02	4.35	.353	36
CTS	62.53	15.44	62.66	16.92	3.76	.363	35
CM	45.90	9.32	47.06	11.01	3.70	.485	50
Total	55.37	14.76	55.61	15.54	3.96	.474	159

Table 4.29: Multivariate test for conceptual understanding, achievement and motivation by the group differences

Source	Pillai's Trace	F	Hypothesis df	Error df	Sig	η^2
Intercept	.991	5464.64	3	153	.000	.991
Treatment	.528	11.047	9	465	.000	.176

Design: Intercept + GROUPS

Exact statistic

The statistic is an upper bound on F that yields a lower bound on the significance level

Computed using alpha = .017

Table 4.28 shows descriptive statistics and Table-4.29 shows MANOVA results. MANOVA used to see whether the combination of conceptual knowledge, achievement, and motivation ratings changed between the four groups. The MANOVA impact was found to be statistically significant (Pillai's Trace =.528, $F(9, 465) = 11.047$, $p < 0.0001$). This high F, calculated as a linear combination of conceptual understanding, achievement, and motivation scores, indicates that there are significant differences across the intervention groups. The group factor accounted for approximately 17.6% of the variation in the dependent variables (multivariate partial $\eta^2 = .176$). This is large sized effect (Cohen, 1988). However, this MANOVA result needs to be broken down to find out exactly what is going on using follow-up ANOVA.

Table 4.30: ANOVA Summary Table for Separate post-CU, post-Ach and post-Mot Test Scores among Groups

Source	DV	Type II SS	df	SS	F	Sig.	η^2
Groups	Post-CU	8223.063 ^a	3	2741.021	16.230	.000	.239
	Post-Ach	6695.757 ^b	3	2231.919	11.004	.000	.176
	Post-Mot	11.261 ^c	3	3.754	23.924	.000	.316

a=R squared=.239 (adjusted R squared=.224)

b=R squared=.176 (adjusted R squared=.160),

c= R squared=.316 (adjusted R squared=.303)

Table 4.31: ANOVA Summary Table for Separate Conceptual understanding, achievement and motivation Posttest Scores among Groups (Bonferroni correction at $p=.00425$)

DV	(I)	(J)	(I-J)	S.E	Sig.	99.575% CI		
						LB	UB	
Post-CU	CSA	REPs	-8.2997	3.0225	.040	-18.745	2.145	
		CTS	-8.1810	3.0446	.048	-18.702	2.340	
		CM	8.4467	2.7968	.018	-1.218	18.112	
	REPs	CSA	8.2997	3.0225	.040	-2.145	18.745	
		CTS	.1187	3.0849	1.000	-10.542	10.779	
		CM	16.7464*	2.8406	.000	6.930	26.563	
	CTS	CSA	8.1810	3.0446	.048	-2.340	18.702	
		REPs	-.1187	3.0849	1.000	-10.779	10.542	
		CM	16.6277*	2.8641	.000	6.730	26.525	
	CM	CSA	-8.4467	2.7968	.018	-18.112	1.218	
	Post-Ach	CSA	REPs	-6.8322	3.3124	.245	-18.279	4.614
			CTS	-7.9311	3.3366	.112	-19.461	3.599
CM			7.6649	3.0650	.081	-2.927	18.257	
REPs		CSA	6.8322	3.3124	.245	-4.614	18.279	
		CTS	-1.0989	3.3807	1.000	-12.782	10.584	
		CM	14.4971*	3.1130	.000	3.740	25.255	
CTS		CSA	7.9311	3.3366	.112	-3.599	19.461	
		REPs	1.0989	3.3807	1.000	-10.584	12.782	
		CM	15.5960*	3.1387	.000	4.749	26.443	
CM		CSA	-7.6649	3.0650	.081	-18.257	2.927	
Post-Mot		CSA	REPs	-.2316	.0921	.078	-.550	.087
			CTS	.3584*	.0928	.001	.038	.679
	CM		.4204*	.0852	.000	.126	.715	
	REPs	CSA	.2316	.0921	.078	-.087	.550	
		CTS	.5900*	.0940	.000	.265	.915	
		CM	.6520*	.0866	.000	.353	.951	
	CTS	CSA	-.3584*	.0928	.001	-.679	-.038	
		REPs	-.5900*	.0940	.000	-.915	-.265	
		CM	.0620	.0873	1.000	-.240	.364	
	CM	CSA	-.4204*	.0852	.000	-.715	-.126	
			CTS	-.0620	.0873	1.000	-.364	.240

*. The mean difference is significant at the 0.00425 level.

As a follow-up to the MANOVA, one-way ANOVAs were performed on the conceptual understanding, achievement, and motivation scores (Table 4.6, 4.11, 4.15 and 4.18). In order to protect against Type I error, the researcher can employ the conventional Bonferroni technique and test each ANOVA at the .017 level ($.05/3$). Follow-up ANOVA revealed significant differences in conceptual understanding ($F(3,155) = 16.230, p < 0.0001, \text{partial } \eta^2 = .239$), achievement ($F(3,155) = 11.004, p < 0.0001, \text{partial } \eta^2 = .176$), and motivation test scores ($F(3,155) = 23.924, p = 0.000, \text{partial } \eta^2 = .316$) among the four groups, (Table 4.30). According to the mean scores, REPs ($M = 62.64, SD = 13.26$) and CTS ($M = 62.53, SD = 15.44$) groups have higher levels of conceptual understanding than CSA ($M = 54.34, SD = 14.38$) and CM ($M = 45.90, SD = 9.32$). In terms of achievement scores of REPs ($M = 61.56, SD = 15.02$) and CTS ($M = 62.66, SD = 16.92$) have higher scores than CSA ($M = 54.73, SD = 14.58$) and CM ($M = 47.06, SD = 11.01$). Moreover, the mean motivation scores in REPs ($M = 4.35, SD = .353$) and CSA ($M = 4.12, SD = .326$) were slightly higher than those in CTS ($M = 3.76, SD = .363$) and CM ($M = 3.70, SD = .485$). The CSA group has higher mean scores in all three dependent variables than the CM group (refer to Table 4.28).

The results of the between-subjects effect tests revealed a statistically significant mean score difference between groups in all linear combinations of dependent variables, but they did not reveal which group was different from the other. As a result, post-hoc multiple comparisons were utilized to determine which group was distinct from the others. The researcher had previously examined ANOVA at $P = 0.017$ alpha level to account for Type I error. To be consistent with this conclusion, it is important also to control the likelihood of making one or more Type I errors over a large number of pairwise comparisons for the dependent variables at the 0.017 alpha level. The Bonferroni method was also used to account for Type I error in pairwise comparisons of conceptual understanding, achievement, and motivation scores, with each comparison evaluated at the alpha level for ANOVA divided by the number of interventions ($.017/4 = .00425$).

With the exception of the REPs and CM groups and the CTS and CM groups, the post-hoc multiple comparison result revealed no statistically significant mean difference in post-conceptual understanding and achievement test mean scores between any pair of groups ($p > .00425$). Post-hoc multiple comparisons revealed significant mean differences in post-motivation scores between groups, including CSA and CTS ($p = .001$), CSA and CM ($p = .000$),

REPs and CTS ($p=.000$), and REPs and CM ($p=.000$), with the exception of the CTS alone and CM groups ($p =1.000$). In every case, the impact followed a nearly linear pattern. That is, the REPs and CTS groups had higher mean scores in learning outcomes than the CSA group, while the CSA group had higher mean scores in learning outcomes than the CM group. Table 4.30 displays the effect size determined with eta square (η^2). It can be demonstrated that motivation had the greatest impact, with eta square (η^2) value 0.316, indicating a large effect according to Cohen's (1988) guidance.

The post-hoc multiple comparison analysis revealed regular patterns in the effectiveness of different instructional strategies on conceptual understanding, achievement, and motivation. While there were no statistically significant mean differences in conceptual understanding and achievement scores between certain group pairs such as REPs vs. CM and CTS vs. CM significant differences were observed in motivation scores across most group comparisons. Specifically, significant mean differences in motivation were found between CSA and CTS, CSA and CM, REPs and CTS, and REPs and CM, with the REPs and CTS groups consistently outperforming others. This trend indicates a nearly linear impact on learning outcomes, with REPs and CTS yielding the highest scores, followed by CSA, and then CM. Moreover, motivation emerged as the most influential factor, as indicated by a large effect size ($\eta^2 = 0.316$), underscoring its critical role in enhancing student performance.

These findings are consistent with previous studies emphasizing the critical role of desire in promoting academic performance. Studies have shown that technology-integrated teaching strategies, such as those employed in the REPs and CTS groups, not only improve engagement but also dramatically increase learners' interest in learning (Brame, 2016; Mayer, 2005). The roughly linear association shown in learning outcomes across groups is consistent with constructivist theories, which state that strategies encouraging active, multimodal learning lead to gradually increased performance (Treagust et al., 2003). Furthermore, the significant effect size for motivation supports the concept that intrinsic and extrinsic motivating variables have a considerable impact on students' success and understanding of concepts in STEM disciplines (Ryan & Deci, 2000).

However, the lack of significant differences in conceptual comprehension and success between some groups (REPs vs. CM and CTS vs. CM) contradicts previous research indicating a

uniformly large impact of technology-enhanced instruction. This mismatch might be caused by contextual variables such as changes in implementation commitment, students' prior knowledge, or disparities in classroom dynamics. Furthermore, the motivational similarity between the CTS and CM groups ($p = 1.000$) calls into doubt the scalability of CTS-based techniques across all educational contexts. These findings indicate the need for more research into contextual modifiers that impact the efficacy of new instructional approaches.

4.6. Prediction of Motivation Subscales on the Conceptual Understanding and Achievement scores

Research question Four: How well do motivation and its components predict Grade 11 students Conceptual understanding and achievement?

To answer this research question multiple-linear regression was used. Multiple regression analysis is a statistical technique for determining the association between a continuous dependent variable and two or more continuous independent variables (Pallant, 2013). This method allows researchers to evaluate the model's overall fit by determining how much variance in the dependent variable can be explained by the independent variables. Furthermore, it allows for an estimation of each predictor's proportionate contribution to the total variance explained by the model. This study looked especially at the association between motivational subscales and the two outcome variable (conceptual understanding and achievement test scores). The predictor variable, motivation, was broken down into five subscales: intrinsic motivation, self-efficacy, self-determination, mark motivation, and career motivation. The dependent variable was the students' posttest exam scores, which evaluated their conceptual understanding and achievement in learning chemical kinetics and equilibrium concepts.

Pearson correlation coefficients and corresponding p-values were used to measure the strength and significance of the correlations between each motivation subscale and students' performance on understanding exams. Multiple regression analysis revealed the contribution of each motivational construct to the differences in test results, providing a thorough picture of how the predictors affect students' learning outcomes.

In the present study, the assumptions of multiple linear regression were extensively tested using normal statistical procedures stated in SPSS manuals and literature. Residuals followed a near-

normal distribution, as seen by histograms and normal probability plots, confirming the normality assumption (Field, 2018; Pallant, 2020). Scatterplots of predicted vs. actual results revealed linearity, whereas residual plots indicated homoscedasticity with consistent variation (Pallant, 2020). The Durbin-Watson statistic was used to measure residual independence, which confirmed that there was no substantial autocorrelation (Field 2018). The sample size also met the typical recommendation of at least 15-20 instances per predictor, giving sufficient power for the research (Pallant, 2020). These tests follow standard practices for validating regression models, as outlined in basic and advanced SPSS guidelines, to guarantee accurate and interpretable results.

4.6.1. Prediction of Motivation Subscales on the Conceptual Understanding Scores

Tables 4.32 and 4.33 include details on the model description, ANOVA results, and multiple regression coefficients for conceptual and procedural test scores.

Table 4.32: Model fitting information on the Conceptual understanding

Model summary table				ANOVA table		
Model	R	R square	Adjusted R ²	SEE	F value	Sig.
1	.821	.674	.664	8.495	62.959	.000

Dependent Variable: conceptual understanding

Predictors: (Constant), intrinsic motivation, self-efficacy, self-determination, mark motivation, Career motivation.

Table 4.32 above provides essential information about multiple linear regression model. The R-squared value of 0.674 indicates that 67.4% of the variation in the dependent variable (Conceptual understanding) can be predicted using the independent variables (motivation components). This means that 67.4% of the change in conceptual understanding was attributed to intrinsic motivation, self-efficacy, self-determination, mark motivation, and career motivation. However, the remaining 32.6% of the change in conceptual understanding is attributable to other variables not considered in this study. The positive linear relationship between motivation components and conceptual understanding is significant for the three motivation sub scales (IM, Mm and CM) (Table 4.33), indicating that these motivation sub scales (intrinsic motivation, mark motivation and career motivation) are important predictors of the dependent variable.

Moreover, as can be seen from table 4.32, the F-value is 62.96, and the p-value associated with the F-value ($p = .000$) is less than the alpha level of 0.05. This reveals that the F-value is statistically significant. Therefore, one can conclude that the motivation sub scales have reliably predicted the conceptual understanding in learning chemical kinetics and equilibrium concepts (Samuel, 2011).

According to Muijs (2004), goodness of fit values less than 0.1 indicate poor fit, values between 0.11 and 0.30 represent modest fit, values between 0.31 and 0.50 represent moderate fit, and values greater than 0.50 indicate strong fit. In this study, the value of goodness of fit (R^2) is 0.674, indicating that the model is strongly fit to predict the dependent variable, in learning chemical kinetics and equilibrium concepts. Based on Muijs' description, the model explaining the conceptual understanding of the identified chemistry concepts is a strong fit. Therefore, it is possible to conclude that motivation components are good predictors of conceptual understanding in the identified chemistry concepts.

Table 4.33: Regression coefficient analysis motivation subscales on conceptual understanding

Variable	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Zero-order
	B	SD	Beta			
(Constant)	-20.351	4.76		-4.273	.000	
Intrinsic motivation	7.14	1.36	.353	5.257	.000	.715
Self-efficacy	-2.27	1.64	-.106	-1.387	.168	.519
Self-determination	.947	1.45	.051	.651	.516	.499
Mark motivation	9.18	1.46	.431	6.309	.000	.752
Career motivation	3.36	1.23	.200	2.733	.007	.634

Dependent Variable: conceptual understanding

Based on the regression coefficient analysis (Table 4.33), mark motivation ($\beta = .431$) and intrinsic motivation ($\beta = .353$) are the most significant positive predictors of conceptual understanding of chemical kinetics and equilibrium concepts after the intervention, with the highest and second-highest beta coefficients, respectively. Career motivation ($\beta = .200$) and self-efficacy ($\beta = -.106$) have positively and negatively influenced on conceptual understanding. This negative beta value of self-efficacy indicated that as self-efficacy of the student increases, the

conceptual understanding decreased in learning chemical kinetics and equilibrium concepts (Çalışkan, 2004). The negative relationship between conceptual understanding and self-efficacy among Grade 11 students may be attributed to a misalignment of perceived and actual ability, in which students with high self-efficacy overestimate their understanding and, as a result, put in less effort to grasp complex concepts (Pajares & Urdan, 2006). Overconfidence caused by excessive self-efficacy can lead to cognitive overload and superficial engagement, hindering deeper conceptual understanding. Furthermore, developing self-efficacy in learning the complex concept takes time and not easily visible in topics level. Intrinsic and mark motivation were the most important predictors of student comprehension in chemical kinetics and equilibrium, whereas self-determination ($\beta = .051$) had limited impact on conceptual knowledge. Mark motivation had the most beneficial influence, followed by intrinsic motivation, with career drive and self-determination playing supporting roles. The complexity of these chemical kinetics and equilibrium concepts necessitates strong fundamental knowledge and problem-solving abilities; nevertheless, weak intrinsic motivation restricted resources, and inadequate feedback may inhibit self-directed learning and academic accomplishment. Curriculum and instructional practices must focus deeper engagement and motivating variables to improve students' conceptual understanding (Deci & Ryan, 2000).

The intercept (B), often known as the constant, shows the predicted value of the dependent variable when all of the independent variables are zero. In this study, $B = -20.351$, which means that with all independent variables set to zero, the dependent variable should have a mean of -20.351 . Furthermore, the p-values for intrinsic motivation, mark motivation, and career motivation are all less than 0.05, showing statistical significance. This implies that changes in conceptual comprehension can be linked to these motivating variables. The F-value also demonstrates that the combined effect of the explanatory variables is statistically significant, which supports the model's overall validity (Field, 2018; Pallant, 2020).

Based on the results obtained in Table 4.33, the following linear regression model can be obtained:

$$\text{CU} = -20.94 + .352\text{IM} - 0.106\text{SE} + 0.051\text{SD} + 0.431\text{GM} + 0.200\text{CM} + 4.76$$

Where: IM = Intrinsic Motivation. SE = Self-Efficacy. SD = Self-Determination, MM = Mark Motivation, CM = Career Motivation. CU= Conceptual understanding. e = standardized error.

The regression equation above provides valuable insights into the relationship between the independent variables and conceptual understanding of chemical kinetics and equilibrium of the chemistry concepts. By examining the coefficients of each independent variable, we can determine how changes in each variable influences conceptual understanding.

For instance, with a unit increase in intrinsic motivation, where other factors remain constant, conceptual understanding would increase by .353. This indicates that when students are more intrinsically motivated, they are more likely to have a deeper understanding of the concepts. Similarly, a unit increase in self-determination would lead to an increase in conceptual understanding by .051. This suggests that when students have a greater sense of autonomy and control over their learning, they are more likely to engage more deeply with the material and develop a better understanding.

A one-unit rise in self-efficacy results in a -0.106 drop in conceptual knowledge, indicating that students with low self-efficacy may struggle with the content and require further assistance. In contrast, a unit rise in mark motivation results in a 0.431 increase in conceptual comprehension, demonstrating that students who are driven by grades are more likely to interact with the material and develop deeper knowledge. Similarly, a unit increase in professional motivation corresponds to a 0.200 gain in conceptual knowledge, indicating that students driven by career goals are more engaged with the content. Overall, the regression equation provides useful information on how various motivating variables affect students' conceptual knowledge of chemical kinetics and equilibrium. These data can inform focused actions to improve student learning and success (Field, 2018; Pallant, 2020).

Based on the beta values, z-order (r) values, and R² value, the following equation was derived to determine how much percentage each predictor variable contributes to the change in conceptual understanding:

$$(R^2)(100) = 100((\beta r)_{IM} + (\beta r)_{SE} + (\beta r)_{SD} + (\beta r)_{MM} + (\beta r)_{CM})$$

$$67.4\% = (.353*0.715IM - .106*0.519SE + .051*.499SD + .431*0.752GM+.200*.634CM)*100$$

This gives us: 67.4% = 25.2%IM - 13.0%SE + 2.5%SD +32.4%GM+20.5%CM

The results show that 25.2% of the change in conceptual understanding can be attributed to changes in intrinsic motivation, 13.0% to changes in self-efficacy, 2.5% to changes in self-determination, 32.4% to changes in mark motivation, and 20.5% to changes in career motivation. Furthermore, the results indicate that three of the motivation components (intrinsic motivation, mark motivation, and career motivation) are significant predictors of conceptual understanding, while self-efficacy and self-determination were not significant. This means that 67.4% of the variation in conceptual understanding was attributed to the change in the hypothesized predictors, while the remaining 32.6% is due to other factors not considered in the study. Among the predictor variables, mark motivation is the most predicting variable, followed by intrinsic motivation. However, self-determination was the least predicting variable in determining the conceptual understanding of chemical kinetics and equilibrium of chemistry concepts. Finally, self-efficacy lowered the conceptual understanding of the students by 13% when topic specific PCK based instruction has employed. This negative influence includes overconfidence, misalignment of self-assessment and actually occurring ability, anxiety and pressure, inadequate study practices, a lack of feedback, motivating factors, instructional methods and evaluations, as well as cultural and contextual influences (Pajares & Urda, 2006). High self-efficacy might cause students to underestimate the complexity of topics, resulting in insufficient effort or preparation. Misalignment between self-assessment and actual ability, anxiety and pressure, and dependence on previous study practices can all lead to poor conceptual understanding. Furthermore, cultural attitudes, support structures, and other external variables may impact students ability to comprehend complex concepts.

4.6.2. Prediction of Motivation Subscales of the Achievement Scores

Table 4.34: Model fitting information

Model summary table					ANOVA table	
Model	R	R ²	Adjusted R ²	SEE	F value	Sig.
1	.805	.647	.636	9.309	55.818	.000

Dependent Variable: Chemistry Achievement, SEE: Standard Error of the Estimate

Predictors: (Constant), intrinsic motivation, self-efficacy, self-determination, mark motivation, Career motivation.

Table 4.34 reveals crucial information about the model. The R-value indicates a strong, positive linear relationship between the motivation components and students' chemistry achievement scores. The R-squared value of .647 indicates that 64.7% of the variation in the dependent variable (Achievement) can be predicted using the independent variables (intrinsic motivation, self-efficacy, self-determination, mark motivation, and career motivation). This means that these motivational components explain 64.7% of the change in students' achievement in chemical kinetics and equilibrium. The remaining 35.3% of the variation in students' achievement was attributed to other variables not considered in this study.

Moreover, as can be seen from table 4.34, the F-value is 55.818 and the p-value associated with the F-value ($p = .000$) is less than the alpha level of 0.05. This reveals that the F-value is statistically significant, indicating that the motivation subscales have reliably predicted the achievement scores on chemical kinetics and equilibrium (Samuel, 2011). Furthermore, the goodness of fit value (R^2) is 0.647, indicating that the model is strongly fitted to predict the achievement on the chemical kinetics and equilibrium of the chemistry concepts. According to Muijs' (2004) description, a goodness of fit value less than 0.1 is considered poor fit, 0.11 to 0.30 is modest fit, 0.31 to 0.50 is moderately fit, and a value greater than 0.50 is considered strong fit. In this study, the model of multiple regression explained students' achievement post-test scores on these two topics has strong fit, indicating that the motivation components are good predictors of students' academic achievement in chemical kinetics and equilibrium concepts. Therefore, based on the results of the multiple linear regression analysis, it is possible to conclude that motivation subscales are reliable predictors of students' academic achievement in chemical kinetics and equilibrium concepts. This suggests that motivation subscales have played a significant role in determining students' academic achievement in these chemistry concepts.

Table 4.35: Regression coefficient analysis motivation subscales on students' achievements

Variable	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Zero-order
	B	SD	Beta			
(Constant)	-21.788	5.219		-4.174	.000	
Intrinsic motivation	8.221	1.489	.386	5.523	.000	.708
Self-efficacy	-3.619	1.795	-.160	-2.016	.046	.483
Self-determination	1.675	1.595	.085	1.051	.295	.479
Mark motivation	9.701	1.595	.432	6.081	.000	.733
Career motivation	2.750	1.349	.156	2.039	.043	.600

Dependent Variable: Students' Chemistry Achievement

On Table 4.35 above, the beta coefficients indicated that how and to what extent the independent variables influence the dependent variable. That means, it indicated how much the chemistry achievement scores varies due to the change in motivation subscales, when all other independent variables have held constant. Accordingly, the result of regression coefficient analysis indicated the highest predictor of students' Chemistry achievement score in mark motivation ($\beta = .432$) followed by intrinsic motivation ($\beta = .386$), and again followed by career motivation ($\beta = .156$). Self-efficacy ($\beta = -.160$) predicted chemistry achievement negatively. The least predictors of chemistry achievement is self-determination as function of motivation component ($\beta = .085$). Thus, from the results one can deduced that mark motivation and intrinsic motivation are the most positive significant predictors of students' Chemistry achievement of chemical kinetics and equilibrium concepts.

The intercept B (the constant) is the expected mean value of the chemistry achievement scores when all the motivation subscales becomes zero. It is the constant value where the linear regression line intercepts the y- axis representing the amount of chemistry achievement scores, when all the motivation subscales are zero. In this study, the value of B (the constant) is -21.788. On the other hand, the p-value for each explanatory variable is less than alpha 0.05, which implied that F-value for each explanatory variable is statistically significant. This implies that the variation in chemistry achievement scores due to each postulated predictor variable is significant.

Besides, as it was revealed from F value, the combined hypothesized explanatory variables are statistically significant.

On Table 4.35 above, the beta coefficients indicate how and to what extent the motivation subscales have influenced the chemistry achievement scores. Specifically, the beta coefficients show how much the chemistry achievement scores varies due to a change in motivation subscales. According to the regression coefficient analysis results, mark motivation ($\beta = .432$) is the highest predictor of students' chemistry achievement scores, followed by intrinsic motivation ($\beta = .386$), and career motivation ($\beta = .156$). On the other hand, self-efficacy ($\beta = -.160$) predicts chemistry achievement negatively that indicated that inversely related to the chemistry achievement scores, while self-determination ($\beta = .085$) is the least predictor of chemistry achievement. Therefore, it has inferred that mark motivation and intrinsic motivation are the most significant positive predictors of students' chemistry achievement in chemical kinetics and equilibrium concepts.

Finally, based on the results obtained (Table 4.35), the following regression model (linear equation) was obtained:

$$\text{CAT} = -21.788 + 0.386\text{IM} - .160\text{SE} + 0.085\text{SD} + 0 + 0.432\text{MM} + 0.156\text{CM}$$

Where CAT is the dependent variable (chemistry achievement Test), MM is mark motivation, IM is intrinsic motivation, CM is career motivation, SE is self-efficacy, and SD is self-determination.

According to the regression equation, each unit increase in intrinsic motivation is connected with a 0.386 rise in chemical achievement, implying that stronger intrinsic motivation leads to better chemistry performance. In contrast, a unit increase in self-efficacy results in a -0.160 change in chemistry accomplishment, demonstrating that higher levels of self-efficacy might have a detrimental influence on performance. This paradox implies that overconfidence owing to increased self-efficacy may result in less effort and inferior outcomes (Bandura, 1997).

Furthermore, contextual variables such as insufficient educational assistance and a mismatch between perceived and real ability may exacerbate this unfavorable link (Schunk & Pajares, 2005). These findings highlight the need for combining self-belief with suitable challenges and support structures in educational environments.

The regression analysis shows that different motivators have diverse effects on chemistry achievement. A unit increase in self-determination increases accomplishment by 0.085, whereas mark motivation has a bigger effect of 0.432. Career motivation causes a 0.156 variation in chemistry achievement. These findings highlight how several motivational subscales, including as self-determination, mark motivation, and job motivation, play roles in student performance. Understanding how these factors influence learning outcomes enables educators and policymakers to develop more targeted strategies to improve student engagement and performance in chemistry, particularly in complex topics such as chemical kinetics and equilibrium (Deci & Ryan, 2000; Schunk & Pajares, 2005).

Lastly, based on the above beta values, z-order (r) values, and R² value, the following equation was derived to determine how much percentage each predictor variable accounts for change in achievement or how much percentage of the change in it was explained by each predictor variables postulated in this study:

$$(R^2)(100) = 100((\beta r)_{IM} + (\beta r)_{SE} + (\beta r)_{SD} + (\beta r)_{MM} + (\beta r)_{CM})$$

$$64.7\% = (.386*.708IM - .160*.483SE + .085*.479SD + .432*.733MM + .156*.600CM)*100$$

$$64.7\% = 27.3\%IM - 7.7\%SE + 4.1\%SD + 31.7\%MM + 9.4\%CM$$

The above computed results indicate that 27.3%, 7.7%, 4.1%, 31.7%, and 9.4% of the change in students' Chemistry achievement is due to the change in intrinsic motivation, self-efficacy, self-determination, mark motivation, and career motivation, respectively. Four of these motivation components (intrinsic motivation, self-efficacy, mark motivation, and career motivation) are significant predictors of chemistry achievement on these two concepts ($p < .05$). However, self-determination was not a significant predictor of chemistry achievement ($p = .295$). This indicated that self-determination was not significant predictor of the chemistry achievement scores. In conclusion, this implies that 64.7% of the variation in students' Chemistry achievement is due to the change in the hypothesized predictors (IM, SE, SD, MM, and CM), while the remaining 35.3% is due to other factors not considered in this study. Moreover, among the predictor variables, mark motivation is the most predictive variable, followed by intrinsic motivation. However, self-determination was the least predictive variable for students' Chemistry achievement of chemical kinetics and equilibrium chemistry concepts.

In conclusion, the study found that intrinsic motivation, self-efficacy, mark motivation, and career motivation are significant predictors of chemistry achievement on chemical kinetics and equilibrium concepts. These findings suggest that students who are motivated by internal factors, such as interest and enjoyment, and external factors, such as grades and career aspirations, tend to perform better in chemistry. Additionally, the study found that self-determination was not a significant predictor of chemistry achievement, suggesting that external factors may be more important than internal factors in determining students' achievement in chemistry.

Overall, the study found that 64.7% of the variation in students' Chemistry achievement is due to the change in the hypothesized predictors, while the remaining 35.3% is due to other factors not considered in this study. These findings have important implications for educators and policymakers who seek to improve students' achievement in chemistry and other STEM fields. By focusing on the development of intrinsic motivation, self-efficacy, mark motivation, and career motivation, educators may be able to enhance students' achievement and interest in chemistry.

4.7. Qualitative Data Analysis and Interpretations

Research Question Five: What chemical kinetics and equilibrium concepts-related misconceptions exist among Grade 11 students and how effective is TSPCK-based instruction in learning these concepts?

To answer this particular research question, qualitative data were collected using semi-structured interviews and observation Checklist. The purpose of this research question was to explore the misconceptions and check the effectiveness of TSPCK-based instruction in learning chemical kinetics and equilibrium concepts. In this section results were presented using thematic approach, and opinions of students and teachers in relation to the interventions.

This section presents a thematic analysis of misconceptions in chemical equilibrium based on responses from semi-structured interviews with six students (coded as A, B, C, D, E, and F). The analysis aims to explore prevalent misconceptions, discuss the origins of these misunderstandings, and interpret the findings to provide insights for instructional improvement. The themes identified include misconceptions about reaction rates, rate laws, factors affecting reaction rates, rate law calculations, and reaction mechanisms. Each theme is illustrated with students' opinions and supported by relevant research literature.

4.7.1. Analysis of Misconceptions in Chemical Equilibrium Concepts

Misconceptions about the Rate of Reaction

Students generally demonstrated a basic understanding that reaction rates decrease over time as reactants are consumed. However, significant challenges emerged regarding the accurate measurement of reaction rates at different intervals and the distinction between instantaneous and average rates. For example,

Student A: *“The rate of reaction decreases over time because the reactants are being used up. However, I’m not sure how to measure this precisely at different times.”*

Student C: *“The rate of reaction is faster at the beginning and slows down as the reactants are used up. I am unsure about how to distinguish between instantaneous and average rates.”*

These findings highlight a common struggle among students in understanding the procedural and conceptual aspects of reaction rates. The confusion stems from the abstract nature of rate measurement, particularly the mathematical concepts underlying instantaneous rates.

Students demonstrated a general understanding that reaction rates decrease over time as reactants are consumed. However, significant challenges were identified in measuring and distinguishing between instantaneous and average rates. This aligns with Justi (2002), who found that students often struggle with the mathematical and graphical representations of reaction rates. The confusion between instantaneous and average rates appears rooted in the abstract nature of these concepts and limited instructional emphasis on their practical applications (Van Driel & Graber, 2002).

For instance, Student A stated, *“I get confused when trying to understand how the rate of reaction is measured at different intervals.”* Similarly, Student C remarked, *“The concept of instantaneous rate versus average rate is unclear to me.”* These insights suggest a need for teaching strategies that integrate conceptual clarity with hands-on activities. Interactive tools, such as simulations and dynamic graphs, have proven effective in visualizing reaction rate

changes over time (Kozma et al., 1996). Moreover, guided problem-solving approaches have been shown to improve students' ability to calculate rates (Tsaparlis, 2007).

Previous research corroborates these findings, indicating that students often fail to grasp the quantitative aspects of reaction rates due to inadequate emphasis on graphical and mathematical representations during instruction (Justi, 2002; Van Driel & Graber, 2002). Targeted interventions, such as the use of interactive tools and dynamic simulations, could address these gaps by providing visual and practical contexts.

Misconceptions about Rate Laws and Theories

Students displayed a fundamental understanding of rate laws as relationships between reaction rates and concentrations. However, they struggled to apply these laws to diverse reactions and to understand the theoretical basis for concentration effects.

Student B: *"I understand the basic idea of rate laws but struggle with applying them to more complex reactions."*

Student E: *"I get the basic idea of rate laws but applying them in different situations is challenging. Concentration effects are also confusing."*

Students demonstrated a basic understanding of rate laws but struggled to apply them to varied chemical reactions and link concentration changes to reaction rates. This finding is consistent with Ardac and Akaygun (2004), who reported that students often fail to grasp the quantitative relationship between concentration and reaction rates, particularly in non-laboratory contexts. For example, Student B noted, *"I understand the basic idea of rate laws but struggle with applying them to more complex reactions."*

Inquiry-based activities and interactive visual tools have been found effective in addressing such challenges. These tools allow students to observe the effects of concentration changes on reaction rates, thereby enhancing conceptual clarity (Carragher et al., 2016). However, traditional methods without scaffolded approaches often fall short of bridging the gap between theory and

application (Jere, 2020). Educators are encouraged to adopt a mixed approach, combining inquiry-based learning with technology-enhanced instructional strategies.

Studies have shown that inquiry-based activities and scaffolded problem-solving tasks can enhance students' understanding of rate laws (Ardac & Akaygun, 2004). Integrating these methods into the curriculum, along with interactive simulations, could help bridge the gap between theory and application.

Misconceptions about Factors Affecting Reaction Rates

While students recognized factors such as temperature, catalysts, and concentration as influencers of reaction rates, they struggled to articulate the specific effects of each factor. For instance,

Student D: *“I understand that concentration and temperature affect the rate of reactions, but explaining the specific impact of each factor is challenging.”*

Student F: *“Understanding the precise roles of catalysts and temperature is difficult for me.”*

While students recognized the key factors affecting reaction rates such as temperature, catalysts, and concentration, they struggled with understanding their specific roles. For instance, Student D stated, *“I understand that concentration and temperature affect the rate of reactions, but explaining the specific impact of each factor is challenging.”*

These findings align with Hanson and Wolfe (2017), who emphasized that students often fail to grasp the kinetic molecular theory's application to reaction rates. Digital simulations and animations that visualize molecular collisions have been shown to improve students' understanding of these factors (Chiu et al., 2018). Additionally, scaffolded instruction focusing on the interplay between collision frequency, energy, and activation energy is crucial for addressing these misconceptions. Research highlights the effectiveness of digital simulations in illustrating molecular interactions and their impact on reaction rates (Chiu et al., 2018). Incorporating such tools into teaching can provide students with clearer visualizations, enhancing their conceptual understanding.

Misconceptions about Rate Law and Order of Reaction Calculations

Students struggled with calculating rate laws and understanding reaction orders, particularly in complex scenarios involving experimental data. For example,

Student A: *“I know rate laws involve experimental data, but calculating them for complex reactions is difficult.”*

Student C: *“I grasp the idea of rate laws but struggle with calculating them from data and understanding reaction order.”*

Students exhibited difficulties in deriving rate laws from experimental data and interpreting reaction orders. For example, Student F remarked, *“Understanding and applying reaction orders to calculate rate laws is difficult for me.”* This supports Bain and Towns (2016), who identified the abstract nature of reaction orders and inadequate emphasis on experimental determination as major contributors to students’ misconceptions.

While mathematical difficulties are often cited as barriers, the issue extends to a failure to link mathematical procedures with chemical concepts. Carraher et al. (2016) argue that scaffolded experimental settings, such as spectrophotometry-based activities, can significantly enhance students’ understanding of reaction orders. Such activities provide students with hands-on experience and help them connect theoretical concepts to real-world applications. Studies suggest that hands-on experiments combined with guided problem-solving can significantly improve students’ ability to derive rate laws and interpret reaction orders (Bain & Towns, 2016). Addressing these misconceptions requires integrating experimental data analysis and mathematical reasoning into instructional practices.

Misconceptions about Reaction Mechanisms

Students exhibited limited understanding of reaction mechanisms, particularly in connecting these to overall reaction rates. For example,

Student B: *“I understand the basics of reaction mechanisms but find it hard to see how they affect the overall rate.”*

Student E: *“I get the idea of reaction mechanisms but have trouble connecting them to the overall rate of reaction.”*

Students expressed challenges in understanding the relationship between reaction mechanisms and overall reaction rates. For instance, Student A stated, *“I know reaction mechanisms involve intermediate steps, but connecting them to the overall reaction rate is unclear.”* These findings are consistent with studies that highlight the abstract nature of reaction mechanisms as a barrier to student understanding (Bain & Towns, 2016).

Interactive tools and guided inquiry have been shown to address these challenges effectively. For example, animations that illustrate intermediate steps and the role of rate-determining steps can help students visualize complex mechanisms (Chiu et al., 2018). Educators should also emphasize the connection between proposed mechanisms and experimental data to enhance students' understanding. Interactive teaching methods, such as modeling reaction mechanisms using animations or simulations, could help students visualize intermediate steps and their impact. This aligns with cognitive theories advocating for visual learning aids in science education.

The findings underscore the need for instructional strategies that integrate conceptual clarity with experiential learning. A mixed approach involving inquiry-based activities, interactive visualizations, and scaffolded problem-solving can address persistent misconceptions in chemical kinetics. Additionally, cultural and educational contextual factors, such as curriculum design and prior exposure to these concepts, should be considered in instructional planning.

Future research should explore the effectiveness of these strategies in diverse educational contexts, focusing on their impact on students' conceptual understanding and procedural skills. By addressing these challenges, educators can foster a deeper and more comprehensive understanding of chemical kinetics and equilibrium among students.

4.7.2. Analysis of Misconceptions in Chemical Equilibrium Concepts

Misconceptions in chemical equilibrium present significant challenges to students' understanding of this fundamental concept in chemistry. The purpose of this analysis is to explore students' difficulties in comprehending chemical equilibrium concepts through thematic analysis of semi-structured interview responses. The study aims to identify areas of conceptual misunderstanding and provide insights into potential strategies for addressing these issues. This analysis is structured into four main themes: understanding the basic concept of chemical equilibrium, equilibrium expressions and constants, factors affecting chemical equilibrium, and understanding Le Chatelier's Principle. Findings are discussed with reference to existing literature, and implications for teaching practices are highlighted.

Misconceptions on Basic Concept of Chemical Equilibrium

Students were asked to describe chemical equilibrium and the challenges they face in understanding it.

All students correctly identified chemical equilibrium as a state where the forward and reverse reaction rates are equal, leading to constant concentrations of reactants and products. However, their responses revealed a superficial understanding of the dynamic nature of equilibrium. For example:

Student A: *"I find it hard to grasp how equilibrium can be dynamic, with reactions still occurring even though the concentrations are constant."*

Student E: *"The idea of equilibrium being a dynamic state, where reactions still occur but at the same rate, is confusing to me."*

Students appear to view equilibrium as a static state, struggling to conceptualize its dynamic aspects. This misconception aligns with Talanquer's (2018) observation that students often perceive equilibrium as a "frozen" process. While students can articulate the concept qualitatively, they fail to integrate the notion of dynamic molecular interactions underlying equilibrium. Research by Bain and Towns (2016) highlights the effectiveness of inquiry-based

and visualization tools in addressing this issue. For instance, computer simulations depicting particle-level interactions can help clarify the dynamic nature of equilibrium (Rodriguez et al., 2019). The findings underscore the need for instructional strategies that emphasize molecular-level dynamics and provide visual representations of equilibrium processes.

Misconceptions on Equilibrium Expressions and Constants

Students' understanding of equilibrium expressions and constants was examined through questions about their derivation, significance, and application.

Students demonstrated foundational knowledge of equilibrium expressions and constants but struggled to apply these concepts to practical scenarios. Examples include:

Student B: *“The equilibrium constant helps in determining the position of equilibrium. A large constant means products are favored, while a small constant means reactants are favored.”*

Student D: *“The equilibrium constant indicates how far a reaction proceeds toward products or reactants.”*

While students could describe equilibrium expressions and constants theoretically, their difficulty in applying these concepts mirrors findings by Bain and Towns (2016). Many students rely on memorization rather than understanding the quantitative implications of equilibrium constants. For instance, they struggle with using these constants to predict shifts in reaction equilibria under changing conditions. Rodriguez et al. (2019) suggest integrating problem-based learning and visual aids to enhance students' ability to connect equilibrium constants to reaction dynamics. To bridge the gap between theoretical knowledge and practical application, educators should implement active learning approaches that incorporate real-world scenarios and interactive simulations.

Misconceptions on Factors Affecting Chemical Equilibrium

Students were asked about factors affecting equilibrium and their challenges in predicting the effects of simultaneous changes.

Students understood the individual effects of concentration, pressure, and temperature changes on equilibrium but found it difficult to predict combined effects. Examples include:

Student B: *“Understanding how each factor individually affects equilibrium is straightforward, but combining multiple factors at once is confusing.”*

Student E: *“I have trouble understanding the effects when multiple factors change at the same time.”*

This difficulty reflects a common misconception about the complexity of equilibrium shifts, as noted by Bain and Towns (2016) and Talanquer (2018). Students often oversimplify the application of Le Chatelier’s Principle, especially when multiple variables are involved. Research by Chiu et al. (2018) emphasizes the role of dynamic simulations and real-life scenarios in helping students synthesize these concepts. For example, TSPCK-based instruction has been shown to improve students’ ability to predict equilibrium shifts by using interactive tools and contextual examples (Rodriguez et al., 2019). Addressing these misconceptions requires instructional techniques that encourage students to explore multifactorial changes through guided inquiry and visualization tools.

Misconceptions on Le Chatelier’s Principle

Students’ understanding of Le Chatelier’s Principle and its application was explored.

Students had a general understanding of the principle but struggled with applying it to complex scenarios. Examples include:

Student A: *“I find it challenging to apply this principle to complex reactions and predict the exact shift in equilibrium.”*

Student F: *“I find it difficult to apply this principle to complex reactions and conditions with multiple changes.”*

The difficulty in applying Le Chatelier’s Principle to multifaceted situations aligns with findings by Rodriguez et al. (2019). Students often fail to predict equilibrium shifts involving simultaneous disturbances, such as changes in concentration and temperature. Talanquer (2018) observed that traditional instruction focusing on isolated examples does not adequately prepare students for complex scenarios. Interactive and real-world applications, such as virtual laboratories, can enhance comprehension and predictive ability. To strengthen students’ understanding, educators should integrate TSPCK-based instruction that emphasizes active learning and practical problem-solving.

This thematic analysis highlights persistent misconceptions in students' understanding of chemical equilibrium. While students possess foundational knowledge, they struggle with dynamic equilibrium, practical applications of equilibrium expressions, and predicting shifts under complex conditions. These findings emphasize the need for innovative teaching strategies, including inquiry-based learning, visual aids, and interactive simulations, to address these misconceptions and deepen students’ conceptual understanding. Such approaches not only align with best practices in chemistry education but also equip students with the skills to apply their knowledge in real-world and experimental contexts.

4.7.3. Analysis of Effectiveness of TSPCK-Based Instruction

The thematic analysis of interview responses reveals students' and teachers' perceptions of the effectiveness of Topic-Specific Pedagogical Content Knowledge (TSPCK)-based instruction in fostering conceptual understanding, academic achievement, and motivation in chemical kinetics and equilibrium. The analysis centers on three instructional approaches: Curricular Saliency-Based Instruction (CSA), Representation-Based Instruction, and Conceptual Teaching Strategy-Based Instruction (CTS). The findings, interpreted within the context of relevant literature,

highlight the strengths and limitations of each approach, shedding light on their educational impact.

4.7.4. Effectiveness of CSA-Based Instruction

To check the effectiveness of CSA-based instruction, two students and one teacher (their teacher) were interviewed and the findings were as indicated below.

Q. What was the focus of CSA-based instruction and was this effective strategy in enhancing your understanding, achievement and motivating your students?

The CSA-based instruction emphasizes "big ideas," linking overarching concepts to subordinate details. Interviews with two students and their teacher (T01) demonstrate its effectiveness in improving understanding, achievement, and motivation.

Conceptual Understanding

Student A highlighted that starting with big ideas simplifies complex concepts, enabling connections between details. Similarly, Student B found that organizing material around major concepts enhanced coherence and comprehension. The teacher (T01) supported these views, emphasizing that big ideas scaffold students' understanding by connecting new information to prior knowledge. These findings align with Jang and Lee (2017), who observed that curricular saliency facilitates meaningful learning and integration of knowledge.

Academic Achievement

Both students attributed better performance to the structured approach. Student A credited the systematic progression from overarching to detailed concepts for improving retention and application, while Student B emphasized the clarity of the concept sequencing. Teacher T01 confirmed that this method supports assessment performance by reinforcing students' grasp of key ideas. This corroborates Mende and Redish's (2020) assertion that structured, concept-first teaching improves science education outcomes.

Motivation

The students' motivation stemmed from the relevance and clarity of CSA-based instruction. Student A noted increased engagement due to the connection between lessons and overarching concepts, while Student B valued the purposeful organization of material. Teacher T01 further

highlighted that understanding the relevance of learning enhances engagement, consistent with Schunk's (2012) findings that relevance-focused instruction boosts motivation.

Effectiveness of Representation-Based Instruction

To check the effectiveness of representation-based instruction, two students and one teacher (their teacher) were interviewed and the findings were as indicated below.

Q. How do you see the effectiveness of Representation based instruction (classifying chemical kinetics and equilibrium concepts into macro, micro and symbolic levels, using video lessons and using visual aids) in enhancing your conceptual understanding, achievement and motivation?

Representation-based instruction integrates macroscopic, microscopic, and symbolic levels of chemical concepts, supplemented by videos and visual aids. Analysis of student and teacher responses underscores its effectiveness in fostering a holistic understanding, improving academic outcomes, and enhancing engagement.

Conceptual Understanding

Student C emphasized how the multi-level approach (macro, micro, symbolic) provided a comprehensive framework, making abstract ideas tangible. Student D valued the structured connection between levels, enhancing clarity. Teacher T02 confirmed that this approach caters to diverse learning styles, promoting deeper understanding. These observations align with Ainsworth (2006) and Treagust et al. (2018), who found that multi-representational instruction enhances comprehension in science education.

Academic Achievement

Students reported better performance due to visual aids and interactive tools. Student C highlighted the role of videos in reinforcing abstract concepts, while Student D appreciated the memorability of visual representations. Teacher T02 echoed these sentiments, noting that the use of dynamic, interactive elements simplified complex topics and improved retention.

Motivation

Students and their teacher agreed that visual tools fostered engagement. Student C felt motivated by the tangible nature of abstract concepts, and Student D appreciated how visual aids made

learning more interactive. Teacher T02 observed that these tools sustained student interest and participation. These findings align with Gilbert and Treagust's (2009) assertion that integrating multiple representations in science education enhances motivation and understanding.

Effectiveness of Conceptual Teaching Strategy-Based Instruction

To check the effectiveness of CSA-based instruction, two students and one teacher (their teacher) were interviewed and the findings were as indicated below.

Q. How do you see the effectiveness of conceptual teaching strategy based instruction (ed-puzzle instructional approach, interactive video lessons, and interactive simulations on the chemical kinetics and equilibrium concepts) in enhancing your conceptual understanding, achievement and motivation?

CTS-based instruction employs tools such as EdPuzzle, interactive videos, and simulations to engage students actively. Thematic analysis revealed its effectiveness in addressing conceptual understanding, academic performance, and motivation.

Conceptual Understanding

Interactive features like EdPuzzle questions encouraged critical thinking and reinforced comprehension, as noted by Student E. Student F highlighted simulations' value in visualizing abstract concepts, which the teacher (T03) supported, noting their role in breaking down complex topics. Mayer (2009) similarly emphasized that interactive methods enhance understanding by engaging students actively.

Academic Achievement

Students attributed improved performance to interactive tools. Student E noted that EdPuzzle's segmented pacing reinforced knowledge step-by-step, while Student F highlighted immediate feedback from simulations. Teacher T03 concurred, observing better retention and application of concepts. However, some students found the hands-on nature of simulations distracting, indicating that guidance is essential during implementation (Gok, 2014).

Motivation

Both students found the interactive elements of EdPuzzle and simulations engaging. Student E noted increased interest due to the active involvement required, while Student F appreciated the practical application of concepts. Teacher T03 affirmed that interactive tools sustain motivation through participation. These findings are consistent with Brame (2016) and Mayer (2009), who highlighted the motivational benefits of interactive and dynamic instructional methods.

The findings underscore the effectiveness of TSPCK-based instructional strategies in enhancing learning outcomes. Each approach CSA-based, Representation-Based, and CTS-based demonstrates specific strengths, catering to diverse learning needs and preferences. However, the variability in student responses suggests the importance of customizing instructional methods to maximize their impact. Structured implementation and alignment with students' cognitive styles are essential for optimizing these approaches.

Further research could explore the integration of these strategies to leverage their collective strengths, offering a more holistic framework for chemistry education. Additionally, professional development for teachers in employing these methods effectively is crucial for sustained success in science education.

4.7.4. Classroom Observation Checklist on the TSPCK based Instruction

The effectiveness of instructional methods in promoting student engagement and teacher facilitation is crucial for optimizing learning outcomes in the classroom. This analysis examines the mean scores of classroom observation items related to Teacher Facilitation and Student Engagement by using standard rubrics (see Appendix G) across four instructional methods: Curricular Saliency (CSA), Representation (REP), Conceptual Teaching Strategies (CTS), and Conventional Method. By comparing these scores, we can assess how each method supports problem-solving, conceptual understanding, and student interaction. Based on the suggestions of Gleason et al. (2015), the results are categorized into four levels of presence: No Presence (0.00-1.5), Minimal Presence (1.51-2.00), Moderate Presence (2.10-2.74), and High Presence (2.75-3.00), providing insights into the relative effectiveness of each method. The following results were obtained from the classroom observation based on the rubrics assigned for each items (see Appendix G).

Table 4.36: classroom observation scores on the teacher facilitation and students in engagement in the TSPCK based instruction and conventional method

Teacher Facilitation Scores:				
items	CSA-based	REP-based	CTS-based	Conventional method
Item 4	2.6	2.9	2.8	1.5
Item 6	2.5	2.8	2.7	1.4
Item 7	2.6	3.0	2.9	1.6
Item 8	2.7	2.9	2.8	1.7
Item 9	2.5	2.7	2.6	1.5
Item 10	2.6	2.8	2.7	1.4
Item 11	2.7	2.9	2.8	1.6
Item 13	2.5	2.8	2.6	1.5
Item 16	2.6	2.9	2.7	1.5
Mean score	2.60	2.83	2.76	1.55
Students Engagement				
Item 1	2.5	2.8	2.6	1.6
Item 2	2.6	2.9	2.7	1.5
Item 3	2.7	2.8	2.8	1.6
Item 4	2.5	2.8	2.6	1.4
Item 5	2.6	2.9	2.7	1.5
Item 12	2.5	2.8	2.6	1.6
Item 13	2.6	2.9	2.7	1.5
Item 14	2.5	2.8	2.6	1.5
Item 15	2.6	2.9	2.7	1.5
Mean score	2.56	2.85	2.70	1.52

4.7.4.1. Analysis on Teacher Facilitations

As can be seen from table 4.36 here above and appendix G items 4, 6, 7, 8, 9, 10, 11, 13 and 16 provided information on teachers facilitation role. Both REP and CTS methods exhibit high presence in teacher facilitation. This indicates that these methods effectively support classroom

discourse, guide problem-solving, and foster a structured learning environment. The high scores reflect robust implementation of teaching strategies that enhance the clarity and effectiveness of instruction. Teachers using REP and CTS methods are likely to provide significant support in understanding complex concepts and managing classroom interactions. The CSA method shows a moderate presence in teacher facilitation. While it is effective, it is not as impactful as REP and CTS. This suggests that CSA provides a good level of support for problem-solving and discourse but may lack some of the more advanced facilitation strategies found in REP and CTS. The Conventional Method has a minimal presence in teacher facilitation, indicating a less effective approach in guiding and structuring lessons. This method is likely to show limited support for student problem-solving and classroom interactions, which could hinder overall learning outcomes.

The findings from Table 4.36 and Appendix G reveal variations in teacher facilitation effectiveness across instructional methods. Both REP and CTS methods exhibit a strong presence, effectively supporting classroom discourse, guiding problem-solving, and fostering a structured learning environment. This aligns with research highlighting the role of active facilitation in enhancing instructional clarity and conceptual understanding (Gleason et al., 2015). The CSA method demonstrates moderate facilitation, providing valuable support for problem-solving and discourse but lacking the advanced strategies inherent in REP and CTS (Mayer, 2009). In contrast, the Conventional Method shows minimal facilitation, reflecting limited support for interactive learning and problem-solving, consistent with findings on its inability to engage diverse learning styles (Gok, 2014). However, occasional success in structuring lessons with visual aids suggests variability in execution (van der Meij & de Jong, 2011). Overall, REP and CTS emerge as the most effective strategies, while CSA holds moderate potential, and the Conventional Method highlights the need for improved facilitation approaches.

4.7.4.2. Analysis on Student Engagement

As can be seen from table 4:36 here above and Appendix G items 1, 2, 3, 4, 5, 12, 13, 14 and 15 provided information on student engagement. REP demonstrates high presence in students' engagement. This reflects a high level of student involvement, motivation, and interaction during lessons. The REP method effectively engages students through various activities and discussions, leading to greater participation and interest in the subject matter. Both CSA and CTS methods

show moderate presence in students' engagement. This suggests that while these methods are effective in engaging students, there may be room for improvement compared to REP. CSA and CTS likely provide solid opportunities for student involvement but do not achieve the same level of engagement as REP. The Conventional Method shows minimal presence in students' engagement. This indicates that students are less involved and motivated under this method. The lack of engagement opportunities and interactive elements in the Conventional Method may contribute to lower levels of student participation and interest.

The findings from Table 4.36 and Appendix G regarding student engagement align with consistent and inconsistent findings from prior research. The high engagement observed in the REP method is consistent with studies emphasizing the effectiveness of multi-representational and activity-based approaches in fostering active participation and motivation (Gleason et al., 2015; Brame, 2016). By integrating macro, micro, and symbolic representations, REP effectively connects abstract concepts with practical applications, enhancing student involvement (Mayer, 2009). The moderate engagement levels in CSA and CTS align with research indicating that strategies emphasizing problem-solving and critical thinking can engage students but may lack the dynamic and multimodal interaction necessary for peak engagement (Gok, 2014). In contrast, the minimal engagement associated with the Conventional Method reflects its reliance on lecture-based approaches, which often fail to address diverse learning needs (Gok, 2014). However, some studies, such as van der Meij and de Jong (2011), suggest that traditional methods supplemented with visual aids or structured guidance can occasionally improve student involvement, highlighting the variability in teacher implementation. Overall, REP emerges as the most effective method for promoting student engagement, while CSA and CTS show moderate success, and the Conventional Method underscores the need for improvement. These findings emphasize the value of adopting and refining interactive strategies to maximize student engagement.

CHAPTER FIVE: SUMMARY, CONCLUSION, RECOMMENDATION AND LIMITATION

This portion of the dissertation consists of four main sub-sections. These are summary of the findings, conclusions, recommendations and limitations of this study.

5.1. Summary of the Findings

This sub-section of the study presents summaries of the findings and discussions. A mixed-method research approach was employed in this study. Findings and discussions of quantitative and qualitative data were presented. The study used a quasi-experimental design, with participants assigned to treatment and comparison groups based on their availability in their intact classes. Participants in the current study are grade 11 students who learn as one core subject in the four public schools in Addis Ababa administrative city, Ethiopia, during the academic year 2021/2022. Findings and discussions of the dissertation are summarized in terms of the research questions, in this sub-section.

The main purpose of this study was to investigate the effect of TSPCK-based instruction on grade 11 students' conceptual understanding, achievement, and motivation in Chemical kinetics and equilibrium concepts at Addis Ababa Administrative City. In relation to this major purpose five specific purposes guided the study. These were:

- To examine the effect of TSPCK-based instructions on students' conceptual understanding, achievement and motivation.
- To examine the interaction effect between groups and gender in learning chemical kinetics and equilibrium concepts.
- Evaluate the effect of TSPCK-based instruction on students' conceptual understanding, achievement and motivation as measured by combined dependent variables.
- To predict the effect of motivation subscales on the students' conceptual understanding and achievement after TSPCK-based instruction was employed in learning chemical kinetics and equilibrium.

- To explore the misconceptions and check the effectiveness of TSPCK-based instruction in learning chemical kinetics and equilibrium concepts.

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

- Are there significant mean score differences between intervention and comparison groups in their conceptual understanding, achievement, and motivation in learning chemical kinetics and equilibrium?
- Do groups and gender have interaction effects on conceptual understanding, achievement and motivation?
- Are there significant mean score differences between Intervention and comparison groups on a linear combination of conceptual understanding, achievement and motivation in learning chemical kinetics and equilibrium?
- How well do motivation and its components predict Grade 11 students Conceptual understanding and achievement?
- What chemical kinetics and equilibrium concepts-related misconceptions exist among Grade 11 students and how effective is TSPCK-based instruction in learning these concepts?

Different data collection instruments were used in this study for gathering data and answering the five research questions here above. This sub-section of the study summarizes results obtained through chemical kinetics and equilibrium conceptual understanding tests (CKE-CUT), Chemistry achievement test (CAT), Chemistry motivation questionnaires (CMQ), semi-structured interviews, and observation. The first research question was to compare the posttest mean scores of conceptual understanding, achievement and motivation between intervention and control groups. The second research question was to compare the posttest mean scores of the three dependent variables and the interaction effect of the groups with gender. The third research question focused on the linear combination effect of the three dependent variables on the groups. The fourth research question addressed whether there were a relationship between motivation dimensions (intrinsic motivation, self-efficacy, self-determination, mark motivation and career motivation) with both conceptual understanding and achievement. Furthermore, the fifth research question was answered through getting data using semi-structured interviews and classroom observations.

5.1.1. Research Question One

Are there significant mean score differences between intervention and comparison groups in their conceptual understanding, achievement, and motivation in learning chemical kinetics and equilibrium?

This sub-section offers a summary of the findings and discussions on Grade 11 students conceptual understanding, achievement, and motivation result. The quantitative data gathering tools helped in getting data on these three dependent variables in relation to chemical kinetics and equilibrium.

In general, the study results revealed statistically significant mean differences between the four groups in terms of their posttest scores on Conceptual understanding test, chemistry achievement test and chemistry motivation questionnaires. In addition, the motivation dimensions were statistically significant on the posttest scores of conceptual understanding and achievement of chemical kinetics and chemical equilibrium concepts. After this general finding remarks, we had been seen the finding of all dependent variables (conceptual understanding, achievement and motivation) on the intervention and comparison groups. Furthermore, the findings from one way ANOVA, two way ANOVA, MANOVA, followed ANOVA, multiple regressions and the qualitative data analysis on the conceptual understanding, achievement and motivation presented as follows;

Conceptual understanding of Chemical Kinetics and Equilibrium in groups

The study analyzed the conceptual understanding of grade 11 students on chemical kinetics and equilibrium chemistry concepts using three intervention groups (CSA, REPs, and CTS) and CM. The mean scores of posttest conceptual understanding was higher in the intervention groups than the comparison group. This was showed us the conceptual understanding of grade 11 students was statistically significant among the intervention and comparison groups on these concepts. The Games-Howell multiple comparison test revealed the significant differences have seen between the intervention groups (CSA, REPs, CTS) and CM groups, with mean differences of 8.45, 16.75, and 16.34, respectively, indicating a significant difference between the intervention and comparison groups were sound (Table 4.7).

The mean gain of the intervention and comparison groups on the conceptual understanding of chemical kinetics and chemical equilibrium concepts has found to be higher in representation-

based instruction and conceptual teaching strategy-based instruction compared to curricular saliency-based instruction and comparison groups. Representation-based instruction improved the conceptual understanding of grade 11 students on these concepts, followed by conceptual teaching strategy-based instruction. However, curricular saliency-based instruction also outperformed better than the comparison group.

In addition to enhancing the conceptual understanding, the TSPCK based instruction involved in reduction of misconception, no understanding, and partial understanding between the intervention and comparison groups on learning chemical kinetics and equilibrium concepts.

Following the implementation of TSPCK-based instruction, there was a significant decrease of 15.8%, 5.2%, and 18.4% in misconceptions (MS), partial understanding (PU), and no understanding (NU) of chemical kinetics; REP-based and CTS-based instruction also significantly reduced these levels, with REP reducing NU, PU, and MS by 19.3%, 11.5%, and 15.8%, and CTS reducing NU, PU, and MS by 17.2%, 11.4%, and 17.2%, respectively.

Chemical kinetics misunderstandings were reduced to a minimum, mainly through the use of CTS-based and REP-based instructions. Misconceptions were also decreased by CSA-based instruction, but the conventional method had little effect on the reduction of misconceptions; less than 5% was seen at all levels.

The use of CSA, REP, and CTS methodologies resulted in a considerable improvement in the level of conceptual understanding of the students in chemical kinetics. The largest mean gains was seen in REP (46.2%), followed by CTS (45.7%) and CSA (39.5%). The conventional method demonstrated a poor 11.7% improvement. Similarly, TSPCK-based instruction decreased NU, PU, and MS for chemical equilibrium, with CSA, REP, and CTS approaches demonstrating differing degrees of efficacy. The conventional method demonstrated a little normalized learning gain in NU and minor reductions in PU and MS, whereas REP-based instruction was the most effective in reducing misconceptions and misunderstandings of the students in learning chemical kinetics and equilibrium concepts.

Achievement of students between groups on the chemical kinetics and Equilibrium

The study analyzed the posttest achievement scores of grade 11 students in Addis Ababa secondary schools using TSPCK-based instruction in between intervention and comparison

groups. The results showed that the intervention groups had higher mean posttest achievement scores than the comparison group, indicating that the topic specific PCK teaching strategy (TSPCK) was effective in improving academic performance.

The ANOVA result revealed that there was a statistically significant difference between the intervention and comparison groups on selected chemistry concepts, this statistical significant difference was not showed us the specific difference among the groups. Therefore, the Games-Howell multiple comparison post hoc test revealed that there were a statistically significance difference between all the three intervention groups and comparison group (Table 4.11) in achievement posttest scores. The mean and normalized learning gains of the intervention and comparison groups were also revealed the existence of the difference among the groups found to be higher and comparable for the conceptual teaching strategy-based (25%) with the representation-based instruction (22%) (Table 4.13). This indicates that the TSPCK-based instruction improved the academic performance of the students by 25%, in CTS and the representation-based instructional strategy increased by 22% than the conventional instructional teaching strategy. Additionally, the curricular saliency-based instruction outperformed than the conventional method of teaching chemical kinetics and chemical equilibrium concepts by 17%. In conclusion, the study found that TSPCK-based instruction significantly improved the academic performance of grade 11 students in Addis Ababa secondary schools on the chemical kinetics and chemical equilibrium concepts.

Effect of TSPCK based instruction on Motivation in learning chemical kinetics and chemical equilibrium

The study found that the TSPCK-based instruction (CSA, REPs, and CTS) groups were a statistically significant and enhanced the motivation of grade 11 students in learning chemical kinetics and equilibrium concepts compared to the conventional method of teaching. The intervention groups had higher mean scores of intrinsic motivation, self-efficacy, self-determination, mark motivation, and career motivation compared to the comparison group (Table 4.15). The representation-based instruction and conceptual teaching instruction improved motivation by using computer-assisting material preparation to visualize microscopic and symbolic levels and interactive ways of chemistry teaching. The study assumed equal variances for intrinsic motivation, self-efficacy, and career motivation, and unequal variances for self-

determination and mark motivation. As a result, we used Tukey's post hoc multiple comparison test for equal variances and Games-Howell post hoc multiple comparison for unequal variances. The study reveals that the implementation of TSPCK-based instruction significantly improved the motivation of grade 11 students in learning chemistry concepts. The study found that intrinsic motivation, self-efficacy, self-determination, mark motivation, and career motivation were statistically significantly different between the intervention and comparison groups. The Tukey's post hoc multiple comparison tests revealed significant differences in intrinsic motivation between (CSA and CM, REPs, CM; CSA and CTS), self-efficacy (CSA and REP, CTS, CM; REP and CM), and career motivation (CSA and CTS, CM; REP and CM) posttest scores of grade 11 students on kinetics and chemical equilibrium concepts (Table 4.19). However, there is no statistical significance difference between CTS and CM in intrinsic motivation, REPs and CTS in self-efficacy, and no a statistically significance between (CSA and REPS; CTS and CM) in career motivation.

For self-determination and mark motivation, there were significant differences between CSA and CM; REPs and CM; CTS and the comparison group (Table 4.20). However, there was no significant difference between intervention groups in self-determination after TSPCK-based instruction has implemented. This significant difference in motivational construct between groups also confirmed with the mean and normalized learning that revealed it was found to be higher in REPs and CSA based instruction as compared to conceptual teaching strategy based and conventional teaching method. Accordingly, the normalized learning gain in overall motivation between CSA, REPs, CTS and CM were 38%, 59%, 20%, and 9%, respectively (Table 4.21). The study concludes that TSPCK-based instruction significantly improved the motivation of grade 11 students in learning chemical kinetics and equilibrium concepts compared to conventional teaching strategy.

5.1.2. Research Question Two

Do groups and gender have interaction effects on conceptual understanding, achievement and motivation?

Interaction Effect of TSPCK-based instruction and Gender

There was no significant interaction between gender and instructional groups for any of the three variables examined in the study, which showed diverse findings on the effects of TSPCK-based

instruction across conceptual understanding, achievement, and motivation. The major effect of instructional groups was significant for conceptual comprehension, indicating that varied teaching approaches had a significant impact on students' understanding of chemical kinetics and equilibrium, regardless of gender. Similarly, rather than gender, the type of instruction had a substantial impact on achievement, with intervention groups demonstrating notable improvements in achievement when compared with conventional teaching approaches.

While there was no significant interaction between gender and groups in terms of motivation, there was a substantial main effect of the instructional groups, indicating that students' motivation was significantly impacted by various teaching methods. Overall, both genders benefited equally from the TSPCK-based strategies; specific strategies, such as REP-based instruction, showed larger impacts on conceptual understanding and achievements; nevertheless, motivation varied, particularly across different instructional contexts.

5.1.3. Research Question Three

Are there significant mean score differences between Intervention and comparison groups on a linear combination of conceptual understanding, achievement and motivation in learning chemical kinetics and equilibrium?

The MANOVA results demonstrated statistically significant differences across the intervention groups in terms of conceptual understanding, achievement, and motivation, with the group factor explaining 17.6% of the variance in these combined dependent variables. This represents a large effect size, indicating that the instructional interventions had a substantial impact on student outcomes.

Follow-up analyses using one-way ANOVAs confirmed these significant differences. Specifically, the effect sizes for conceptual understanding and achievement were moderate, suggesting a meaningful, though slightly smaller, and impact in these areas. In contrast, motivation exhibited the largest effect size, underscoring its considerable influence across the groups.

The results suggest that the intervention strategies particularly those based on TSPCK were highly effective in enhancing student motivation, followed by improvements in conceptual understanding and achievement. Motivation, in particular, showed the strongest impact, emphasizing the importance of engagement in the learning process. These findings highlight the

effectiveness of TSPCK-based instructional strategies in promoting student outcomes, with motivation being the most significantly influenced factor.

5.1.4. Research Question Four

- How well do motivation and its components predict Grade 11 students' Conceptual understanding and achievement?

Prediction of motivation components on the conceptual understanding

The study found a strong positive relationship between motivational components (intrinsic motivation, self-efficacy, self-determination, mark motivation, and career motivation) and conceptual understanding in learning chemical kinetics and equilibrium. The motivational aspects account for 67.4% of the variation in students' comprehension, demonstrating their importance in shaping learning outcomes.

The statistical research, which yielded an R-square value of 0.674, demonstrates that motivational dimensions predict conceptual knowledge in chemical kinetics and equilibrium. The F-value and p-value imply that these motivational factors have an important role in shaping students' conceptual understanding of chemical kinetics and equilibrium chemistry concepts.

The most significant indicators of conceptual understanding were mark motivation and intrinsic motivation. The study indicated that these factors have the greatest influence on students' understanding of chemical kinetics and equilibrium, but self-efficacy and self-determination were not significant predictors.

The study found that motivational constructs account for 67.4% of the variation in conceptual knowledge, with the remaining 32.6% impacted by factors not investigated in this study. This implies that, while motivation is important, other factors influence students' learning outcomes. Mark motivation was found to be the strongest predictor of conceptual understanding, followed by intrinsic and career motivation. This underlines the importance of specific motivating strategies for improving students' comprehension of chemical kinetics and equilibrium, while also noting that self-efficacy and self-determination have less influence in this context.

Prediction of motivation Dimensions on the Achievement

The study found a positive linear association between motivational components and students' achievement in chemical kinetics and equilibrium. Motivational factors account for 64.7% of the variation in student achievement, highlighting their strong impact on learning outcomes ($R^2=0.647$). Mark motivation appeared as the most powerful predictor of students' chemistry achievement, followed by intrinsic motivation and career motivation. The correlations show that a rise in mark motivation and intrinsic motivation greatly improves success, whereas self-efficacy, while influential, has a negative effect on performance.

5.1.5. Research Question Five

- What chemical kinetics and equilibrium concepts-related misconceptions exist among Grade 11 students and how effective is TSPCK-based instruction in learning these concepts?

Summary on Students Misconception on chemical Kinetics and Equilibrium

Students often encounter difficulties in measuring and quantifying reaction rates, especially when distinguishing between instantaneous and average rates. They also struggle to apply theoretical concepts such as rate laws and reaction mechanisms to real-world scenarios. Misconceptions regarding reaction ordering, rate laws, and the influence of concentration on reaction rates are common. This highlights the need for clearer explanations, practical examples, and the use of TSPCK-based instruction with differentiated techniques to bridge the gap between theory and application effectively.

Structured interviews with students reveal key insights into their understanding and misconceptions about chemical equilibrium. Students grasp the basic concept of equilibrium as a state where the forward and reverse reaction rates are equal, resulting in constant concentrations. However, they struggle with understanding the dynamic nature of equilibrium, especially when established from different initial conditions. While students can construct equilibrium expressions and interpret constants, they need further reinforcement to apply these concepts practically. Although students understand that factors like concentration, pressure, and temperature can shift equilibrium, they find it challenging to predict the effects of multiple simultaneous changes. They also understand Le Chatelier's Principle but face difficulties applying it to complex reactions or situations with multiple disturbances.

Summary on the Effectiveness of TSPCK-based Instruction in Learning Chemical Kinetics and Equilibrium

Curricular saliency-based instruction, which emphasizes teaching key overarching ideas and their related concepts in a structured sequence, significantly enhances students' conceptual understanding. This approach fosters better integration of complex concepts, improves achievement, and increases motivation by connecting learning to broader, more relevant ideas. Overall, it supports deeper comprehension, better performance, and greater student engagement.

Representation-based instruction, utilizing macro, micro, and symbolic levels, improves students' understanding of chemical kinetics and equilibrium by offering a multi-faceted view of the material. This approach aids in integrating abstract concepts with visual aids and video lessons, enhancing retention, application, and student motivation. It leads to better comprehension, performance, and sustained interest in learning.

The use of Ed-puzzle, interactive video lessons, and simulations (conceptual teaching strategy based-instruction) enhances understanding of complex topics like chemical kinetics and equilibrium. By actively engaging students and breaking down difficult concepts, these strategies improve retention, boost achievement, and increase motivation. The interactive nature of these tools makes learning more enjoyable and effective, offering a comprehensive approach to mastering challenging material.

Summary of Classroom Observation on TSPCK-based Instruction

Classroom observations show that the REP and CTS strategies provide good teacher facilitation and high levels of engagement among students. Both strategies effectively promote classroom conversations, problem solving, and an organized learning environment. In comparison, the CSA technique exhibits moderate facilitation and engagement, providing adequate support but not as robust as REP and CTS. The conventional method falls behind significantly, with little facilitation and engagement, resulting in less effective supervision and decreased student participation.

5.2. Conclusions

Based on the summary of the findings, the following conclusions were made.

In the current study, there was a significant mean difference in conceptual understanding, chemistry achievement and motivation in learning chemical kinetics and equilibrium concepts among gender, intervention groups (CSA, REPS and CTS) and comparison groups. Regarding the level of conceptual understanding (NU, PU and MS), the intervention groups were highly minimized than the conventional method of teaching after TSPCK based instruction has employed. Similarly, the level of conceptual understanding in misconceptions for female students diminished highly as compared to the male counter parts. In general, the sound level of conceptual understanding of the intervention is higher than the conventional method. Among the three interventions groups, the technology-supported representation based instruction and the technology supported conceptual teaching strategies enhanced the level of conceptual understanding as compared to the CSA and conventional method of teaching. Besides, participants in the treatment groups achieved significantly higher means as measured after the intervention in CU, ACH and MOT, despite the fact that normalized gains were generally at a medium levels of category. Grade 11 students, chemistry teacher educators all agreed that the interventions greatly helped their learning of chemical kinetics and equilibrium. The teachers who assigned for implementing the TSPCK based instruction, asked extensive computer skills, ed-puzzle, and interactive simulation training in order to improve the conceptual understanding, achievement and motivation in learning chemical kinetics and equilibrium concepts.

Conclusions on the Level of Conceptual Understanding on Chemical Kinetics and Equilibrium

The study found that TSPCK-based instruction improves conceptual understanding of chemical kinetics and equilibrium among grade 11 students by lowering levels of no understanding, partial understanding, and misconceptions by 8.73%, 5.7%, and 8.46%, respectively. Notably, full comprehension increased by 23.25% after using TSPCK-based strategies, demonstrating their efficacy in explaining complex topics and engaging students at the macro, micro, and symbolic level. Furthermore, REPs-based instruction, which included interactive animations, was particularly helpful in enhancing the full understanding of chemical equilibrium, with improvements of 34.2% compared to conventional instructional methods. This technique also

drastically minimized misunderstandings, with notable improvements in the CSA, REPs, and CTS groups. Overall, TSPCK-based instruction is seen as a critical method for educators seeking to build deeper conceptual grasp in chemistry, particularly among low achievers, since it increased their understanding by over 50%. This study emphasizes the need for professional development for educators as well as the use of effective instructional strategies to help all students learn complicated scientific concepts.

Conclusions on Conceptual understanding in chemical kinetics and Equilibrium

The study examined the conceptual understanding of grade 11 students on chemical kinetics and equilibrium chemistry concepts using three intervention groups. The results showed statistically significant differences between the intervention and comparison groups. The mean gain of the intervention and comparison groups was higher in representation-based instruction and conceptual teaching strategy-based instruction compared to curricular saliency-based instruction and comparison groups. Representation-based instruction improved the conceptual understanding of grade 11 students on these concepts, followed by conceptual teaching strategy-based instruction. The study also examined the impact of TSPCK-based instruction on the conceptual understanding of grade 11 chemistry students in Addis Ababa. The mean gain and learning for male students increased by 15% and 20% after intervention, respectively. The study also found that TSPCK-based instruction equally taught the chemical kinetics and equilibrium concepts to low, medium, and high achiever levels.

Conclusions on Achievement in Chemical Kinetics and Equilibrium

The study analyzed the academic performance of grade 11 students in Addis Ababa secondary schools using TSPCK-based instruction and computer-assisted material preparation. Results showed that the topic-specific PCK teaching strategy (TSPCK) significantly improved academic performance. The ANOVA table output showed significant differences between the intervention and comparison groups on selected chemistry concepts. The mean gains and learning gains were higher for representation-based instruction and the conceptual teaching strategy-based instruction. The study also found a statistically significant difference in academic achievement between male and female students in learning chemical kinetics and equilibrium concepts. Female students outperformed male students, with more engagement and questioning. The results also showed that the TSPCK-based instruction made all achiever levels involved in

learning to increase achievement. In general, low and medium achiever students' academic achievement improved due to TSPCK-based instruction than high achiever students.

Conclusions on Motivation Components on Chemical Kinetics and Equilibrium

The study found that TSPCK-based instruction significantly improved the motivation of grade 11 students in learning chemical kinetics and equilibrium concepts compared to conventional teaching methods. The intervention groups showed higher mean scores of intrinsic motivation, self-efficacy, self-determination, mark motivation, and career motivation compared to the comparison group. The study also found that female students were more motivated to learn chemistry concepts compared to male students, except for curricular saliency-based instruction. Female students outperformed male students in learning selected chemistry topics, and overall motivation increased by 27% and 34%, respectively. The study also found that TSPCK-based instruction significantly improved the motivation of medium and low achiever level students in learning these concepts. The mean gain and learning gain of low, medium, and high achiever students in learning these concepts increased by 31%, 31%, and 26% after intervention, respectively.

Conclusion on the Prediction of motivational components on Conceptual Understanding and Achievement

Prediction of motivation components on Conceptual Understanding

The study examined the impact of motivational components on conceptual understanding in learning chemical kinetics and equilibrium concepts. Five assumptions have tested, including linear relationship, multiple collinearity problems, interdependence, homoscedasticity, and multivariate normality. The results showed a strong positive linear relationship between intrinsic motivation, self-efficacy, self-determination, mark motivation, and career motivation. The goodness of fit value of .674 indicated that 67.4% of the variation in the model can be predicted using the independent variables, explaining 67.4% of the change in conceptual understanding. The study concluded that 67.4% of variation in conceptual understanding is due to the change in hypothesized predictors, while the remaining 32.6% is due to other factors not considered in this study.

Prediction of motivation components on Achievement

The study examined the predictive power of motivational components on students' achievement in chemical kinetics and equilibrium concepts. The results showed a positive linear relationship between motivation components and students' achievement. 64.7% of the variation in the model can be predicted using independent variables, explaining 64.7% of change in students' achievement. The model is strongly fit to predict chemistry achievement on identified chemistry concepts. Mark motivation was the highest predictor of students' chemistry achievement score, followed by intrinsic motivation. The study found that 27.3%, 7.7%, 4.1%, 31.7%, and 9.4% of changes in chemistry learning achievement were due to these intrinsic motivation, self-efficacy, self-determination, mark motivation and carer motivation respectively.

Conclusions on Students' Misconception on Chemical Kinetics and Equilibrium

Students frequently fail to distinguish between instantaneous and average reaction speeds, emphasizing the need for more explicit instructional strategies that properly elucidate these concepts. Misconceptions can cause confusion and gaps in comprehension if not addressed properly. Furthermore, students encounter difficulties when applying theoretical ideas like rate laws and reaction mechanisms to real-world circumstances. This shows that including practical examples and hands-on exercises in the curriculum is critical for helping students relate abstract ideas to real-world applications. Misconceptions surrounding reaction orders and rate laws further complicate students' ability to perform accurate calculations and manage complex reactions. This underscores the necessity for targeted teaching strategies that directly address these misunderstandings, enhancing students' grasp of critical concepts. To bridge the knowledge gap of the students between theoretical and practical application, improved instructional methods are vital. Implementing TSPCK-based and differentiated teaching approaches can foster personalized and effective learning experiences. These strategies can clarify complex topics in chemistry, providing practical examples that enable students to develop a deeper and more comprehensive understanding.

Conclusions on effectiveness of TSPCK-based instruction in between Groups

CSA-based instruction significantly enhances students' conceptual understanding, achievement, and motivation in chemical kinetics and equilibrium. By prioritizing key ideas before diving into specifics, this approach enables students to integrate and comprehend complex information more

effectively. Both students and teachers note that a systematic presentation bring up better knowledge retention and application, while the clarity and relevance of lessons enhance motivation, making learning more purposeful and engaging. Similarly, REP-based instruction is admired for its positive impact on understanding, achievement, and motivation. By categorizing topics into macro, micro, and symbolic levels, students find that this structured approach not only clarifies concepts but also connects different representations, accommodating diverse learning styles and enriching their overall comprehension.

The incorporation of technologies like Ed-Puzzle, interactive video lessons, and simulations further supports conceptual understanding by breaking down complex ideas into engaging, interactive sections. Ed-Puzzle's interactive features encourage active participation, while simulations bridge theoretical concepts with real-world applications, reinforcing learning. These interactive strategies not only enhance academic achievement through hands-on experiences but also significantly boost student motivation. The active presentation of material makes learning enjoyable and less abstract, raising a positive attitude towards education and creating a more engaging and fulfilling learning experience.

Conclusions on effectiveness of TSPCK-based instruction from Observation

The REP and CTS strategies are highly effective in enhancing teacher facilitation and student engagement. These approaches promote interactive classroom interactions and problem-solving, leading to clearer and more effective instruction. By incorporating participatory activities, they significantly boost student involvement and motivation, making learning a more dynamic experience. In contrast, the CSA strategy offers limited support for facilitation and engagement. While it establishes a solid foundation for classroom discourse and problem-solving, it falls short compared to the REP and CTS methods, which set higher expectations. To enhance its effectiveness, CSA could benefit from incorporating more advanced facilitation techniques. The conventional teaching method performs poorly in terms of facilitation and engagement, lacking interactive elements and structured support. This results in diminished teacher guidance and lower student participation, negatively impacting overall learning outcomes. To enhance classroom effectiveness, integrating REP and CTS practices is essential. Their proven facilitation and engagement strategies offer a pathway to improved teaching and increased student interest and participation.

5.3. Recommendations

Based on the findings and conclusions, the following recommendations are made:

5.3.1. Recommendation to the Teachers

Teachers should participate in ongoing professional development to expand their knowledge of specific chemical topics and stay current on good instructional practices and assessments. They should adjust their instructional methods to each chemical topic's distinct qualities and problems, employing a variety of teaching methodologies to accommodate different learning styles and demands. Establishing efficient feedback mechanisms is critical for assessing student understanding and altering teaching strategies accordingly, as timely and constructive feedback improves learning, particularly with complicated chemistry concepts. Teachers could also explain the real-world relevance of specific chemistry concepts to motivate students by illustrating how they relate to everyday life and potential job options, making learning more engaging and relevant.

Use TSPCK-based instruction and diversified teaching strategies to effectively address student misconceptions. Use practical examples and hands-on exercises to help students understand the relationship between theoretical principles and real-world applications. Use straightforward, step-by-step explanations and interactive technologies to clarify complicated topics, ensuring that students understand both fundamental and advanced concepts.

Using CSA-based, REP-based, and CTS-based instructional strategies make the chemistry teaching effective and sound. Use CSA-based strategies to create a clear, orderly framework that connects major ideas to specific notions. Incorporate REP-based ways to deliver material at the macro, micro, and symbolic levels, as well as CTS-based resources such as interactive videos and simulations, to actively engage students and reinforce learning. Therefore incorporating these TSPCK-based instructional strategies will help learners increase their comprehension, achievement, and motivation.

5.3.2. Recommendation to Curriculum Developers

Curriculum developers should verify that curriculum materials are consistent with the PCK requirements in order to properly teach certain chemistry topics. They should provide materials to help teachers build and implement topic-specific PCK-based instruction. It is critical to look

for ways to incorporate interdisciplinary linkages into the curriculum, particularly by emphasizing the links between chemistry topics and other scientific fields. For example, in the context of chemical kinetics and equilibrium, it is critical to consider the integration of mathematical concepts such as differentiation and integration. Furthermore, curriculum developers should use technology tools and simulations that correspond to topic-specific PCK to improve the learning experience for both teachers and students.

Create and combine lessons that focus on practical applications of theoretical concepts, notably in chemical kinetics and equilibrium. Make sure your educational resources offer a variety of examples and interactive features that address common misconceptions. Encourage the use of TSPCK-based approaches to instruction to improve the relevancy and accessibility of complex subject matter.

Create and adapt curricula that use CSA-, REP-, and CTS-based educational strategies. To support comprehensive learning, the curriculum should include structured sequences of big ideas, multi-level representations, and interactive lessons. Incorporating these approaches allows the curriculum to meet students' different learning styles, improve their conceptual comprehension, and raise their engagement and achievements in chemical kinetics and equilibrium.

5.3.3. Recommendation to Policymakers

Policymakers ought to allocate resources and support efforts that encourage continuing professional development for teachers, with a particular emphasis on establishing topic-specific PCK for teaching chemical instruction. They should advocate for assessment methods that are tailored to the unique elements of each chemistry topic, promoting flexibility in assessment processes to allow for varied approaches that address topic-specific difficulties. Furthermore, policymakers should provide incentives and recognition to schools and teachers that effectively employ creative and effective topic-specific PCK-based instructional approaches.

Support educational policies that encourage the use of innovative teaching approaches, such as TSPCK-based instruction, and make tools for hands-on learning accessible. Encourage the advancement of professional development programs for teachers that concentrate on successful ways of teaching complicated chemical concepts and correcting student misconceptions.

Advocate and support the use of novel instructional strategies such as CSA-based, REP-based, and CTS-based instruction in educational policies and funding. Encourage professional development programs for teachers that center on these effective methods of instruction. Supporting these strategies will help to improve conceptual comprehension, academic achievement, and student motivation across schools.

5.3.4. Recommendation to Chemistry Education Researchers

Chemistry education researchers should perform studies to investigate the impact of topic-specific PCK-based instruction on student conceptual comprehension, achievement, and motivation when learning chemistry, taking into account a variety of contexts and large sampled student populations. They should conduct longitudinal studies to determine the long-term impact of topic-specific PCK on students' knowledge retention and continuing interest in chemistry. Furthermore, chemistry education researchers should share their findings with educators, policymakers, and curriculum developers to help shape evidence-based practices and legislation. These recommendations emphasize the need for collaboration among students, teachers, curriculum developers, policymakers, and researchers to improve the effectiveness of topic-specific PCK-based instruction in chemistry education.

Investigate and create novel instructional methodologies that particularly address and correct misconceptions about chemical kinetics and equilibrium. Conduct a study to determine the efficiency of various teaching tools and strategies in enhancing students' comprehension and application of these concepts. Investigate techniques for incorporating real-world applications into chemistry education to improve understanding and retention.

Investigate and assess the effects of CSA-based, REP-based, and CTS-based teaching approaches on student learning outcomes. Concentrate on how these strategies can improve conceptual understanding, achievement, and motivation in learning chemical kinetics and equilibrium. Investigate effective methods to incorporate these concepts into various educational situations and make evidence-based suggestions to improve teaching practices and student learning outcomes.

5.4. Limitations of the Study

While topic-specific pedagogical content knowledge (TSPCK)-based instruction shows promise in improving conceptual understanding, achievement, and motivation in high school chemistry, there are numerous limitations to consider when designing and interpreting such studies.

The study was conducted with 159 Grade 11 students. A much larger sample in different schools in Ethiopia could be included to improve the generalizability. Generalizability is a major challenge, as outcomes from specific interventions may not be easily applied to other situations, schools, or populations.

The efficiency of TSPCK-based instruction varies depending on factors such as instructor expertise, student background, and educational resources. Furthermore, the success of these teaching strategies is strongly dependent on the teacher's ability to implement them effectively. Although teachers which are with similar experience and qualifications are involved in this investigation, factors like variability in teacher skill, and commitment can have impact on intervention outcomes.

Although the schools that participated in the study are nearly the same resource-wise. Presence of limited resources in these schools might have affected the outcomes. Additional resources may be required to implement PCK-based instruction, such as specialized teacher training, access to technology, and materials for hands-on activities. Not all schools may have the resources to fully support these interventions.

Time limits also provide a barrier, as high school curricula are sometimes densely packed with content, leaving little time for in-depth investigation of certain topics. The time necessary for effective TSPCK-based instruction may be a limiting factor, perhaps resulting in insufficient curriculum coverage.

High school classes often include a diverse student population with different levels of prior knowledge, interests, and learning styles. One-size-fits-all solutions may not be helpful in meeting the different requirements of students. Furthermore, while TSPCK-based instruction might boost motivation, the exact elements impacting student motivation are difficult and

multidimensional. It can be difficult to distinguish between the effects of TSPCK-based instruction on motivation and other factors.

5.5. Implications and Further Research Directions

Enhancing Teacher Training and Instructional Strategies

The findings emphasize the need for continuous professional development in TSPCK-based instruction. Future research should explore effective teacher training models that enhance educators' ability to implement CSA-, REP-, and CTS-based strategies to address student misconceptions and improve conceptual understanding. Longitudinal studies are needed to assess the sustained impact of teacher training on instructional effectiveness and student learning outcomes.

Curriculum Development and Resource Allocation

The study highlights the importance of integrating TSPCK-based approaches into chemistry curricula and ensuring adequate educational resources. Further research should investigate how structured curricula incorporating hands-on activities, technology-enhanced learning, and interdisciplinary connections can optimize student engagement and achievement. Studies should also assess the role of resource availability and how disparities in school infrastructure affect the effectiveness of innovative instructional methods.

Expanding the Scope and Generalizability of Findings

Given the study's limited sample size and contextual constraints, future research should involve larger and more diverse student populations across multiple schools and regions. Comparative studies across different educational settings can provide deeper insights into how TSPCK-based strategies impact student motivation, conceptual understanding, and achievement in varied learning environments. Additionally, research should examine the long-term retention of knowledge and the influence of TSPCK-based instruction on students' interest in pursuing STEM-related careers.

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Publications and Achievements

1. Belayneh, K. D., & Belachew, W. (2024). TSPCK-Based instruction and academic achievement of grade 11 students on chemical kinetics and equilibrium. *Cogent Education*, 11(1), 2292873. <https://doi.org/10.1080/2331186X.2023.2292873>
2. Dejene, K., & Belachew, W. (2023). Topic-specific pedagogical content knowledge-based instruction and level of conceptual understanding of chemical kinetics and equilibrium concepts on grade 11 students. *Science Education International*, 34(2), 96-108. <https://doi.org/10.33828/sei.v34.i2.3>
3. **Acceptance letter on conference presentation:** The Barcelona Conference on Education (BCE2024): Topic Specific PCK-Based Instruction and Grade 11 Students' Motivation and Its Influence on Conceptual Understanding and Achievement in Chemical Kinetics and Equilibrium.
4. **Certificates on Review of Different articles for the journal publications**
 - ✓ Certificate of Appointment for Reviewer from Journal of Infrastructure, Policy and Development
 - ✓ Reviewer's Certificate from Journal of BP international
 - ✓ Reviewer's Certificate from Journal of Advances in Mathematics and Computer Science
 - ✓ Reviewer's Certificate from Journal of Education, Society and behavioral Science

5. Other publication on the impact COVID-19 on Science Education during my study:

Belayneh, K. D. (2023). Impact of COVID-19 on Performance of College and University Graduate Students: Implications for Science Education. *Pedagogical Research*, 8(4). <https://doi.org/10.29333/pr/13407>

APPENDIXES

Appendix A: Chemical Kinetics and Equilibrium Conceptual Understanding Test

Addis Ababa University College of Education and Behavioral Studies Department of Science and Mathematics Education Chemistry Education PhD Program

Name _____ Rol.NO _____ School _____ sex _____

allowed time; **1:30 Hrs**

Dear students:

This exam has used to study *Topic Specific Pedagogical Content Knowledge-Based Instruction and Grade 11 students' Chemistry Learning*. The exam has a multiple-choice item with two tier (concept and reason based) parts for conceptual understanding test. The result you have scored is used only for the purpose of this dissertation only and any form of information you gave me is kept confidentially.

Thank You in advance for giving the responses you have in your mind.

Instruction: Choose the best answer from the given alternatives and write your answer on the space provided. Each question has only two correct answers one for concept answer and other to reason answer for conceptual understanding. Both concept and reason items has 1 mark each.

PART ONE: CONCEPT OF CHEMICAL KINETICS TOOLS

A. Basic concepts and Rate of chemical reaction (CK1)

_____ **1.** The rate constant of zero-order reactions has the unit

A. s^{-1}

C. $L^2 mol^{-2} s^{-1}$

B. $mol L^{-1} s^{-1}$

D. $L mol^{-1} s^{-1}$

_____ **1.1.** Because:

A. zero order reaction was independent of the concentration of reactants

B. zero order reaction directly proportional to the concentration of the reactants

C. zero order reaction inversely proportional to the concentration of the reactants

_____ 2. Consider the following reaction: $N_{2(g)} + 3H_{2(g)} \rightarrow 2NH_{3(g)}$. The rate of formation of NH_3 is $9.0 \times 10^{-4} M/s$, the rate of consumption of N_2 is _____

- A. $4.5 \times 10^{-4} M/s$ B. $9.0 \times 10^{-4} M/s$ C. $1.4 \times 10^{-3} M/s$

_____ 2.1. Because

- A. The rate of appearance of N_2 is twice of the appearance of NH_3 .
B. The rate of disappearance of N_2 is one-half of the appearance of NH_3 .
C. The rate of disappearance of N_2 is one-third of the appearance of NH_3 .

_____ 3. Consider the reaction of magnesium ribbons and Sulphuric acid. $Mg_{(s)} + H_2SO_{4(aq)} \rightarrow MgSO_{4(aq)} + H_{2(g)}$. The volume of H_2 (g) measured from the initial to 5.00 cm^3 is shown below. What is the average rate of H_2 (g) production?

- A. $0.17 \text{ cm}^3/s$ B. $0.25 \text{ cm}^3/s$ C. $0.50 \text{ cm}^3/s$

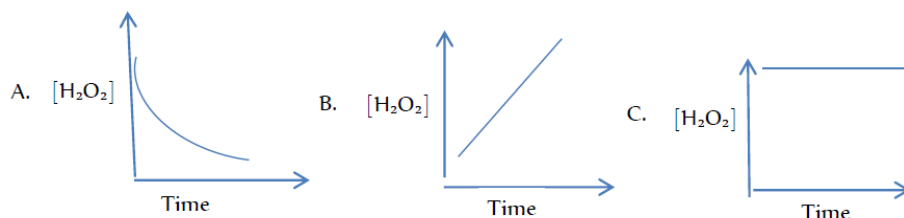
Volume (cm^3) of H_2 (g)	1.00	2.00	3.00	4.00	5.00
Time (s)	4.00	6.00	9.00	14.00	20.00

_____ 3.1. Because:

- A. A total sum of volume divided by time intervals
B. The product of volume and time interval
C. The difference between volumes divided by time intervals

_____ 4. Consider the following reaction $2H_2O_2(l) \rightarrow 2H_2O(l) + O_2(g)$

Which graph shows the relationship between rate of consumption of H_2O_2 and time?



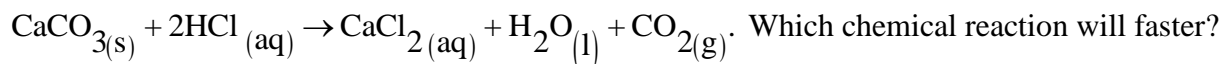
_____ 4. 1. Because

- A. The rate of a reaction is the same at any time during the reaction.

- B. The rate of a reaction decreases with passage of time as the concentration of reactants decreases.
- C. The concentration of a reactant is directly proportional to the time of a reaction.
- D. The reaction rate is constant because no additional concentration.

B. Theories of Rate of Reaction (CK2)

_____ 5. Consider the rate of a chemical reaction using the same masses of marble and Powdered CaCO₃ with similar amount of hydrochloric acid.



- A. The reaction between marble CaCO₃ and hydrochloric acid
- B. The reaction between powdered CaCO₃ and hydrochloric acid
- C. Both marble and powdered CaCO₃ react in equal time with hydrochloric acid
- D. practically CaCO₃ do not react with hydrochloric acid

_____ 5.1. Because _____

- A. Substances with big particle size move slower than those with small particle size, their reaction rate decreases.
- B. The powdered CaCO₃ has a greater surface area, thus rate of reaction increases.
- C. If the surface is small then the reaction will be faster, and if a large surface area, the reaction will be slower.
- D. As the size of a solid reactant decrease the surface area decrease, thus rate of reaction increases.

_____ 6. Consider the rate of the reaction of copper and magnesium with hydrochloric acid. Which metal reacts faster with hydrochloric acid?

- A. Copper (s) B. Magnesium (s) C. Silver

_____ 6.1. Because _____

- A. Reactions involving the breaking of stronger bonds proceed faster.
- B. Generally, alkaline earth metals are more active than transition metals.
- C. When the particle size of a solid reactant is decreased, its volume is decreased, and therefore rate of reaction increases.

C. Factors Affecting Rate of Reaction (CK3)

_____7. Assume that you stored some food in a fridge to prevent spoilage. What factor were you applying to slow the rate of reaction?

- A. Effect of temperature.
- B. Effect of catalyst
- C. Effect of concentration of a reactant.
- D. Effect of pressure

_____7.1. Because _____

- A. Reaction rate is independent of reactants' concentration.
- B. As temperature decreases the activation energy, it enables the reaction to decrease its rate.
- C. Decreasing in temperature causes decrease in frequency of collision, thus rate of reaction decreases.
- D. When temperature increases, rate of reaction decreases.

_____8. A student placed 3.0 g of Mg into some HCl in two different experiments. In each case, it reacted according the following equation: $\text{Mg}_{(s)} + 2\text{HCl}_{(aq)} \rightarrow \text{MgCl}_{2(aq)} + \text{H}_{2(g)}$

In the first experiment, it took 3.2 minutes for all of the Mg to react. In the second experiment, it took 5.4 minutes for all of the Mg to react. Which of the following could account for the change in rate of the second experiment?

- A. The magnesium was powdered.
- B. The temperature was decreased.
- C. the Magnesium was marble chips
- D. temperature was increase

_____8.1. Because _____

- A. When temperature decreases, the frequency for collision decreases, thus the time required for the reaction increases.
- B. If a surface area is smaller, the reaction will be slower and the time required for the reaction increases.
- C. If the surface is small then the reaction will be faster, and the time required for the reaction increases.
- D. A change in temperature does not affect reaction rate.

_____9. A student has prepared 10M, 5M, 1M and 0.5M nitric acid solutions in four test tubes and he put 2cm long magnesium ribbon in each test tube; then he observed the fastest consumption of magnesium ribbon in the test tube that contains 10M solution. What does the fastest reaction rate indicate? _____

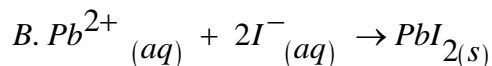
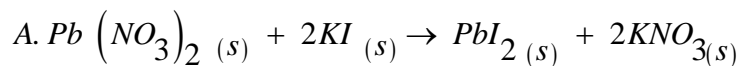
- A. Temperature dependence of the reaction

- B. Concentration dependence of the reaction
- C. Surface area dependence of the reaction

_____ **9.1.** Because _____

- A. When temperature of a substance increases, its kinetic energy decreases; thus, rate of reaction increases.
- B. While a reaction occurs, concentration of products increases in time; thus, reaction rate increases.
- C. When particle size of reactant is decreased, its volume is decreased and therefore rate of reaction increases.
- D. When concentration of a reactant increases, the number of collision between the reacting species per second increases, thus, rate of reaction increases.

_____ **10.** Consider that individual properties of substances or nature of reactants could affect the rate of a reaction. Which of these reactions react rapidly at room temperature?



_____ **10.1.** Because _____

- A. In solid reaction, the ionic bonding in each compound is weak, thus rate of reaction is fast.
- B. Generally, reactions involving ionic species tend to proceed faster than solids.
- C. The surface area in solid reaction is greater, thus the rate of the reaction is fast.
- D. Reactions between ions occur usually faster.

_____ **11.** Consider the following reaction. $2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$. Which factor explains why the above reaction speeds up in the presences of $MnO_2(s)$?

- A. Nature of reactant
- B. Presence of catalyst
- C. Change in concentration

_____ **11.1.** Because _____

- A. When solid substance added to aqueous solution, increases the concentration, thus the rate of reaction increases.

- B. Reaction involving solid tends to faster than aqueous solution.
- C. A catalyst provides an alternative pathway to reaction mechanism, thus the rate of reaction increases.
- D. Catalysts accelerate the reaction rate and ease of collision.

D. Rate Laws and order of Reaction (CK4)

_____ 12. Which of the following observations is incorrect about the order of a reaction?

- A. Order of a reaction is always a whole number
- B. The stoichiometric coefficient of the reactants doesn't affect the order
- C. Order of reaction is the sum of power to express the rate of reaction to the concentration terms of the reactants.
- D. Order can only be assessed experimentally

_____ 12.1. Because:

- A. The stoichiometric coefficients can affect the order of the reaction for first order
- B. The order of the reaction is a whole number, fraction and determine experimentally.
- C. Order of the reaction is the product of the power in the rate equation

_____ 13. In the reaction $2A + B \rightarrow A_2B$, if the concentration of A is doubled and that of B is halved, then the rate of the reaction will

- A. increase 2 times
- B. increase 4 times
- C. decrease 2 times
- D. remain the same

_____ 13.1. Because:

- A. The reaction is first order in A and B
- B. The reaction is second order in A and half order in B
- C. The reaction is second order in A and first order in B

_____ 14. The first order rate law is given by

- A. $k_1 = \frac{2.303}{t} \log \frac{x}{a-x}$
- B. $k_1 = \frac{2.303}{t} \log \frac{a}{a-x}$

$$C. k_1 = \frac{t}{2.303} \log \frac{a}{a-x}$$

$$D. k_1 = \frac{t}{2.303} \log \frac{x}{a-x}$$

_____ **14.1.** Because

- A. As concentration of reactant double, the rate also doubled
- B. As concentration of reactant increased by three fold, the rate decreased by one-third
- C. the rate doesn't affect by concentration changes

_____ **15.** The half-life of a substance in second order reaction is 10 minutes. What is the value of rate constant when the initial concentration is 0.25M?

- A. 0.40 Lmol⁻¹min⁻¹
- B. 0.025 Lmol⁻¹min⁻¹
- C. 40 mol L⁻¹min
- D. 25 mol L⁻¹min

_____ **15. 1.** Because:

- A. Rate is independent of concentration
- B. Rate is directly proportional to the concentration
- C. Rate is inversely proportional to the concentration

_____ **16.** A substance 'A' decomposes by a first-order reaction starting initially with [A] = 2.00M and after 200min, [A] becomes 0.15M. For this reaction t_{1/2} is

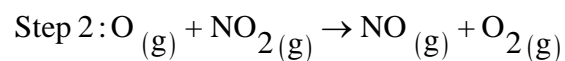
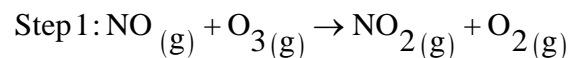
- A. 53.51 min
- B. 50.49 min
- C. 48.45 min
- D. 46.45 min

_____ **16.1.** This is because:

- A. half-life of first order is independent on concentration
- B. Half-life first order increases with increase in concentration

E. Reaction Mechanism (CK5)

_____ **17.** Consider the following reaction mechanism:



The species NO is a _____

- A. Catalyst

- B. Reaction intermediate
- C. Limiting reactant
- D. Excess reactant

_____ **17.1.** Because _____

- A. Catalyst is a substance which is formed and then consumed during a reaction.
- B. The substance which participates in a reaction and gets out as the same substance is an intermediate substance.
- C. A catalyst is a substance which accelerates the rate of a reaction and may be recovered unchanged at the end of the reaction.
- D. Catalyst is an intermediate substance which participates in a reaction as a reactant but gets out without affecting the reaction.

_____ **18.** The reaction $A + B + C \rightarrow \text{Product}$ is

- A. Unimolecular
- B. Trimolecular
- C. Bimolecular
- D. Tetramolecular

_____ **18.1.** Because

- A. molecularity depends on the stoichiometric coefficient of the reacting species
- B. molecularity of the reaction was determined experimentally

_____ **19.** What happens when molecules collides with less than activation energy needed for the reaction

- A. they reacts if bonds are arranged in a correct orientation
- B. they do not react, they simply bounce of each other
- C. they stick together but do not react
- D. they react, but more slowly

_____ **19.1.** This is due to

- A. There was no proper orientation between reacting species
- B. The reacting species very fast to be collide to one another

PART TWO: CHEMICAL EQUILIBRIUM CONCEPTUAL TEST (CECT)

Category A. Basic concepts of chemical equilibrium

_____20. Carbon monoxide and hydrogen react according to the following equation.
 $\text{CO}_{(g)} + 3\text{H}_{2(g)} \rightleftharpoons \text{CH}_{4(g)} + \text{H}_2\text{O}_{(g)}$ When 0.02 M CO and 0.03 M H₂ are introduced into a

vessel at 800 K and allowed to come to equilibrium, what can we say about the rate of reverse and forward reactions at equilibrium?

- A. the rates are equal
- B. Forward reaction rate is greater than the reverse one
- C. Reverse reaction rate is greater than the forward one

_____20.1. *Because:*

- A. Forward reaction goes to completion before the reverse reaction starts
- B. The rates of the forward and reverse reactions are equal when the system reaches equilibrium
- C. As time passes, the concentrations of products increase
- D. At equilibrium, the concentrations of the reactants and products are equal

Category B: Equilibrium expression and equilibrium constant (CE2)

_____21. An equilibrium that strongly favors product has _____

- A. $K \gg 1$
- B. $K \ll 1$
- C. $Q \gg 1$
- D. $K = Q$

_____21.1. *Because*

- A. As equilibrium constant much larger at constant temperature, the product are favored
- B. As equilibrium constant much larger at constant temperature, the reactants are favored
- C. As equilibrium constant much larger at constant temperature, the product and reactants are equal

_____22. The equilibrium between sulphur dioxide gas, oxygen gas and sulphur trioxide gas is as follows: $2\text{SO}_{2(g)} + \text{O}_{2(g)} \rightleftharpoons 2\text{SO}_{3(g)}$. If the reaction starts with the concentration of 0.02 M

SO₂, 0.01 M O₂ and 0.00 M SO₃, and reaches equilibrium at a constant temperature. What can we say about the equilibrium concentrations of SO₂ gas and O₂ gas?

- A. Decrease
- B. Become zero
- C. Remain unchanged

_____22.1. *Because:*

- A. Equilibrium reactions go on until all of the reactants run out

- B. Concentrations are constant because no reaction occurs at equilibrium
- C. As time passes, SO_2 and O_2 reactants are consumed, decreasing their concentrations
- D. This system does not reach equilibrium because there is no SO_3 at the beginning

_____ **23.** For the equilibrium $A + 2B \rightleftharpoons 2C$, the value of equilibrium constant, K is 10. What is the value of equilibrium constant for the reaction written in reverse: $2C \rightleftharpoons A + 2B$, $K'=?$

- A. 0.10 B. 10 C. 1.00 D. 100

_____ **23.1.** Because

- A. the equilibrium constant for the second reaction is the same as the first
- B. the equilibrium constant for the second reaction is greater than the first
- C. the equilibrium constant for the second reaction is $1/k$ of the first reaction

_____ **24.** In the ICE table started for calculating equilibrium concentrations of the reaction shown, the three terms in the change row are _____



	$[\text{M}^{2+}]$	$[\text{L}]$	$[\text{ML}_2^+]$
I	0.20M	0.40M	0.0M
C	_____	_____	_____
E	_____	_____	_____

- | | |
|-----------------|------------------|
| A. $-x, -x, +x$ | C. $-x, -2x, +x$ |
| B. $+x, +x, -x$ | D. $+x, +2x, -x$ |

_____ **24.1.** This described by

- A. The concentration of the reactants were decreased by x and $2x$ and the concentration of Product increased by x
- B. The concentration of the reactants were increased by x and $2x$ and the concentration of product decreased by x

Category C: Factors Affecting Chemical equilibrium

_____ **25.** Limestone decomposes to form quicklime and carbon dioxide as follow:
 $\text{CaCO}_3(\text{s}) \rightleftharpoons \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$. What can we say about any equilibrium shift after removing some solid CaCO_3 from the equilibrium mixture?

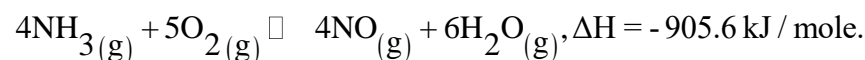
- A. Shift to the reactants' side

- B. Will not shift the equilibrium
- C. Will not be predictable

_____ **25.1. Because:**

- A. The amount of CaCO_3 is increased in the system and a new equilibrium is established
- B. Because CaCO_3 is solid, removing it does not affect the equilibrium
- C. CO_2 and CaO react to form more CaCO_3 according to Le Chatelier's principle
- D. The amount of solid CaCO_3 removed is not known

_____ **26.** In the first step of the Ostwald process for the synthesis of nitric acid, ammonia is oxidized to nitric oxide by the reaction:



How does the equilibrium constant vary with an increase in temperature?

- A. Increases
- B. Decreases
- C. Remains the same

_____ **26.1. Because:**

- A. An increase in temperature always increases the numerical value of K_{eq}
- B. Because the reaction is exothermic, the concentration of product increases
- C. The equilibrium will shift to the left with an increase in temperature
- D. Whether the reaction is endothermic or exothermic does not affect the K_{eq}

_____ **27.** Calcium carbonate decomposes to form calcium oxide and carbon dioxide according to the equation: $\text{CaCO}_3(\text{s}) + \text{heat} \rightleftharpoons \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$. After the system reaches equilibrium in a closed container, extra solid CaCO_3 is added to the equilibrium mixture. What will happen to the concentration of carbon dioxide after addition?

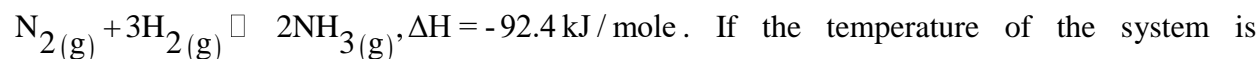
- A. Increases
- B. Decreases
- C. Remains unchanged

_____ **27.1. Because:**

- A. Increasing the amount of $\text{CaCO}_3(\text{s})$ that is at equilibrium causes more dissolved ions to be produced.

- B. Because $\text{CaCO}_3(s)$ is added to the reactants' side, equilibrium will shift the products' side
- C. Because $\text{CaCO}_3(s)$ is added to reactants' side, equilibrium will shift the reactants' side
- D. The concentrations of pure solids, that is, the quantities in a given volume or densities, are constant

_____ **28.** Consider the following reversible reaction that is in a state of equilibrium.



If the temperature of the system is increased, the equilibrium position will

- A. Shift to the left
- B. Shift to the right
- C. Remain unchanged

_____ **28.1. Because:**

- A. When the temperature is increased, more products form
- B. If the temperature is increased, more reactants are formed
- C. When the temperature is changed, whether the reaction is endothermic or exothermic does not affect the direction of the equilibrium shift
- D. Temperature changes do not affect the system that is at equilibrium.

Category D: Le Chatlier Principle

_____ **29.** In what manner will increase of pressure affect the following equation:



- A. Shift in the reverse direction
- B. Shift in the forward direction
- C. Increase in the yield of H_2
- D. No effect

_____ **29.1. Because:**

- A. Increase pressure shift causes to increase in the direction of higher moles of gases
- B. Increase pressure shift the equilibrium in the direction of smaller moles of gases
- C. change of pressure no change on the equilibrium

_____ **30.** Which of the following occurs when reactants are removed from a chemical reaction in solution or gas phase at equilibrium?

- A. Q increases, so the equilibrium shift to produce more products
- B. Q increases, so the equilibrium shift to produce more reactants
- C. Q Decreases, so the equilibrium shifts to produce more products
- D. Q Decreases, so the equilibrium shifts to produce more reactants

_____ **30.1.** This because:

- A. the value of Q increases and more products are formed
- B. The value of Q increases and more reactants are formed

Thank you very much!

Appendix B: Chemical Kinetics and Equilibrium Achievement Test

Addis Ababa University College of Education and Behavioral Studies
Department of Science and Mathematics Education Chemistry Education
PhD Program

Name _____ Roll NO _____ School _____ sex _____ **1:30 Hrs**

Dear students:

This exam has used to study *Topic Specific Pedagogical Content Knowledge-Based Instruction and Grade 11 students' Chemistry Learning*. The exam has a multiple-choice item with concept based for achievement test. The result you scored have used only for the purpose of this dissertation only and any form of information you gave me kept confidentially.

Thank You in advance for giving the responses you have in your mind.

Instruction: Choose the best answer from the given alternatives and write your answer on the space provided. Each question has only one correct answers for academic achievement. Each item has one mark.

PART ONE: CONCEPT OF CHEMICAL KINETICS TOOLS

A. Basic concepts and Rate of chemical reaction (CK1)

_____ 1. The rate constant of zero-order reactions has the unit

A. s^{-1}

C. $L^2 \text{ mol}^{-2} s^{-1}$

B. $\text{mol L}^{-1} s^{-1}$

D. $L \text{ mol}^{-1} s^{-1}$

_____ 2. Consider the following reaction: $N_{2(g)} + 3H_{2(g)} \rightarrow 2NH_{3(g)}$. The rate of formation of NH_3 is $9.0 \times 10^{-4} \text{ M/s}$, the rate of consumption of N_2 is _____

A. $4.5 \times 10^{-4} \text{ M/s}$

B. $9.0 \times 10^{-4} \text{ M/s}$

C. $1.4 \times 10^{-3} \text{ M/s}$

_____ 3. Consider the reaction of magnesium ribbons and Sulphuric acid.

$\text{Mg (s)} + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{MgSO}_4(\text{aq}) + \text{H}_2(\text{g})$. The volume of H_2 (g) measured from the initial

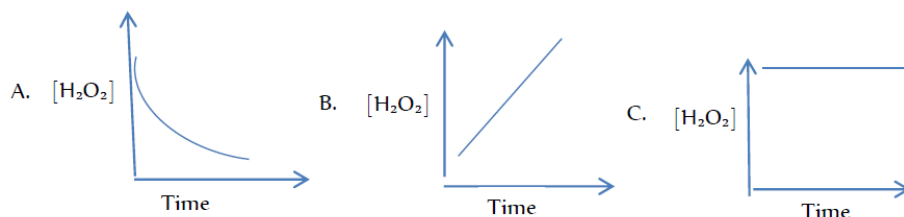
to 5.00 cm^3 is shown below. What is the average rate of H_2 (g) production?

A. $0.17 \text{ cm}^3/\text{s}$ B. $0.25 \text{ cm}^3/\text{s}$ C. $0.50 \text{ cm}^3/\text{s}$

Volume (cm^3) of H_2 (g)	1.00	2.00	3.00	4.00	5.00
Time (s)	4.00	6.00	9.00	14.00	20.00

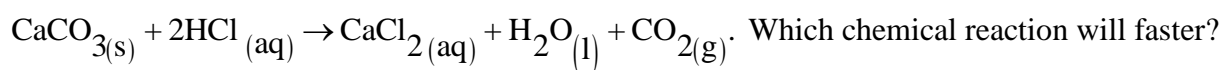
_____ 4. Consider the following reaction $2\text{H}_2\text{O}_2(l) \rightarrow 2\text{H}_2\text{O}(l) + \text{O}_2(g)$

Which graph shows the relationship between rate of consumption of H_2O_2 and time?



B. Theories of Rate of Reaction (CK2)

_____ 5. Consider the rate of a chemical reaction using the same masses of marble and Powdered CaCO_3 with similar amount of hydrochloric acid.



- A. The reaction between marble CaCO_3 and hydrochloric acid
- B. The reaction between powdered CaCO_3 and hydrochloric acid
- C. Both marble and powdered CaCO_3 react in equal time with hydrochloric acid
- D. practically CaCO_3 do not react with hydrochloric acid

_____ 6. Consider the rate of the reaction of copper and magnesium with hydrochloric acid.

Which metal reacts faster with hydrochloric acid?

- A. Copper (s)
- B. Magnesium (s)
- C. Silver

C. Factors Affecting Rate of Reaction (CK3)

_____ 7. Assume that you stored some food in a fridge to prevent spoilage. What factor were you applying to slow the rate of reaction?

- A. Effect of temperature.
- B. Effect of catalyst
- C. Effect of concentration of a reactant.
- D. Effect of pressure

_____8. A student placed 3.0 g of Mg into some HCl in two different experiments. In each case, it reacted according the following equation: $\text{Mg}_{(s)} + 2\text{HCl}_{(aq)} \rightarrow \text{MgCl}_{2(aq)} + \text{H}_{2(g)}$

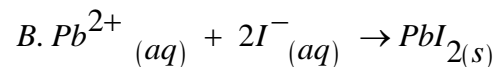
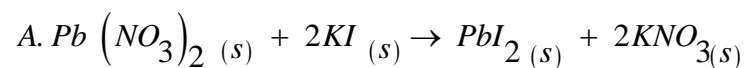
In the first experiment, it took 3.2 minutes for all of the Mg to react. In the second experiment, it took 5.4 minutes for all of the Mg to react. Which of the following could account for the change in rate of the second experiment?

- A. The magnesium was powdered. C. the Magnesium was marble chips
B. The temperature was decreased. D. temperature was increase

_____9. A student has prepared 10M, 5M, 1M and 0.5M nitric acid solutions in four test tubes and he put 2cm long magnesium ribbon in each test tube; then he observed the fastest consumption of magnesium ribbon in the test tube that contains 10M solution. What does the fastest reaction rate indicate? _____

- A. Temperature dependence of the reaction
B. Concentration dependence of the reaction
C. Surface area dependence of the reaction

_____10. Consider that individual properties of substances or nature of reactants could affect the rate of a reaction. Which of these reactions react rapidly at room temperature?



_____11. Consider the following reaction. $2\text{H}_2\text{O}_2(aq) \rightarrow 2\text{H}_2\text{O}(l) + \text{O}_2(g)$. Which factor explains why the above reaction speeds up in the presences of $\text{MnO}_2(s)$?

- A. Nature of reactant B. Presence of catalyst C. Change in concentration

D. Rate Laws and order of Reaction (CK4)

_____12. Which of the following observations is incorrect about the order of a reaction?

- A. Order of a reaction is always a whole number
B. The stoichiometric coefficient of the reactants doesn't affect the order
C. Order of reaction is the sum of power to express the rate of reaction to the concentration terms of the reactants.
D. Order can only be assessed experimentally

_____ **13.** In the reaction $2A + B \rightarrow A_2B$, if the concentration of A is doubled and that of B is halved, then the rate of the reaction will

- A. increase 2 times
B. increase 4 times
C. decrease 2 times
D. remain the same

_____ **14.** The first order rate law is given by

- A. $k_1 = \frac{2.303}{t} \log \frac{x}{a-x}$
B. $k_1 = \frac{2.303}{t} \log \frac{a}{a-x}$
C. $k_1 = \frac{t}{2.303} \log \frac{a}{a-x}$
D. $k_1 = \frac{t}{2.303} \log \frac{x}{a-x}$

_____ **15.** The half-life of a substance in second order reaction is 10 minutes. What is the value of rate constant when the initial concentration is 0.25M?

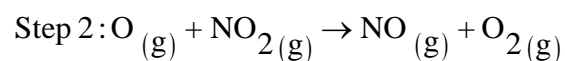
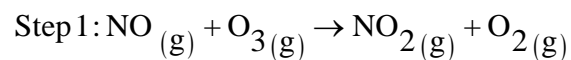
- A. $0.40 \text{ Lmol}^{-1}\text{min}^{-1}$
B. $0.025 \text{ Lmol}^{-1}\text{min}^{-1}$
C. $40 \text{ mol L}^{-1}\text{min}$
D. $25 \text{ mol L}^{-1}\text{min}$

_____ **16.** A substance 'A' decomposes by a first-order reaction starting initially with $[A] = 2.00\text{M}$ and after 200min, $[A]$ becomes 0.15M. For this reaction $t_{1/2}$ is

- A. 53.51 min
B. 50.49 min
C. 48.45 min
D. 46.45 min

E. Reaction Mechanism (CK5)

_____ **17.** Consider the following reaction mechanism:



The species NO is a _____

- A. Catalyst B. Reaction intermediate C. Limiting reactant D. Excess reactant

_____ **18.** The reaction $A + B + C \rightarrow \text{Product}$ is

- A. Unimolecular
B. Trimolecular
C. Bimolecular
D. Tetramolecular

_____19. What happens when molecules collide with less than activation energy needed for the reaction

- A. they react if bonds are arranged in a correct orientation
- B. they do not react, they simply bounce off each other
- C. they stick together but do not react
- D. they react, but more slowly

PART TWO: CHEMICAL EQUILIBRIUM CONCEPTUAL TEST (CECT)

Category A. Basic concepts of chemical equilibrium

_____20. Carbon monoxide and hydrogen react according to the following equation.
 $\text{CO}_{(g)} + 3\text{H}_{2(g)} \rightleftharpoons \text{CH}_{4(g)} + \text{H}_2\text{O}_{(g)}$ When 0.02 M CO and 0.03 M H₂ are introduced into a vessel at 800 K and allowed to come to equilibrium, what can we say about the rate of reverse and forward reactions at equilibrium?

- A. the rates are equal
- B. Forward reaction rate is greater than the reverse one
- C. Reverse reaction rate is greater than the forward one

Category B: Equilibrium expression and equilibrium constant (CE2)

_____21. An equilibrium that strongly favors product has _____

- A. $K \gg 1$
- B. $K \ll 1$
- C. $Q \gg 1$
- D. $K = Q$

_____22. The equilibrium between sulphur dioxide gas, oxygen gas and sulphur trioxide gas is as follows: $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g})$. If the reaction starts with the concentration of 0.02 M SO_2 , 0.01 M O_2 and 0.00 M SO_3 , and reaches equilibrium at a constant temperature. What can we say about the equilibrium concentrations of SO_2 gas and O_2 gas?

- A. Decrease B. Become zero C. Remain unchanged

_____23. For the equilibrium $A + 2B \rightleftharpoons 2C$, the value of equilibrium constant, K is 10. What is the value of equilibrium constant for the reaction written in reverse: $2C \rightleftharpoons A + 2B$, $K'=?$

- A. 0.10 B. 10 C. 1.00 D. 100

_____24. In the ICE table started for calculating equilibrium concentrations of the reaction shown, the three terms in the change row are _____



	$[\text{M}^{2+}]$	$[\text{L}]$	$[\text{ML}_2^+]$
I	0.20M	0.40M	0.0M
C	_____	_____	_____
E	_____	_____	_____

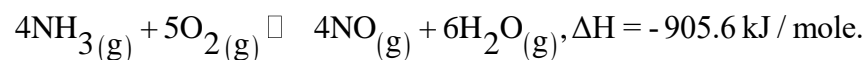
- A. -x, -x, +x
 B. +x, +x, -x
 C. -x, -2x, +x
 D. +x, +2x, -x

Category C: Factors Affecting Chemical equilibrium

_____25. Limestone decomposes to form quicklime and carbon dioxide as follow: $\text{CaCO}_3(\text{s}) \rightleftharpoons \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$. What can we say about any equilibrium shift after removing some solid CaCO_3 from the equilibrium mixture?

- A. Shift to the reactants' side
 B. Will not shift the equilibrium
 C. Will not be predictable

_____26. In the first step of the Ostwald process for the synthesis of nitric acid, ammonia is oxidized to nitric oxide by the reaction:



How does the equilibrium constant vary with an increase in temperature?

- A. Increases B. Decreases C. Remains the same

_____27. Calcium carbonate decomposes to form calcium oxide and carbon dioxide according to the equation: $\text{CaCO}_3(\text{s}) + \text{heat} \rightleftharpoons \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$. After the system reaches equilibrium in a closed container, extra solid CaCO_3 is added to the equilibrium mixture.

What will happen to the concentration of carbon dioxide after addition?

- A. Increases B. Decreases C. Remains unchanged

_____28. Consider the following reversible reaction that is in a state of equilibrium.

$\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g})$, $\Delta H = -92.4 \text{ kJ/mole}$. If the temperature of the system is increased, the equilibrium position will

- A. Shift to the left B. Shift to the right C. Remain unchanged

Category D: Le Chatlier Principle

_____29. In what manner will increase of pressure affect the following equation:



- A. Shift in the reverse direction C. Increase in the yield of H_2
B. Shift in the forward direction D. No effect

_____30. Which of the following occurs when reactants are removed from a chemical reaction in solution or gas phase at equilibrium?

- A. Q increases, so the equilibrium shift to produce more products
B. Q increases, so the equilibrium shift to produce more reactants
C. Q Decreases, so the equilibrium shifts to produce more products
D. Q Decreases, so the equilibrium shifts to produce more reactants

Thank you very much!

አዲስ አበባ ዩኒቨርሲቲ የትምህርትና ስነ-ባህሪ ኮሌጅ

በሳይንስና ሒሳብ ትምህርት ክፍል የኬሚስትሪ ትምህርት ፒ.ኤች ዲ ፕሮግራም

በተማሪዎች የሚሞላ ቅፅ

ወድ ተሟዎች: ቀጥሎ የቀረበው ማጠቃለያ ተሟዎች ኬሚስትሪ የመመዘኛ ተነሳሽነት ታቸውን ለማጥናት የቀረቡ ናቸው። የዚህ ማጠቃለያ ዋና ዓላማ ተሟዎች ኬሚስትሪን በመመዘኛ ላይ ያላቸውን ተነሳሽነት በአዲስ አበባ ዩኒቨርሲቲ የሳይንስ እና ሒሳብ ትምህርት ክፍል ለ3ኛ ዲግሪ (PhD) ጥናት ማግኘት የሚጠይቁ ነው። የዚህ ጥናት ዓላማ ከግብረሰብ ለመድረስ ወድ ተሟዎች ያሏቸውን ሃሳቦች የሚጠብቀው ጥያቄዎች ከታች ተቀምጠዋል። ስለሆነም ወድ ተሟዎች ለማጠቃለያ የምትሰጡት ሃሳብ የጥናቱን ዓላማ እንዲሳካ ለመድረግ ዓይነት ተገዳሪ እንዳለው ይታመናል። ስለዚህ እያንዳንዱን ማጠቃለያ በሚገባ በማንበብ እና በሚረዳት ተገቢውን ወድ ተሟዎችን ምላሽ በማስጠቀም እንድትተባበሩን በታላቅ አክብሮት እንጠይቃለን። ወድ ተሟዎች በዚህ ጥናት ተሳታፊ ለመሆን የእናንተን በጎ ፈቃድ እና ፍላጎት ብቻ የሚፈልግ እንደሆነ ለጥናቱ ሲባል የምትሰጡት ሃሳቦች እና ምላሾች ማሉ በማሉ በሚገባ ጥር የሚያደርጉ እና የሚጠበቁና በምንም ሁኔታ ከሌላ አላማ የሚወጡ ማህተን ማረጋገጥ እንደሚገባ ጥላይታለሁ።

ለትብብራችሁ በቅድሚያ በጣም አመክኛለሁ። :

ክፍል 1: የተሳታፊዎች መግለጫ

መላያ: _____ **የት/ቤት ስም** _____

ፆታ _____ **እድሜ** _____

ክፍል 2: ተሟዎች ኬሚስትሪን በመመዘኛ ላይ ያላቸው ተነሳሽነትን በተመለከተ

ተሟዎች በዚህ የትምህርት ደረጃ ኬሚስትሪን በመመዘኛ ላይ ያላቸው ተነሳሽነት ለመዳሰስ የሚያስችሉ በሊከርት ስኬል ማለት ጥያቄዎች ቀርበዋል። ስኬሎቹም 1= በጣም አልስማማም ፤ 2= አልስማማም ፤ 3= ደረጃ ማስጠንቀቂያ አልችልም ፤ 4= እስማማለሁ ፤ 5= በጣም እስማማለሁ የሚሉ ናቸው። ስለሆነም ለእያንዳንዱ ሃሳብ ይመጥናል ብላችሁ የምታስቡትን ደረጃ ከማጠቃለያ ስር በተደረገው ሰንጠረዥ ውስጥ $\sqrt{\text{ምልክት አስቀምጡ}}$ ።

ወድ ተሟዎች በማጠቃለያ ውስጥ ኬሚስትሪ የሚለው ቃል በአንግሊዘኛው የ **chemical kinetics and equilibrium** ይዘቶችን ታሳቢ እንድታደርጉልን ለማሳሰብ እፈልጋለሁ። :

	የተነሻነት ክፍሎች/ማለጫዎች	በ. አል	አል	ደ.ማስ. አል	እስ	በ.እስ	
I	ውስጣዊ ተነሻነት (Intrinsic motivation)	1	2	3	4	5	
1	ኬሚስትሪ ምርመራ አስደሳች ነው።						
2	ኬሚስትሪን ምርመራ ያስደስተኛል።						
3	የምርመራ ውክሚስትሪ ትምህርት ከህይወቴ ጋር ተዛማጅነት አለው።						
4	በኬሚስትሪ ላይ ስለ ግኝቶች ማወቅ ፍላጎት አለኝ።						
5	ኬሚስትሪን ምርመራ ሕይወቴን የበለጠ ትርጉም ያለው ያደርገዋል						
II	ራስን ማቻል (Self-Efficacy)						
6	በአጠቃላይ ኬሚስትሪ ትምህርት ከፍተኛ ወጠኔ እንዳማኝ አምናለሁ።						
7	በእርግጠኝነት ኬሚስትሪን በደንብ ሚዳት እችላለሁ።						
8	የኬሚስትሪ ለብራቶሪዎችን ጥሩ እንደምሰራ እርግጠኛ ነኝ።						
9	በኬሚስትሪ ትምህርት እወቀትንና ክህሎትን ማዳበር እንደምችል አምናለሁ።						
10	በኬሚስትሪ ፈተናዎች ጥሩ እንደምሰራ እርግጠኛ ነኝ።						
II	ራስን መወሰን (Self-Determination)						
I							
11	ኬሚስትሪ ለምርመራ በቂ ጥረት አድርጌያለሁ።						
12	ኬሚስትሪን በደንብ ለምርመራ ስልቶችን እጠቀማለሁ።						
13	ኬሚስትሪ በምርመራ ብዙ ጊዜ አሳልፋለሁ።						
14	ኬሚስትሪ ለምርመራ ጠንክራ አጠናቃለሁ።						
15	ለኬሚስትሪ ፈተናዎች እና ለብራቶሪዎች በደንብ እዘጋጃለሁ።						
IV	የወጠኔ ተነሻነት (Mark motivation)						
16	በኬሚስትሪ ትምህርት ከፍተኛ ነጥብ ማግኘት አስፈላጊ ነው።						
17	በኬሚስትሪ ትምህርት ጥሩ ወጠኔ ማግኘት ለእኔ						

	አስፈላጊ ነው።						
18	በኬሚስትሪ ፈተናዎች እና በላብራቶሪዎች ላይ ከፍተኛ ነጥብ ማስመዘን ብለእኔ አስፈላጊ ነው።						
19	በኬሚስትሪ ፈተናዎች ላይ ከሌሎች ተማሪዎች የተሻለ ማስራት እፈልጋለሁ።						
20	በኬሚስትሪ ትምህርት ውስጥ ስለማንኛው ወጠክት ሁሉ አስባለሁ።						
V	የሙያ ተነሳሽነት (Career Motivation)						
21	የኬሚስትሪ ትምህርት ለመረጥ ጥሩ ስራ እንዳገኝ ይረዳኛል።						
22	የኬሚስትሪ እውቀትን ማወቅ ለወደፊት የስራ እድል ይፈጥራል።						
23	ኬሚስትሪን በደንብ መረዳቴ ለሙያዬ ይጠቅመኛል።						
24	የወደፊት ሙያዬ በኬሚስትሪ ትምህርት ላይ ይወሰናል።						
25	የኬሚስትሪ ትምህርት ለመረጥ ለወደፊት አስደሳች ሥራ ይፈጥራል።						

ከ Glynn et al (2011) የተተረጎመ እና የተወሰደ

አ ማሳገጫ!!!!!!!

Appendix D: Chemistry motivational Questionnaires (English version)

Addis Ababa University College of Education and behavioral Studies

Department of Science and Mathematics Education

Chemistry Education PhD Program

Form filled out by students

Dear Students, The following question is for students to study their motivation to learn chemistry. The main purpose of this questionnaire is to investigate the motivation of grade 11 students in the Addis Ababa administrative city by using TSPCK-based instruction that used for a PhD dissertation purpose. Below is a list of questions that students have to offer to achieve this goal. Therefore, dear students, your comments to the questionnaire believed to play an important role in the success of the study. Therefore, we respectfully request that you assist us in reading and understanding each questionnaire in response to what you think is appropriate. Dear students, I would like to assure you that your participation in this study is only for your goodwill and that your comments and responses for the study kept confidential and not used for any other purpose.

Thank you in advance for your cooperation

Part 1 : Description of Participants

Code _____ School Name _____

Gender _____ Age _____

Part 2: About students' motivation for learning chemistry

Questions asked in the form of a Likert scale to help students explore their motivation for learning chemistry at this level. The scales are 1 = **Strongly Disagree**; 2 = **Disagree**; 3 = **undecided**; 4 = **Agree**; 5 = **strongly agree**. Therefore, place a "✓" or check box in the box below that you think is appropriate for each idea.

Dear students, I would like to remind you to consider the term chemistry as chemical kinetics and equilibrium in the questionnaire.

Table 1: Conceptual Factors Motivating Students to learn chemical kinetics and chemical equilibrium (Glynn, Brickman, Armstrong, & Taasobshirazi, 2011)

	Components/Statements	SD	D	N	A	SA	
I	Intrinsic Motivation	1	2	3	4	5	
1	Learning chemistry subject is interesting						
2	I enjoy learning chemistry subject						
3	Chemistry concepts I learn is relevant to my life						
4	I am interested about discoveries in Chemistry						
5	Learning chemistry makes my life more meaningful						
II	Self-Efficacy						
6	I believe I can earn a higher mark chemistry subjects						
7	I am sure I can understand chemistry concepts						
8	I am confident I will do well on chemistry labs						
9	I believe I can master chemistry knowledge and skills						
10	I am confident I will do well on chemistry tests						
III	Self-Determination						
11	I put enough effort into learning chemistry subject						
12	I use strategies to learn Chemistry concepts well						
13	I spend a lot of time learning chemistry concepts						
14	I study hard to learn chemistry concepts						
15	I prepare well Chemistry tests and labs						
IV	Mark Motivation						
16	It is important that I get an excellent mark in chemistry subjects						
17	Getting a very good mark in chemistry is important to me						
18	Scoring high on chemistry tests and labs matters to me						
19	I like to do better than other students on chemistry tests						
20	I think about the score I will get in chemistry subjects						
V	Career Motivation						
21	Learning chemistry subject will help me to get a good job						
22	Knowing chemistry knowledge will give me a career advantage						
23	Understanding chemistry will benefit me in my career						
24	My career will determine on chemistry subject						
25	Learning chemistry provide me an interesting career						

Adapted from Glynn et al (2011)

Thank you very much!

Appendix E: Semi-Structured protocol Questions

Interview questions for teachers and selected grade 11 students

Dear teachers and students, this interview questions were used for this study aimed on the effectiveness of TSPCK based instruction on teaching chemical kinetics and equilibrium concepts. Dear teachers and students, I would like to assure you that your participation in this study is only for your goodwill and that your comments and responses for the study kept confidential and not used for any other purpose.

Are you agree_____ Your interview audio and video recorded are you agree_____

Part 1: Back ground information of the participants teacher and students

A. Teachers

Code _____

Qualification:_____

Experiences:_____

Sex _____

B. students

Code:_____

School:_____

Sex: _____

Part 2 Interview questions

I. Semi-Structured Interview Questions for Chemical Kinetics Concepts

1. Rate of Reaction (11.6%)

Q1: Can you describe how the rate of a chemical reaction changes over time? How do you think it varies from the beginning to the end of a reaction?

Q2: Have you ever been confused about how the rate of reaction is measured at different points in time? If so, can you explain what confused you?

2. Rate of Reaction Theories (16.9%)

Q3: What do you understand by the concept of rate laws in chemical reactions? How does it relate to the reaction rate?

Q4: Can you explain what you know about the theories that describe why reaction rates change with concentration? What aspects of these theories are confusing to you?

3. Rate of Reaction Components (11.1%)

Q5: What factors do you think influence the rate of a chemical reaction? Can you explain how each factor affects the rate?

Q6: Have you had any difficulties understanding the roles of catalysts, temperature, or concentration in affecting reaction rates? Please describe these difficulties.

4. Rate Law and Order of Reaction (25.9%)

Q7: How do you determine the rate law for a given reaction? What do you find challenging about calculating or understanding the rate law?

Q8: Can you explain what the order of a reaction means and how it is determined? What misconceptions do you have about reaction orders?

5. Reaction Mechanism (17.6%)

Q9: What do you know about the concept of a reaction mechanism? How do you think it relates to the overall reaction rate?

Q10: Have you encountered any challenges in understanding how reaction mechanisms are proposed or how they affect the reaction rate? Please explain.

II. Semi-Structured Interview Questions on the Chemical equilibrium concepts

1. Basic Concept of Chemical Equilibrium (23.3%)

Q1: Can you describe what chemical equilibrium is and how it is achieved in a chemical reaction?

Q2: What do you find challenging about understanding the concept of chemical equilibrium?

2. Equilibrium Expression and Constants (16.03%)

Q3: How would you explain the equilibrium expression for a given reaction? What does it represent?

Q4: Can you describe what an equilibrium constant is and how it is used to describe the position of equilibrium?

3. Factors Affecting Chemical Equilibrium (13.2%)

Q5: What factors can affect the position of chemical equilibrium in a reaction? Can you explain how each factor influences equilibrium?

Q6: Have you had any difficulties understanding how changes in concentration, pressure, or temperature affect equilibrium?

4. Le Chatelier's Principle (25.9%)

Q7: What is Le Chatelier's Principle and how does it help in predicting the effect of changes on a system at equilibrium?

Q8: Can you provide an example of how Le Chatelier's Principle is applied to a chemical reaction? What aspects of this principle do you find confusing?

III. Semi-interview Questions on the Effectiveness of TSPCK-Based Instruction

1. How do you see the effectiveness of Curricular saliency based instruction (teaching based on big ideas, subordinate ideas and sequencing them) in enhancing students conceptual understanding, achievement and motivation?
2. How do you see the effectiveness of Representation based instruction (classifying chemical kinetics and equilibrium concepts into macro, micro and symbolic levels, using video lessons and using visual aids) in enhancing students conceptual understanding, achievement and motivation?
3. How do you see the effectiveness of conceptual teaching strategy based instruction (ed-puzzle instructional approach, interactive video lessons, and interactive simulations on the chemical kinetics and equilibrium concepts) in enhancing students conceptual understanding, achievement and motivation?

Appendix F: Chemistry classroom Observation protocol (CCOP)

Dear students! I will do this study to investigate students' conceptual understanding, motivation and achievement of chemical kinetics and chemical equilibrium concepts in relation to the dissertation entitled "**Topic Specific Pedagogical Content Knowledge-Based Instruction and Grade 11 students' Chemistry Learning**" the data obtained from this questionnaires used for academic purpose only. Your genuine response to each item has meaning for my study. Therefore, you kindly requested to respond to all questions based on the instruction given. Your cooperation and contribution toward this research is crucial and much appreciated. All information given kept confidentially.

Thank you for your cooperation

Groups: TSPCK based instruction (curricular saliency, **Representation, and conceptual teaching**) and conventional method

Part I : background information of the participants

Sex (put $\sqrt{\quad}$ mark) Male _____ female _____

School (put $\sqrt{\quad}$ mark) A _____ B _____ C. _____ D. _____

Given code _____

Part II; Motivation toward chemical kinetics and equilibrium (put $\sqrt{\quad}$ mark)

In order to understand what you think and how you feel or motivated about the instructional strategy used in your chemistry learning. Please respond to each of the following statement from the perspective "**when I am in learning chemical kinetics and equilibrium concepts**"

1: Strongly disagree

2: Disagree

3: Sometimes

4: Agree

5. Strongly Agree

RNO	Activities	Scores				
		1	2	3	4	5
1	Students engaged in exploration/investigation/problem solving.					
2	Students used a variety of means (models, drawings, graphs, concrete materials, manipulative, etc.) to represent concepts.					
3	Students engaged and motivate in chemistry activities.					
4	Students critically assessed by TSPCK based instruction					
5	Students persevered in problem solving of kinetics and equilibrium concepts					
6	The lesson involved fundamental concepts of the subject to promote relational/conceptual understanding.					
7	The lesson promoted TSPCK based teaching strategies with chemistry					
8	The lesson provided opportunities to examine chemical structure. (Symbolic notation, chemical formulas, equations, stoichiometry, etc.)					
9	The lesson included tasks that have multiple paths to a solution or multiple solutions in the CK and equilibrium					
10	The lesson promoted precision of chemistry language.(symbolic macro and sub-micro concepts)					
11	The teacher's talk motivated student thinking and conceptual understanding.					
12	There were a high proportion of students talking related to chemical kinetics and equilibrium concepts					
13	There was a climate of respect for what others had to say related to kinetics and equilibrium					
14	In general, the teacher provided wait-time					
15	Students were involved in the communication of their ideas to others (peer-to-peer).					
16	The teacher uses student questions/comments to enhance conceptual Understanding in chemistry					

Adopted from (Gleason J. , Livers, Zelkowski, Gleason, & Zelkowski, 2015) or (Gleason et al., 2015)

Appendix G: Rubrics of classroom observation in teaching by CSA-based, REPs-based, CTS-based instruction and conventional method

Roles	Item	Values			
		3	2	1	0
Student engagement	1	The majority of the students engaged in exploration, investigation, conceptual understanding.	The majority of the students engaged in exploration, investigation, conceptual understanding.	Students seldom engaged in exploration, investigation, conceptual understanding not actively participate	not engage in exploration, investigation, or conceptual understanding
	2	Student manipulate of generate two or more representations, connection b/n them and explicit discussion/n teacher and students on the its applicability	Student manipulate of generate two or more representations, connection b/n them not explicit discuss b/n teacher and students on the its applicability	Student manipulate of generate representation	No manipulation of representation in the concept
	3	2/3 of the student engage in chemistry activities and interacting with the lessons	More than ¼ and less than 2/3 of the student engage in chemistry activities and less interacting with the lessons	Less than ¼ students engage in chemistry activities less interacting with the lessons	None of the students engage in chemistry activities no interaction on the lessons
	4	More than half of the students conceptually assess TSPCK based instructions, involve in individual, group and direct teacher instruction	less than half of the students conceptually assess TSPCK based instructions, involve in individual, group and direct teacher instruction	An individual student conceptually assessed TSPCK strategy individual student direct teacher instruction	None of the student conceptually assessed TSPCK strategy strategies, no strategies of TSPCK were used during the lesson
	5	The majority of students looked for entry points and solution paths, monitored and evaluated progress, and changed course if necessary. When confronted with an obstacle (such as how to begin or what to do next), physical tools as well as mental reasoning	Some of students looked for entry points and solution paths, monitored and evaluated progress, and changed course if necessary. When confronted with an obstacle (such as how to begin or what to do next), half of them use physical tools as well as mental reasoning	One student looked for entry points and solution paths, monitored and evaluated progress, and changed course if necessary. When confronted with an obstacle (such as how to begin or what to do next), at least one use but less than half physical tools as well as mental reasoning	None of the student looked for entry points and solution paths, monitored and evaluated progress, and changed course if necessary. When confronted with an obstacle (such as how to begin or what to do next), none of the student use physical tools as well as mental reasoning
	12	¾ of the student talk about chemistry related chemistry of the lesson at a some point during the lesson	More than 1/2 less than ¾ of the student talk about chemistry related chemistry of the lesson at a some point during the lesson	less than 1/2 of the student talk about chemistry related chemistry of the lesson at a some point during the lesson	No students talked related to the mathematics of the lesson
	13	Many students are sharing, questioning, and commenting during the lesson, including their struggles. Students are also listening (active), clarifying, and recognizing the ideas of others.	Some students are sharing, questioning, and commenting during the lesson, including their struggles. Most students listen.	Only a few share as called on by the teacher. Some students are sharing, questioning, or commenting during the lesson, but most students are actively listening to the communication	No students shared ideas
	14	The teacher frequently provided an ample amount of “think time” for the depth and complexity of a task or question posed by either the teacher or a student.	The teacher sometimes provided an ample amount of “think time” for the depth and complexity of a task or question	The teacher rarely provided an ample amount of “think time” for the depth and complexity of a task or question posed by either the teacher or a student.	The teacher never provided an ample amount of “think time” for the depth and complexity of a task or question posed by either

			posed by either the teacher or a student.		the teacher or a student
	15	Considerable time (more than half) was spent with peer to peer dialog (pairs, groups, whole class) related to the communication of ideas, strategies and solution	Some class time (less than half, but more than just a few minutes) was devoted to peer to peer (pairs, groups, whole class) conversations related to the mathematics.	The lesson was primarily teacher directed and little opportunities were available for peer to peer (pairs, groups, whole class) conversations. A few instances developed where this occurred during the lesson but only lasted less than 5 minutes.	No peer to peer (pairs, groups, whole class) conversations occurred during the lesson
Teacher facilitation	4	More than half of the students conceptually assess TSPCK based instructions, involve in individual, group and direct teacher instruction	less than half of the students conceptually assess TSPCK based instructions, involve in individual, group and direct teacher instruction	An individual student conceptually assessed TSPCK strategy strategies, individual student direct teacher instruction	None of the student conceptually assessed TSPCK strategy strategies, no strategies of TSPCK were used during the lesson
	6	The lesson includes fundamental concepts or critical areas of the course, as an objectives and the teacher/lesson uses these concepts to build relational/conceptual understanding of the students with a focus on the "why" behind any procedures included	The lesson includes fundamental concepts or critical areas of the course, as an objectives and the teacher/lesson misses to uses these concepts to build relational/conceptual understanding of the students with a focus on the "why" behind any procedures included	The lesson includes less fundamental concepts or, as an objectives and the teacher/lesson no several opportunities to build relational/conceptual understanding of the students with a focus on the "why" behind any procedures included	The lesson did not includes fundamental concepts or, as an objectives and the teacher/lesson no several opportunities to build relational/conceptual understanding of the students with a focus on the "why" behind any procedures included
	7	Modeling (using a chemistry model to describe a real-world situation	Modeling is a major component, but the modeling has been turned into a procedure	The teacher describes some type of mathematical model to describe real-world situations, but the students do not engage in activities related to using chemistry models	The lesson does not include any modeling with chemistry
	8	The students have a sufficient amount of time and opportunity to look for and make use of chemical structure or patterns.	Students are given some time to examine chemical structure, but are not allowed adequate time or are given too much scaffolding so that they cannot fully understand the generalization	Students are shown generalizations involving chemical structure, but have little opportunity to discover these generalizations themselves or adequate time to understand the generalization.	Students are given no opportunities to explore or understand the mathematical structure of a situation
	9	A lesson which includes several tasks throughout; or a single task that takes up a large portion of the lesson; with multiple solutions and/or multiple paths to a solution and which increases the cognitive level of the task for different students	Multiple solutions and/or multiple paths to a solution are a significant part of the lesson, but are not the primary focus, or are not explicitly encouraged; or more than one task has multiple solutions and/or multiple paths to a solution that are explicitly encouraged.	Multiple solutions and/or multiple paths minimally occur, and are not explicitly encouraged; or a single task has multiple solutions and/or multiple paths to a solution that are explicitly encouraged.	A lesson which focuses on a single procedure to solve certain types of problems and/or strongly discourages students from trying different techniques.
	10	The teacher and the student "attends to precision" in regards to communication during the lesson.	The teachers "attends to precision" in all communication during the lesson, but the students are not always	The teacher makes a few incorrect statements or is sloppy about chemistry language, but generally uses correct chemical terms.	The teacher makes repeated incorrect statements or incorrect names for Chemistry objects instead of their accepted

					chemical names.
11	The teacher's talk focused on high levels of chemistry thinking. Analysis, synthesis and evaluation	The teacher's talk focused on mid-levels of chemistry thinking: interpretation and application	Teacher talk consists of " lower order " knowledge based questions and responses: memory and translation		Any questions/ responses of the teacher related to chemistry ideas were rhetorical in that there was no expectation of a response from the students
13	Many students are sharing, questioning, and commenting during the lesson, Including their struggles. Students are also listening (active), clarifying, and Recognizing the ideas of others.	some students are sharing, questioning, and commenting during the lesson, including their struggles. Most students listen.	Only a few share as called on by the teacher. Some students are sharing, questioning, or commenting during the lesson, but most students are actively listening to the communication		No students shared ideas
16	The teacher frequently uses student questions/ comments to coach students, to facilitate conceptual understanding, and boost the conversation. The teacher sequences the student responses that will be displayed in an intentional order, And/or connects different students' responses to key mathematical ideas.	The teacher sometimes uses student questions/ comments to enhance conceptual understanding	The teacher rarely uses student questions/ comments to enhance conceptual chemistry understanding. The focus is more on procedural knowledge of the task verses conceptual knowledge of the content.		The teacher never uses student questions/ comments to enhance conceptual chemistry understanding

Appendix H: Letter of Permission for the Study

አዲስ አበባ ዩኒቨርሲቲ
ሥነ-ትምህርትና ባሕሪ ጥናት ኮሌጅ
የሳይንስና ሒሳብ ትምህርት ክፍል
አዲስ አበባ፣ ኢትዮጵያ



Addis Ababa University
College of Education and Behavioral Studies
Department of Science and Mathematics Education
Addis Ababa, Ethiopia

Date: February 16, 2022
Ref. No.: SMED/341/2022-14

To: _____
Addis Ababa

Subject:- Support

As part of the PhD studies, Mr. Kassahun Dejene has selected your Secondary School as one of his research sites. Accordingly, he will be taking a number of engagements such as data collection through various approaches. Hence, our Department would like your Secondary School to support him in executing his doctoral studies through the provisions.

We would like to thank in advance for the support rendered.

With regards,



Habtamu Wodaj (PhD)
Chairman, Department of Science and Mathematics Education

☎ 011 1 22 07 67

✉ 1176

Appendix I: Permissions confirmation Notification from Authors on research

Instruments

From: Kassahun Dejene [mailto:kasahundejene2018@gmail.com]

Sent: Saturday, 06 February 2021 1:10 PM

To: Elizabeth Mavhunga <Elizabeth.Mavhunga@wits.ac.za>

Subject: **Asking for tools for research work**

Hello Professor, how are you? I am from Ethiopia, I am a PhD candidate at Addis Ababa University at the department of mathematics and science education with the research area of topic specific PCK of Grade 11 students conceptual understanding, achievement and motivation at high school level in Addis Ababa administrative city. Can I use the TSPCK tools for chemical equilibrium and adapt it to chemical Kinetics?

What can you advise me on the topic areas?

Thanks

Kassahun Dejene from Addis Ababa University, Ethiopia

Dear Kassahun. It gives me pleasure to hear that you have interest in Topic Specific PCK, it is a powerful theoretical construct for developing teacher knowledge. Attached kindly find the tools on Chemical Equilibrium. Just note that they were designed with Secondary School in mind. If your grade 11 level students are teaching other levels, you may need to adjust the concepts for the lower level classes, in line with what is covered e.g. for high School.

I have also attached the rubric that we use to score the completed tools. Remember to have 2 other raters understanding how the tools work and they can be your independent raters for ensuring reliability.

I am attaching 1 or two articles that describes how the tools were used and scored. What is important is to keep in mind that you are not measuring the use of each TSPCK component, but how that particular component is used interactively with other components. It is the extent of interaction that reflects the quality of TSPCK. PCK is about interaction among components irrespective of the grain size of PCK used.

So yes, feel free to adjust to reflect the concepts of your topic. Our aim is that when pre-service teachers have learnt to work with the components of TSPCK as their framework they, develop a competence on how to transform content knowledge. This competence must be applied to each topic (new or old) to develop TSPCK in that topic.

Wish you well with your studies – and enjoy the journey.

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Appendix J: Student Consent Form

I hereby attest that the researcher gave the students adequate information regarding the purpose, methodology, advantages, and risks of the study. I am aware that the study will be turned into a research report in an anonymous manner. I understand that taking part in the study is completely voluntary and that I can stop at any moment without facing any consequences. I got a good opportunity to ask questions and said I was eager to do my own independent research.

Participant's name _____ Researcher's name _____

Signature _____ Signature _____

Date _____ Date _____

Appendix K: Teacher Consent Form Dear Teacher

I am writing to request your help with a PhD study that investigates the impact of topic-specific PCK-based instruction on grade 11 students' chemistry learning. The study has been divided into two sections: interviews and classroom observations. In the first, I videotape each action you take during class and supervise you for three 45-minute sessions as you teach and learn. In the second area, I would like to hear about your experiences with topic-specific PCK-based instruction in your classroom, as well as what you think about it. I hope you will agree to participate because your feedback is valuable and useful to the study. Your participation will be entirely private. Your name will not be published. Thank you for volunteering to participate in this research.

Teacher's name _____

Researcher's name _____

Signature _____

Signature _____

Date _____

Date _____

Appendix L: Daily Lesson plan for Topic Specific PCK based instruction

Name of school _____ Grade _____ Date _____

Teacher's Name _____

Topic of the unit _____

Topic of daily lesson: _____

Objectives of the unit topic:

1. _____
2. _____
3. _____

Objectives of daily lesson:

1. _____
2. _____
3. _____

Topic number	Lesson topics	Activities	Teachers role	Students role	Intervention	Assessment
1		Introduction				
		Presentation				
		Stabilization				
2		Introduction				
		Presentation				
		Stabilization				
		Connection				

Teacher's name _____

Department's coordinator name _____

Teacher's Signature _____

Signature _____

Date: _____

Date: _____

Vice principal Name _____

Signature _____

Date: _____

Appendix M: Testing Statistical Assumptions

Statistical analysis, whether employing parametric or nonparametric methods, is predicated on a set of assumptions specific to the data being analyzed. Parametric tests, known for their rigorous assumptions compared to their nonparametric counterparts, are often considered more conservative, as outlined by Pallant & Manual (2007). The rigorousness of these assumptions means that any deviation may lead to incorrect conclusions about the data, interpreting the statistical inferences drawn potentially invalid. Despite this, certain parametric methods are noted for their robustness, capable of producing reliable results even when specific assumptions are not strictly met.

Key assumptions underlying parametric tests include the normality of data distributions, random sampling, absence of outliers, homogeneity of variances, data independence, and linearity among variables. The assumption of normality is particularly critical, with the expectation that distributions should follow a normal curve. To verify normality as part of exploratory data analysis (EDA), researchers employ graphical methods such as Q-Q plots and Box plots, alongside statistical measures of skewness and kurtosis. Ensuring the normal distribution of the dependent variable across groups is fundamental for the validity of many statistical techniques, including analysis of variance, linear regression, and Pearson correlation.

In this study, the normality of data was assessed through both numerical and graphical methods, looking at skewness and kurtosis z-values within the -1.96 to 1.96 range, and Shapiro-Wilk test p-values above 0.05, as suggested by Mills (2003). The data's distribution was visually inspected using Q-Q plots and box plots confirming a rough adherence to normal distribution. The study utilized SPSS to analyze data from intervention groups and time points, categorized into four ordinal levels. It is crucial, regardless of data distribution, to assess skewness prior to selecting either a parametric or nonparametric test. In this study, one way ANOVA, twoway ANOVA, MANOVA and Multiple linear regressions were employed and their possible assumptions were checked as follows.

1. Sample and Independence of Observations

The principle of independence in statistical analysis is foundational, supporting the validity of inferential statistics. According to Pallant & Manual (2007), this assumption suggests that each observation or data point in a sample must be independent that is, the measurement of

one subject should not influence, nor be influenced by, the measurements of any other subjects. This criterion of independence ensures that the outcome or value observed in one participant is not dependent on or related to the outcomes of others. In the specific study referred to, the researcher aims to assess the mean differences between four independent groups (CSA, REPs, CTS and CM) selected from four distinct schools. By selecting groups from separate schools and ensuring that these groups are independent to one another and their observations were independent to one another and as a result, the researcher is taking steps to uphold the assumption of independence. Such a design choice helps to minimize the risk of interconnected data points, thereby enhancing the credibility of the statistical comparisons made. By adhering to this assumption, this study supports the validity of its inferential statistical analyses, affirming that the assumption of independence has not been violated and that the findings derived from these analyses can be considered more robust and reliable.

2. Tests of Normality for Dependent Variables

Normal distribution is characterized by a symmetric, bell-shaped curve that reflects a balanced distribution of data points around the mean, indicating an equal likelihood of observing values above or below the mean. This symmetry suggests minimal bias, and the distribution's kurtosis a measure of the 'tailedness' of the probability distribution is expected to be zero, highlighting a distribution shape that closely aligns with the normal curve (George & Mallery, 2019).

However, the strictness of the normality assumption can be somewhat moderated for larger sample sizes. In such cases, the Central Limit Theorem comes into play, suggesting that the distribution of the sample means will approximate a normal distribution, even if the underlying data do not, as long as the sample size is sufficiently large. This property allows researchers to apply parametric tests with more confidence, assuming that a large sample can represent the population characteristics accurately.

In practice, assessing the normality of the data involves a variety of statistical tests and graphical methods. This study, for example, engaged in normality tests for variables within the context of topic-specific pedagogical content knowledge (PCK) instruction groups (CSA, REPs, and CTS) and a Conventional Method (CM) group. Tools such as the Shapiro-Wilk test were employed alongside measures of central tendency, skewness, and kurtosis coefficients to evaluate whether the data for each group adhered to a normal distribution.

Visual inspections through Q-Q plots and histograms provided further evidence of the data's conformity to normality, with Box plots checking for symmetry around the mean and median

This approach underscores the flexibility within statistical analysis, allowing for adjustments that enable the application of parametric tests under less-than-ideal conditions. The detailed examination of each variable, such as students' conceptual understanding test scores, was systematically presented in the following tables below, illustrating the thoroughness required to validate the use of parametric methods in the analysis. This careful consideration of normality ensures that the conclusions drawn from the study are based on a solid statistical foundation, enhancing the reliability and validity of the findings.

Table 1: Normality of Conceptual understanding between the groups on pre-test and posttest scores

Mean scores	Group	N	M	SD	Skewness			Kurtosis		
					statistic	S.E	Zs	statistic	S.E	Zk
Pretest	CSA	38	43.86	13.17	-0.75	0.38	-1.95	-0.35	0.75	-0.47
	REPs	36	47.64	9.79	-1.01	0.59	-1.70	0.22	0.77	0.29
	CTS	35	48.00	13.52	-0.12	0.40	-0.30	0.17	0.78	0.22
	CM	50	44.59	7.77	0.39	0.34	1.16	-0.71	0.66	-1.07
Posttest	CSA	38	54.35	14.39	0.29	0.38	0.75	0.10	0.75	0.14
	REPs	36	62.64	13.26	-0.25	0.39	-0.62	-0.18	0.77	-0.23
	CTS	35	52.24	15.65	-0.22	0.40	-0.56	-1.18	0.78	-1.51
	CM	50	45.90	9.32	-0.59	0.34	-1.75	0.17	0.66	0.25

The test scores were fairly regularly distributed among groups, according to Shapiro-Wilk's test and the use of descriptive Q-Q plots, and box plots (Table 1 in Appendix M). The z-values on the pre-tests and posttest on the conceptual understanding were between -1.96 and 1.96, indicating that all data were generally normally distributed. Similarly, the skewness and kurtosis values were found in the acceptable ranges between -1 and +1 for the skewness and found in between -2 and +2 for kurtosis. As a result, the total pre-test and posttest variable values were normally distributed on the conceptual understanding in studying chemical kinetics and equilibrium concepts.

Table 2: Normality of Achievement between the groups on pre-test and posttest scores

Mean scores	Group	N	M	SD	Skewness			Kurtosis		
					statistic	S.E	Zs	statistic	S.E	Zk
Pretest	CSA	38	45.70	13.88	-0.73	0.38	-1.90	0.25	0.75	0.33
	REPs	36	50.83	8.96	0.44	0.39	1.12	-1.05	0.77	-1.37
	CTS	35	50.19	14.06	-0.04	0.40	-0.10	-0.02	0.78	-0.03
	CM	50	45.86	11.98	0.39	0.34	1.16	-0.35	0.66	-0.53
	CSA	38	54.73	14.58	0.83	0.38	2.17	0.26	0.75	0.35
Posttest	REPs	36	61.56	15.01	0.35	0.39	0.89	-0.76	0.77	-0.99
	CTS	35	62.66	16.92	-0.33	0.40	-0.83	-0.90	0.78	-1.16
	CM	50	47.06	11.01	-0.68	0.34	-2.03	0.69	0.66	1.05

The test scores were fairly regularly distributed among groups, according to Shapiro-Wilk's test and the use of descriptive Q-Q plots, and box plots (Table 2 in Appendix M). The z-values on the pre-tests and posttest on the chemistry achievement test were between -1.96 and 1.96, indicating that all data were generally normally distributed. Similarly, the skewness and kurtosis values were found in the acceptable ranges that found in between -1 and +1 for the skewness and found in between -2 and +2 for the kurtosis. As a result, the total pre-test and posttest variable values have normally distributed on the chemistry achievement scores in studying chemical kinetics and equilibrium concepts.

Table 3: Normality of motivation scores between the groups on pre-test and posttest scores

Mean scores	Group	N	M	SD	Skewness			Kurtosis		
					statistic	S.E	Zs	statistic	S.E	Zk
Pretest	CSA	38	3.57	0.58	0.20	0.38	-0.53	0.04	0.75	0.05
	REPs	36	3.40	0.39	-0.50	0.39	1.27	0.39	0.77	0.51
	CTS	35	3.44	0.32	0.24	0.40	-0.60	-1.11	0.78	-1.43
	CM	50	3.58	0.55	0.27	0.34	-0.80	-0.93	0.66	-1.40
	CSA	38	4.12	0.33	0.43	0.38	1.13	-.213	.750	0.28
Posttest	REPs	36	4.35	0.35	-0.24	0.39	-0.62	.718	.768	0.94
	CTS	35	3.76	0.36	-0.03	0.40	-0.08	-.405	.778	-0.52
	CM	50	3.70	0.49	0.01	0.34	0.02	-1.048	.662	-1.59

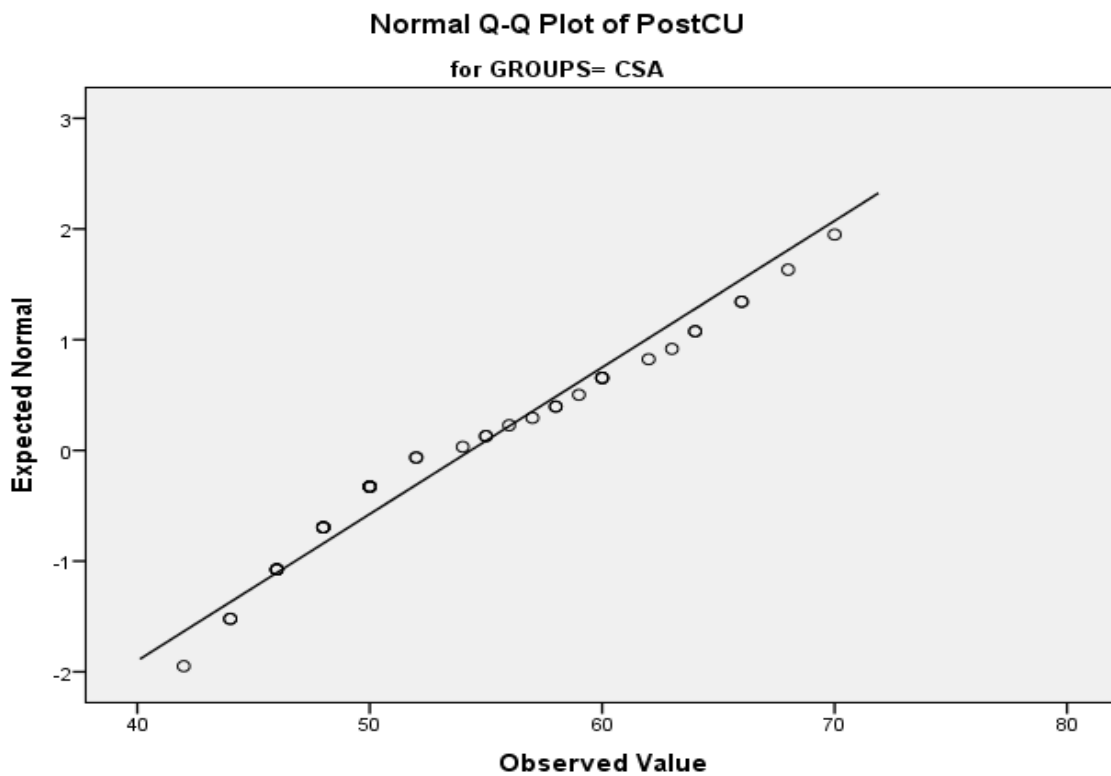
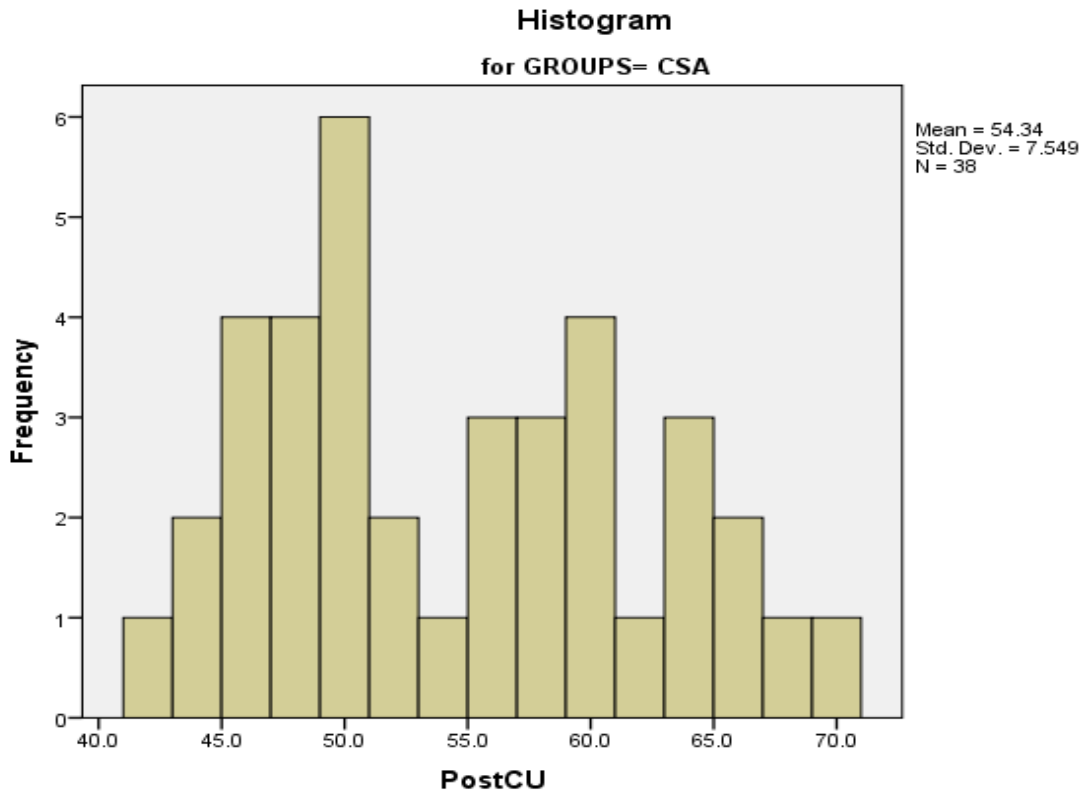
The test scores were fairly regularly distributed among groups, according to Shapiro-Wilk's test and the use of Q-Q plots, and box plots shown below (Table 4 in Appendix M). The z-values on the pre-tests and posttest on the chemistry motivation were between -1.96 and 1.96, indicating that all data were generally normally distributed. Similarly, the skewness and kurtosis values were found in the acceptable ranges-found in between -1 and +1 for the skewness and found in between -2 and +2 for the kurtosis values. As a result, the total pre-test and posttest variable values have normally distributed on the chemistry motivation scores in studying chemical kinetics and equilibrium concepts.

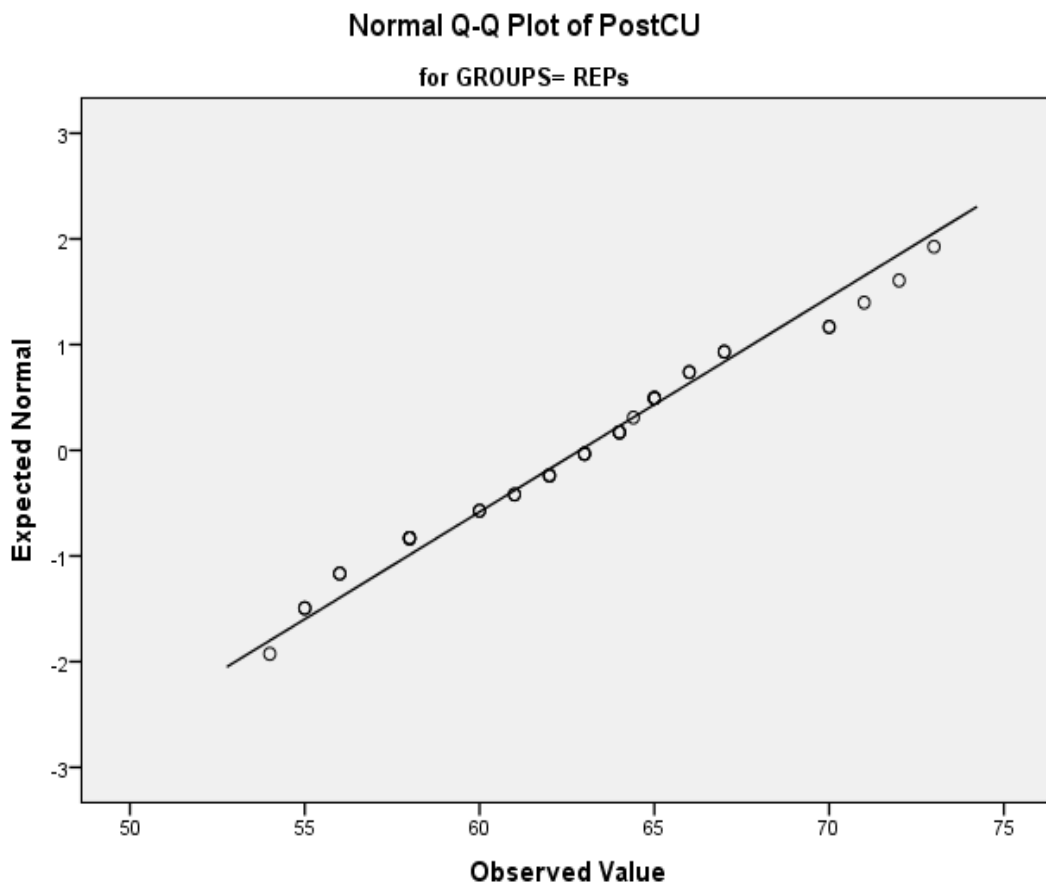
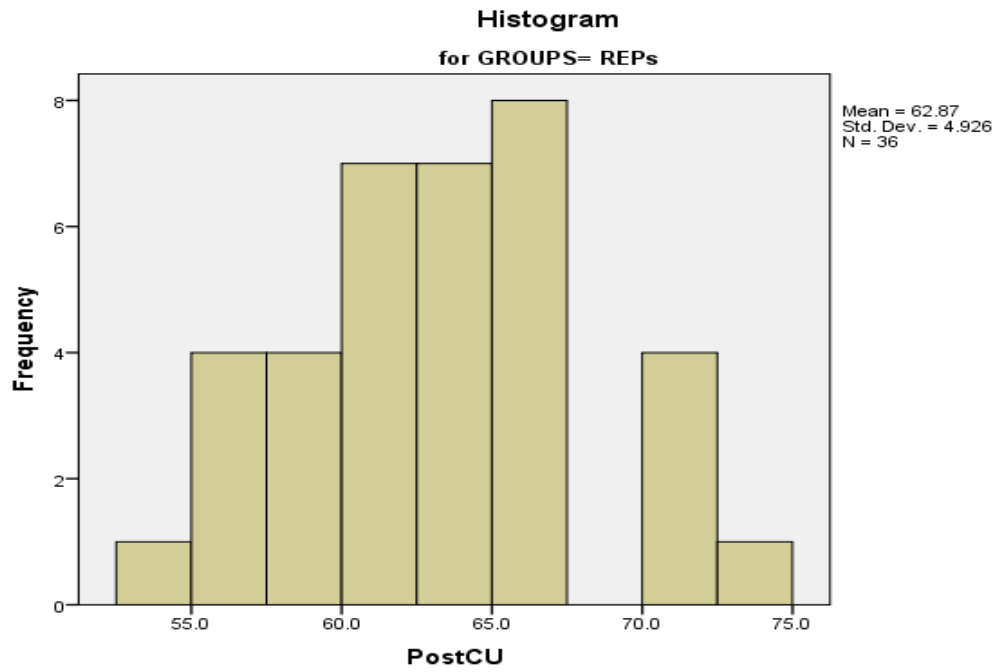
Table 4: statistical test of Normality

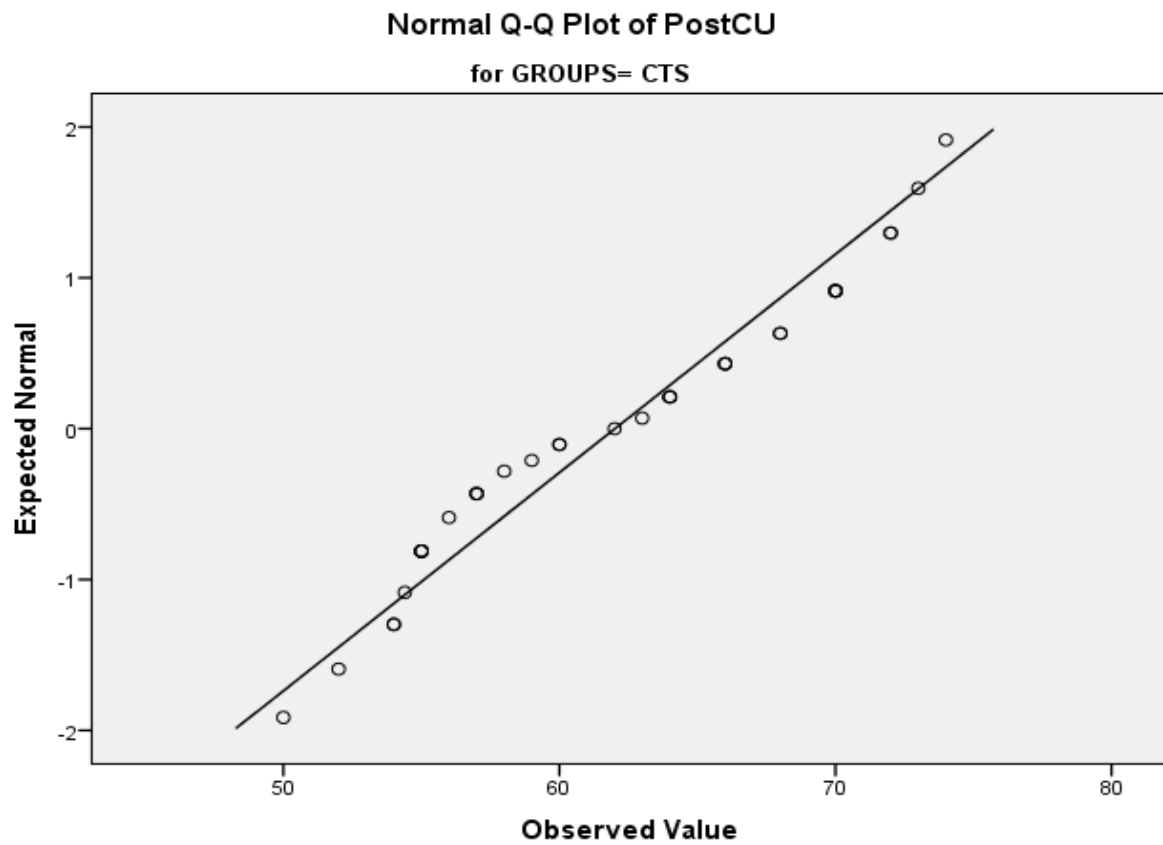
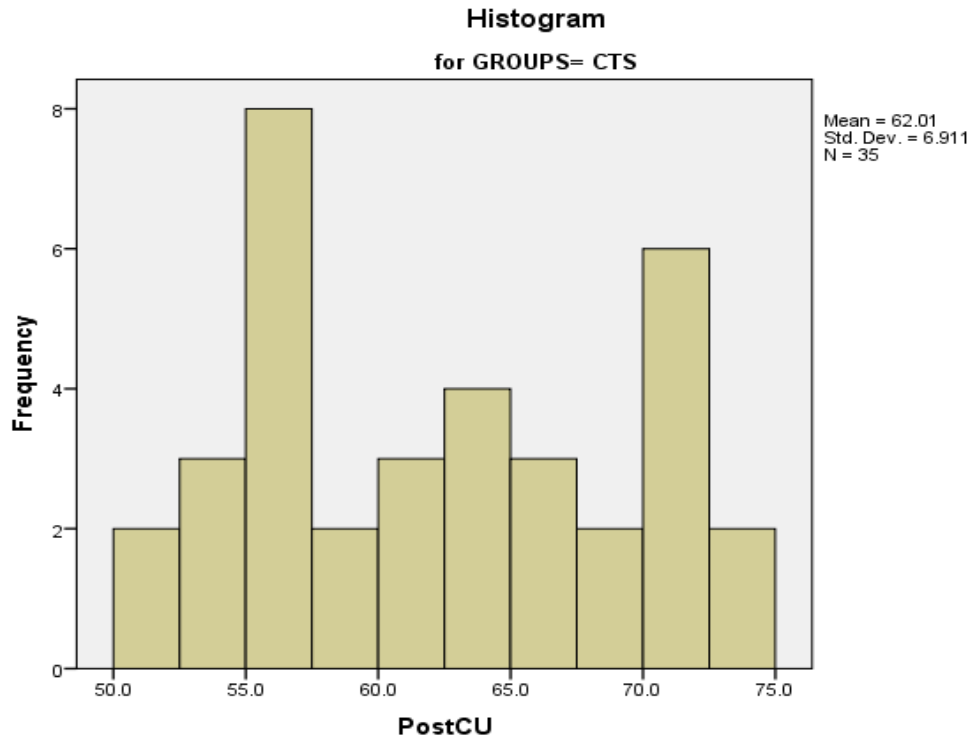
DV	GROUPS	Tests of Normality					
		Kolmogorov-Smirnov ^a			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Post-CU	CSA	.165	38	.011	.953	38	.115
	REPs	.089	36	.200*	.973	36	.501
	CTS	.137	35	.093	.941	35	.062
	CM	.077	50	.200*	.970	50	.233
Post-ACH	CSA	.155	38	.022	.951	38	.099
	REPs	.082	36	.200*	.983	36	.849
	CTS	.125	35	.185	.938	35	.049
	CM	.120	50	.069	.964	50	.128
Post-MOT	CSA	.143	38	.048	.954	38	.121
	REPs	.278	36	.000	.835	36	.000
	CTS	.108	35	.200*	.971	35	.469
	CM	.093	50	.200*	.959	50	.080

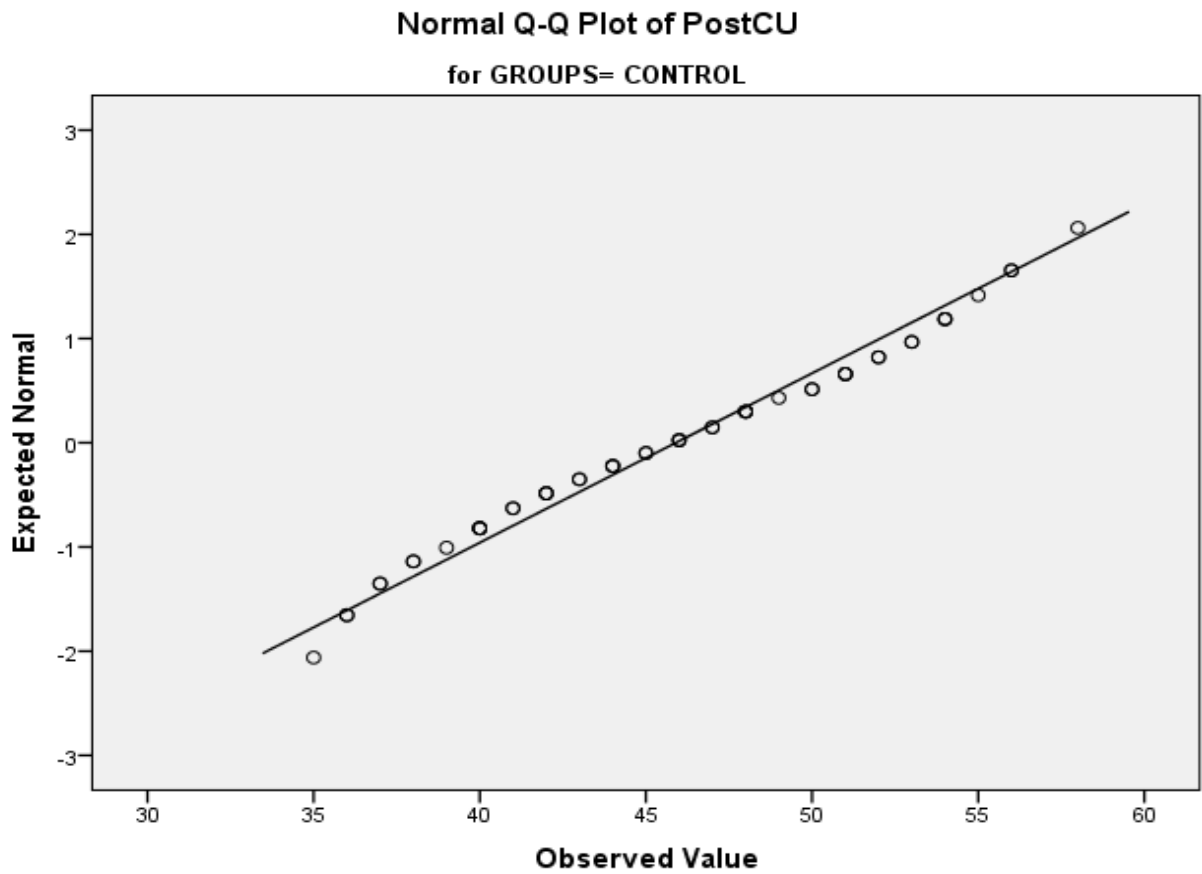
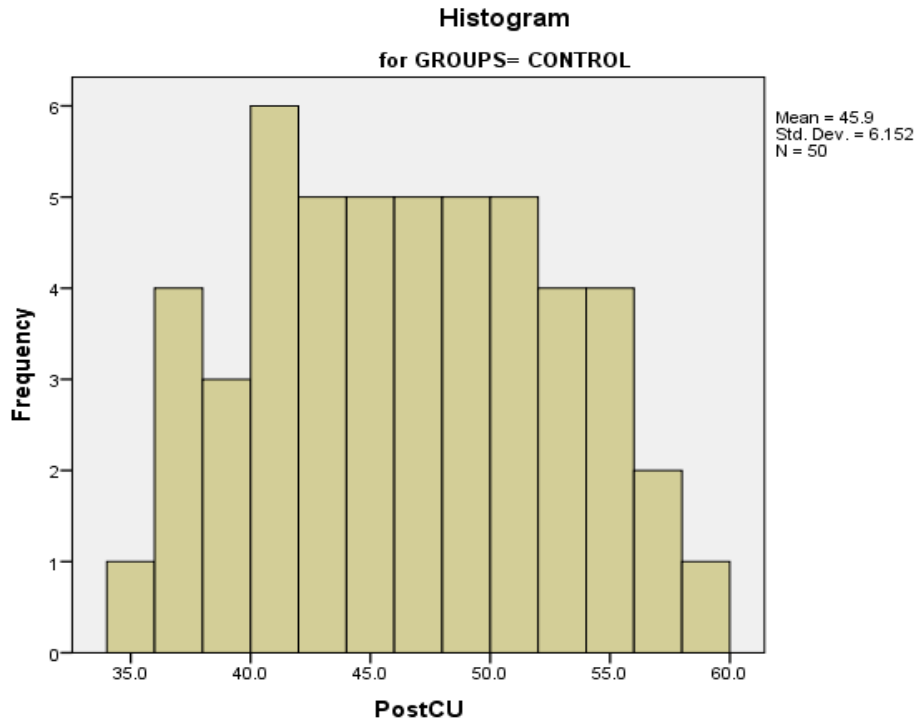
The Shapiro-Wilk test was recommended for small samples in the statistical test of normality shown in Table 4 in Appendix M above, and the p-value for each level of the independent variable was larger than .05, indicating that the data were approximately normally distributed. As indicated in table above, the results revealed that there was no statistical significance difference as indicated by Shapiro-Wilk test, $W(38)=.953$, $p=.115$, $W(36)=.973$, $p=.501$, $W(35)=.941$, $p=.062$ and $W(50)=.970$, $p=.233$, for CSA, REPs, CTS and CM, in conceptual understanding respectively. The Shapiro-Wilk test for achievement scores $W(38)=.951$, $p=.099$, $W(36)=.983$, $p=.849$, $W(35)=.938$, $p=.049$ and $W(50)=.964$, $p=.128$, for CSA, REPs, CTS and CM respectively and $W(38)=.954$, $p=.121$, $W(36)=.835$, $p=.000$, $W(35)=.971$, $p=.469$ and $W(50)=.959$, $p=.080$, for CSA, REPs, CTS and CM for motivation scores. The scores were not deviated from normal distribution. That is, at each level of the independent groups, the Shapiro-Wilk statistical test of normality for posttest scores of the three dependent variables was not statistically significant. It can be concluded that the treatment group's levels (independent variable) were approximately normally distributed, and

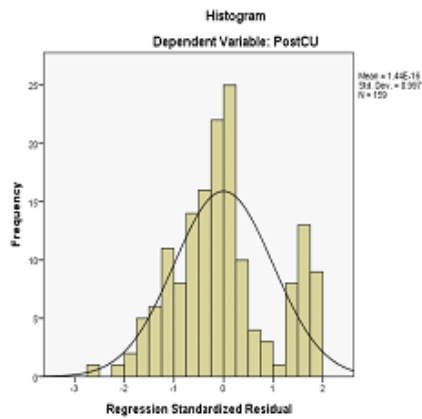
the normality conditions were met. The normality assumptions of the groups over the dependent variables were also illustrated by using Q-Q plot and histogram as follows.



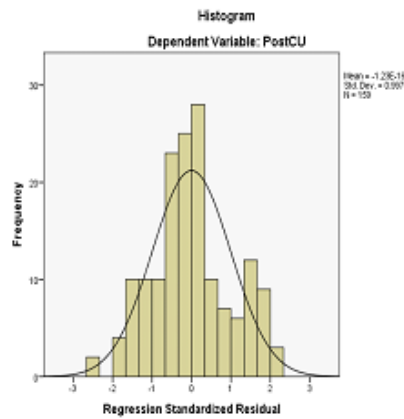




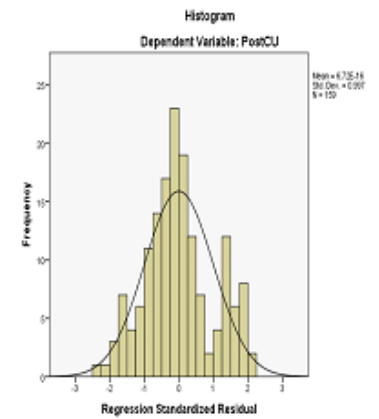




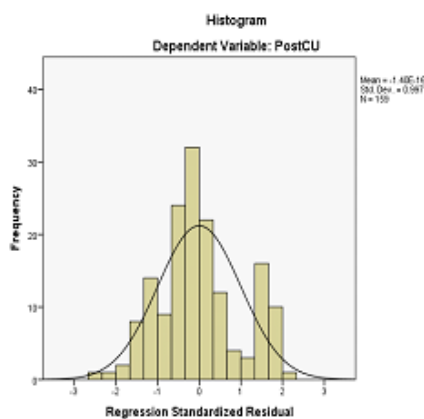
Intrinic motivation



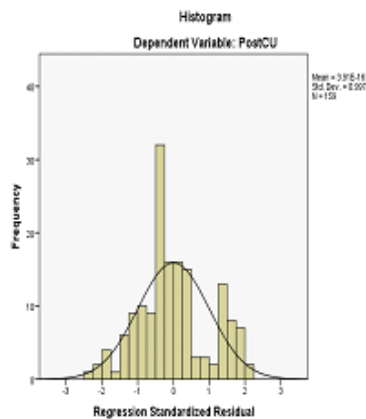
Self-Efficacy



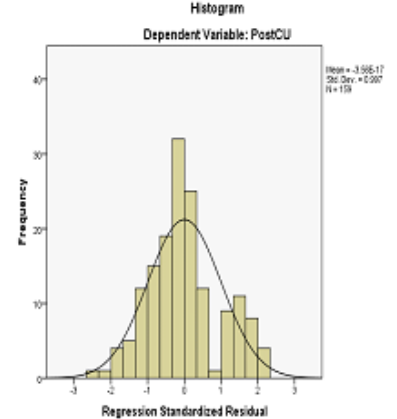
Self-Determination



Mark Motivation



Career Motivation



Total Motivation

3. Examination for Absence of Outliers in the Dependent Variables

Identifying and managing outliers is a critical preliminary step in data analysis for researchers. Outliers are data points that significantly deviate from the majority of a data set, appearing as anomalies or exceptions. These can arise due to various factors, including measurement error, incorrect data entry, or genuinely extreme values that are a part of the distribution (Dattalo, 2013). Outliers have the potential to distort statistical analyses, leading to misleading conclusions. Thus, their identification and appropriate handling are essential to ensure the validity and reliability of research findings.

The process of outlier detection often begins with a visual inspection of the data. Box plots, a graphical display highlighting the central tendency and dispersion of the data, serve as a useful tool for spotting outliers in terms of univariate normality.

In the context of the research described, box plots were employed during the initial data screening to search for univariate outliers among the intervention groups. The analysis

revealed no univariate outliers, indicating a relatively uniform distribution of data points within each group without extreme deviations in any single dimension.

However, univariate analysis does not account for the relationships between variables. Therefore, the Mahalanobis distance was calculated to detect outliers in terms of multivariate normality, which considers the covariance among multiple variables. This distance measures how far a data point is from the mean of a distribution, considering the correlation between variables. A critical chi-square value is used to determine whether a Mahalanobis distance is considered an outlier. In this study, any participant with a Mahalanobis distance less than 16.27 (the critical value for the three dependent variables such as conceptual understanding, achievement and motivation) has to be excluded from the analysis (Hair et al., 2010).

The results showed that the maximum estimated Mahalanobis distance among participants was 11.903, which falls below the critical threshold of 16.27. This outcome indicates that, within the multidimensional space of the three dependent variables (conceptual understanding, achievement, and motivation), there were no exceptional combinations of scores that would be considered outliers. Consequently, the analysis confirmed the absence of multivariate outliers in the dataset, suggesting a coherent and consistent set of observations across the variables of interest in the study of learning chemical kinetics and equilibrium.

4. Homogeneity of Variance for Dependent Variables

Parametric tests assume that sample data come from populations with similar variances, a concept known as homogeneity of variances or homoscedasticity. This assumption is crucial for the validity of statistical inferences and is often influenced by the normality of data distributions. Deviations from normality can affect the residuals and, consequently, the assumption of equal variances across groups. To assess the homogeneity of variances, several statistical tests are available, including Box's M test, Hartley's Fmax, Cochran's, Levene's, and Bartlett's tests. However, due to their sensitivity to non-normality, not all are commonly used in practice.

Levene's test, suitable for univariate analyses, and Box's M test, used in multivariate contexts, are the most frequently applied. Levene's test employs the F-test to examine the null hypothesis that variances are equal across groups, with a p-value below .05 indicating a violation of this assumption. The study's findings regarding homogeneity of variances, as determined by Levene's test across four groups (CSA, REPs, CTS and CM) for conceptual

understanding, achievement tests, and motivation questionnaire scores, are presented in Table 5 in Appendix M.

Table 5: Levene's Test of Homogeneity of Variances for Students' conceptual understanding, chemistry achievement test and chemistry motivation questionnaires

Dependent variables	Levene Statistic	df1	df2	Sig.
Pre-test Conceptual Understanding	4.985	3	155	.092
Posttest Conceptual Understanding	4.381	3	155	.085
Pre-test Chemistry Achievement	1.235	3	155	.299
Posttest Chemistry Achievement	4.404	3	155	.075
Pre-test Chemistry Motivation	6.479	3	155	.089
Posttest Chemistry Motivation	3.869	3	155	.061

Table 5 in appendix M shows the Levene's Test results for the pre-conceptual understanding test ($p = .092$), the pre-Chemistry achievement test ($p = .299$), the pre-motivation questionnaire ($p = .089$), the post-conceptual understanding test ($p = .085$), the post-Chemistry achievement test ($p = .075$), the post-motivation questionnaires ($p = .061$), respectively. These results indicate that there were no significant difference across all groups ($p > .05$), confirming the homogeneity of variance assumption was met.

5. Homogeneity of Variance-covariance Matrices for Dependent Variables

In multivariate analysis, it is assumed that the dependent variables follow a multivariate normal distribution and that the variance-covariance matrices are identical across the groups defined by the between-subjects effects. To verify the homogeneity of these matrices for MANOVA and subsequent ANOVA, the Box's M test was conducted. Additionally, Levene's test was used to assess the univariate homogeneity of variances for each dependent variable, with all results being not significant. However, since Levene's test does not address covariance, the homogeneity of variance-covariance matrices was further examined using Box's M test, focusing on the variance-covariance matrices' consistency across different groups for the dependent variables. The Box's M test, known for its sensitivity, typically considers a significance level of .001. In this study, the Box's M value of 48.79 corresponding to a p-value of .000, indicated significant differences for MANOVA ($p < .001$), suggesting the variance-covariance matrices among groups were not equal (Table 6 in Appendix M). As

a result, Pillai's Trace was utilized for the MANOVA analysis, acknowledging the unequal covariance matrices across the groups.

Table 6: Box's Test of Equality of Covariance Matrices^a

Box's M	48.79
F	2.61
df1	18
df2	73809.81
Sig.	.000

6. Linearity among Dependent Variables

The linearity assumption states that the research variables or the variables of interest have a linear relationship. To preserve the linearity assumption, the first step is to choose variables that are theoretically linearly related. The scatter plot, which is the visual display of a linear connection among data, is the most frequent visual approach for testing linearity. A general linear model comprising two or more scaled dependent (outcome) variables and one or more scaled independent variable has known as multivariate regression. This has checked by conducting a scatterplot of dots between the dependent variables. The data points have shown linearly in the shape of an oval display. If we see any other pattern in the data, it is most likely that the population from which our data has selected is not linear in terms of the variables we are studying. Thus, if we do not observe the oval shape indicative of linearity, the data violates the linearity assumption (Dattalo, 2013). MANOVA is a generic linear model containing one or more category explanatory factors and two or more scaled dependent (outcome) variables. For MANOVA, linearity means that all of the dependent variables have related in a linear way. A scatterplot matrix between the dependent variables have also used to verify this. Linearity has achieved for each MANOVA group independently. As a result, linearity has fulfilled for each MANOVA and multivariate regression group independently. Figures 1 and 2 provide scatter plots of dependent variables that support the linear trend line in the MANOVA assumptions and Figure 3 indicated the linearity of multiple linear regression..

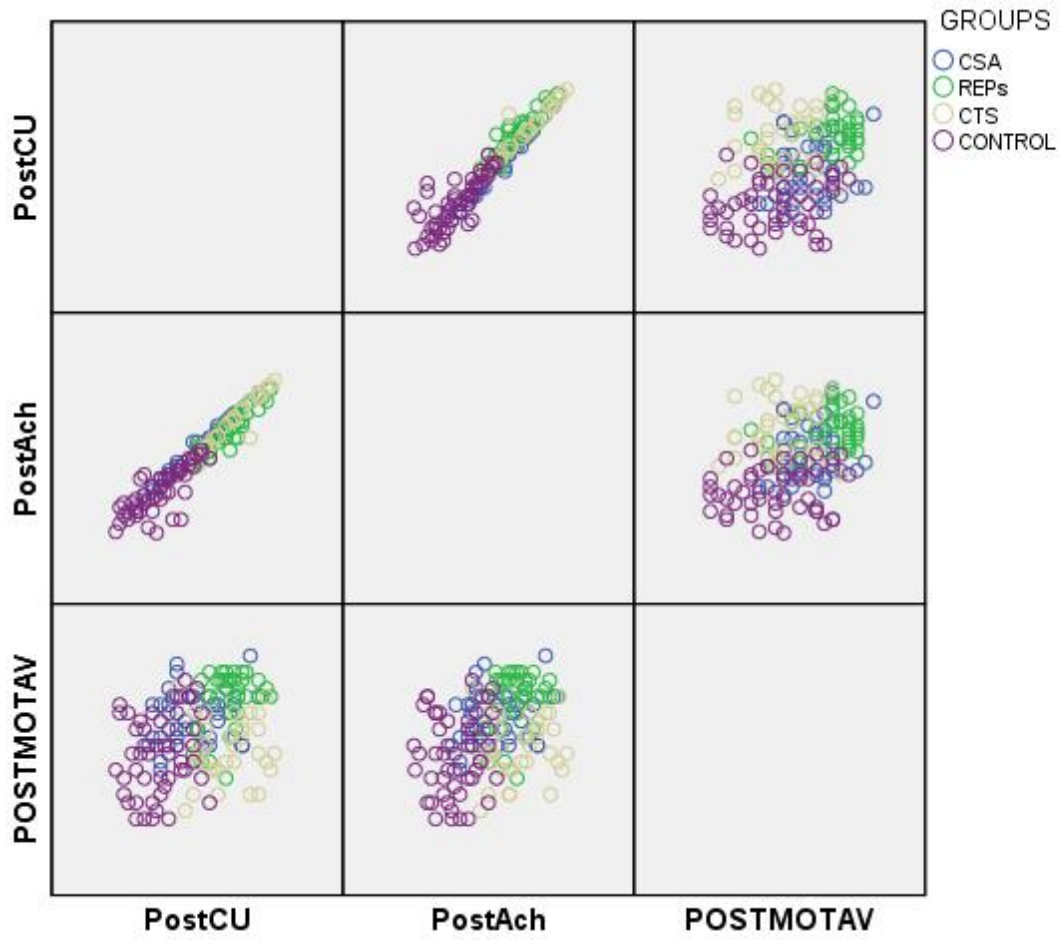


Figure 1 Scatter Matrix Plot of Conceptual understanding, achievement and motivation Test Scores among the Groups

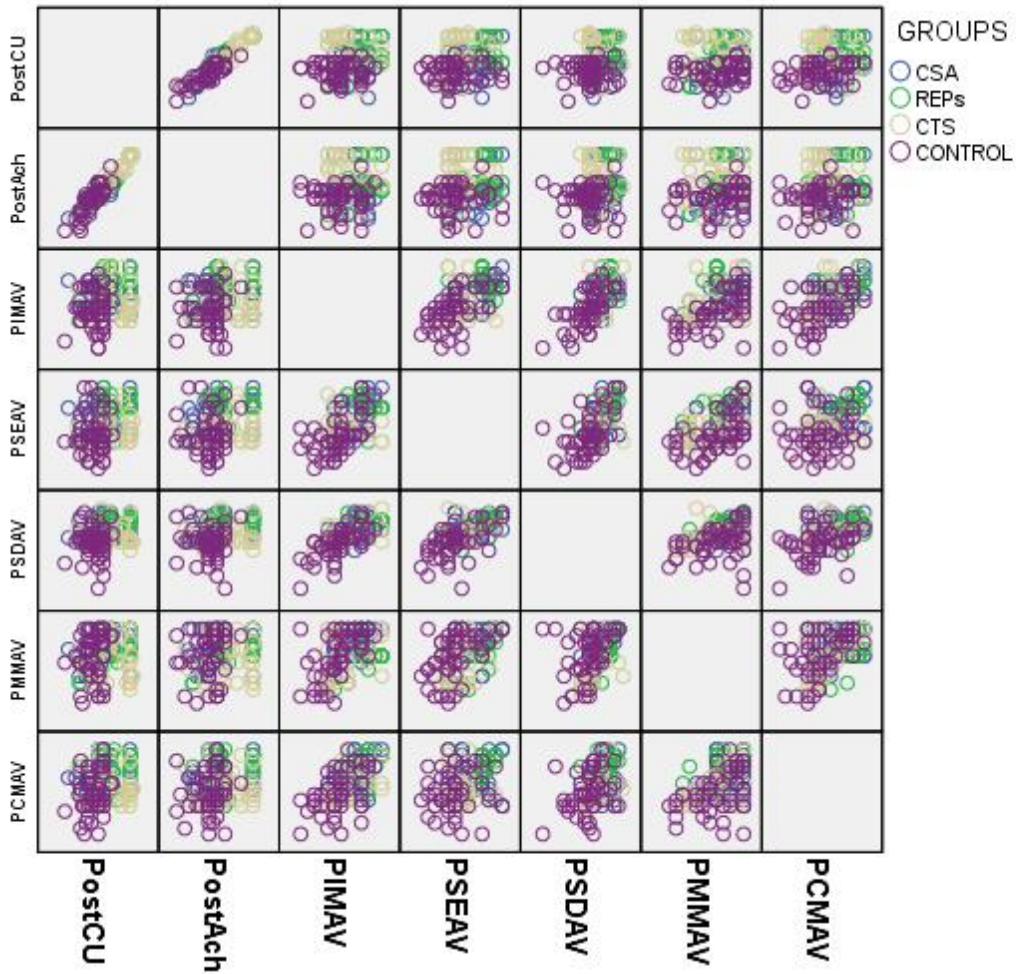
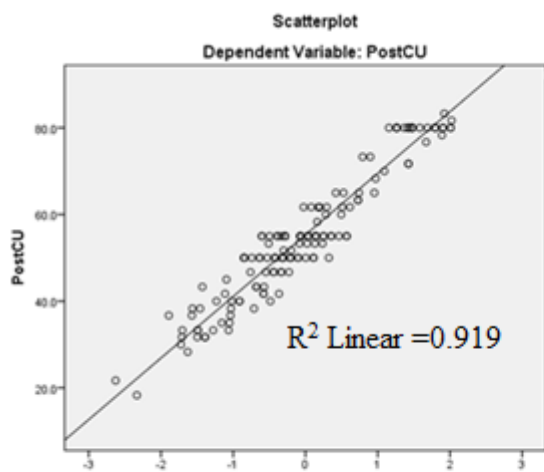
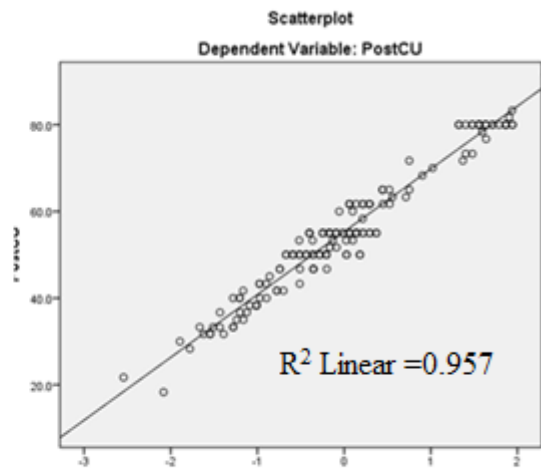


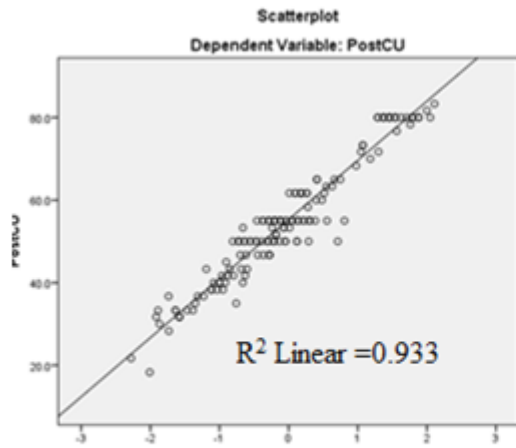
Figure 2 Scatter Matrix Plot for Construct of Motivation versus Conceptual understanding and Achievement Test Scores



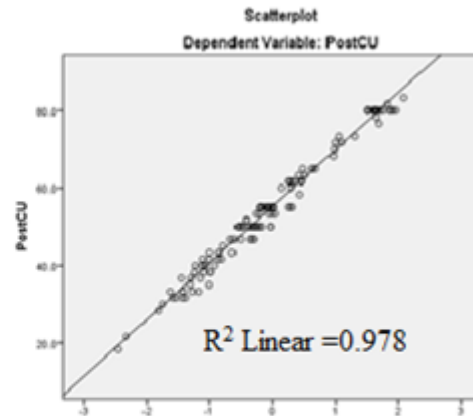
Regression Standardized Residual of posttest PSE



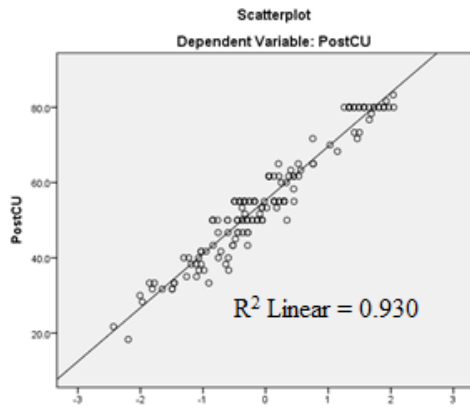
Regression Standardized residual of posttest IM



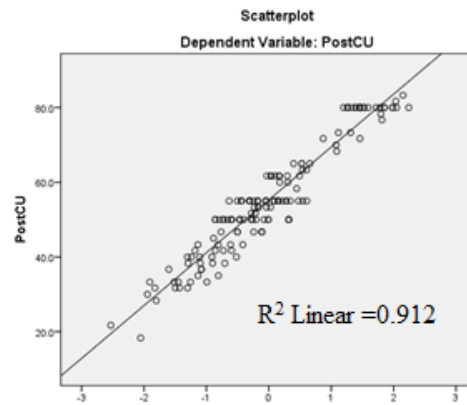
Regression Standardized Residual of posttest PSD



Regression Standardized Residual of posttest PMM



Regression Standardized Residual of posttest PCM



Regression Standardized Residual of posttest tptal motivation

Figure 3: Normality of Conceptual understanding versus Motivational components in Multiple Linear regression

7. Multi-collinearity among Dependent Variables

Multi-collinearity is a statistical phenomenon that arises when independent variables in a regression model are highly correlated with each other, with correlation coefficients (r) of 0.8 or higher, making it difficult to ascertain the individual impact of each predictor on the outcome variable (Field, 2013; Kutner et al., 2004). This high degree of correlation suggests that one predictor variable can nearly perfectly predict another, leading to redundancy among the variables. To identify multi-collinearity, correlations between the predictor variables are examined. While it's expected for the predictor variables to share some degree of correlation, a correlation coefficient greater than 0.8 is indicative of potential multi-collinearity, which can complicate the analysis by making it challenging to distinguish the unique contributions of each independent variable to the dependent variable.

Table 7: Summary of multiple-collinearity results

Variables	Collinearity Statistics	
	Tolerance	VIF(s)
Intrinsic Motivation	.392	2.552
Self-Efficacy	.514	1.946
Self Determination	.440	2.272
Mark motivation	.708	1.412
Career Motivation	.565	1.770

Based on Table 7 in Appendix M, the tolerance values and VIFs are greater than 0.3 and less than 5, respectively, indicating that there is no multi-collinearity issue in the data set. Additionally, homoscedasticity and multivariate normality assumptions were found to be satisfied based on the conceptual understanding, chemistry achievement of the motivation component .

In the context of this study, the Pearson correlation coefficients between the dependent variables were calculated to assess the presence of multi-collinearity. The findings revealed that the dependent variables, specifically the scores from the conceptual understanding test and the achievement in chemical kinetics and equilibrium achievement test, exhibited a moderate correlation ($r=.680$). This moderate correlation, quantified as being less than 0.8, suggests that while there is a relationship between the students' conceptual understanding of chemical kinetics and equilibrium and their performance on the achievement test, the correlation does not reach the threshold that would indicate problematic multi-collinearity. Therefore, the analysis proceeded on the basis that the linear trends between the conceptual understanding of chemical kinetics and equilibrium and the achievement test scores were reasonably distinct and not confounded by multi-collinearity. This moderate level of correlation was deemed appropriate and did not pose a significant risk of multi-collinearity, allowing for clearer interpretation of the effects of the independent variables on the outcome variable within the study.

Table 8: Pearson Correlations, Means and Standard Deviations Associated with the Conceptual understanding and achievement posttest Scores

Variables	Post-CU	Post-Ach	N	M	SD
Post-CU	1		159	55.15	9.71
Post-Ach	.680	1	159	57.28	9.34

Table 8: Pearson Correlations Associated With the subscales of Motivation and conceptual understanding and achievement in learning chemical kinetics and equilibrium

Variables	Post CU	Post Ach	Post IM	Post SE	Post SD	Post GM	Post CM
Post CU	1						
Post Ach	.680**	1					
Post IM	.211**	.178*	1				
Post SE	.286**	.268**	.586**	1			
Post SD	.261**	.226**	.685**	.628**	1		
Post GM	.148	.143	.444**	.470**	.385**	1	
Post CM	.268**	.207**	.630**	.371**	.518**	.408**	1

Table 7 depicted that the correlation between conceptual understanding and chemistry achievement test in learning chemical kinetics and equilibrium concepts. This revealed that the correlation between conceptual understanding and achievement scores were found in acceptable range ($r < 0.8$). Similarly, the correlation between each motivation components (intrinsic motivation, self-efficacy, self-determination, mark motivation and career motivation) reasonable found in an acceptable ranges ($r < 0.8$) (Table 8 in Appendix M). This implies that there were no problems of multi-collinearity issues in between motivation subscales and both conceptual understanding and achievement test.