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The Effect of the 5E Instructional Model on Students' Conceptual Understanding and Attitude toward Learning Enzymes in Fasilo Secondary School, Bahir Dar, Ethiopia

Amlaku, Miniyichil

BAHIR DAR UNIVERSITY

COLLEGE OF EDUCATION

DEPARTMENT OF SCIENCE AND MATHEMATICS EDUCATION

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By

Amlaku Miniyichil Menberu

Advisor: Million Tadesse (PhD).

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Enhancing the 5e Instructional Model to Improve Students' Conceptual Understanding and Attitude toward Learning Enzymes in Fasilo Secondary School, Bahir Dar, Ethiopia

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Masters Education in Biology

By

Amlaku Miniyichil Menberu

Advisor: Million Tadesse (PhD)

June, 2026

Bahir Dar, Ethiopia

Declaration

I, Amlaku Miniyichil, honestly declare that this thesis is the result of my own hard work and dedication. It has never been submitted for any degree or award in any other university. Every idea, word, or work taken from others has been properly acknowledged with respect and gratitude.

This work comes from my heart, and I stand by its authenticity.

Declared by: Name: Amlaku Miniyichil

Signature: ___________

Date: June, 2026

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College of Education

Department of Science and Mathematics Education

Approval of Thesis for Defense

This is to certify that the thesis entitled "Enhancing the 5e Instructional Model to Improve Students' Conceptual Understanding and Attitude toward Learning Enzymes in Fasilo Secondary School, Bahir Dar, Ethiopia" by Amlaku Miniyichil, prepared under my supervision. I recommend that the thesis be submitted for an oral defense.

Million Tadesse (PhD)		June 2, 2011
Advisor's Name	Signature	Date

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Department of Science and Mathematics Education

Approval of Thesis for Defense Result

As members of the Board of Examiners, we have examined this thesis entitled "Enhancing the 5e Instructional Model to Improve Students' Conceptual Understanding and Attitude toward Learning Enzymes in Fasilo Secondary School, Bahir Dar, Ethiopia ," by Amlaku Miniyichil. We hereby certify that the theis is accepted as fulfilling the requirements for the award of the Degree of Masters'of Science Education.

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Mersha Minwuyelet (PhD)		June 2, 201126
Internal Examiner's Name	Signature	Date
Mirtachew Ali (PhD)		June 2, 2011
Chair Person's Name	Signature	Date

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Abstract

This study aimed to evaluate the effect of the 5E inquiry-based instruction on the improvement of Grade 11 students' conceptual understanding and attitude towards learning enzymes at Fasilo Secondary School, Bahir Dar, Ethiopia. A Design-Based Research (DBR) framework was employed, involving iterative cycles of design, implementation, analysis, and redesign. The DBR cycles were used to iteratively design and refine the intervention, while a quasi-experimental embedded mixed-methods design provided rigorous evidence of its effectiveness. Two intact classes (N=38) were assigned to experimental and control groups. Data were collected using the Enzymes Concept Test (ECT), Biology Attitude Scale (BAS), classroom observations, semi-structured interviews, and student artifacts. Quantitative data were analyzed using descriptive statistics, ANCOVA, Mann-Whitney U test, and Wilcoxon signed-rank test. Qualitative data were analyzed thematically. The results revealed that both groups had identical pre-test conceptual understanding (M=4.158), but the experimental group's post-test mean (M=6.947) was significantly higher than the control group's (M=5.211), $F(1,35)=879.70$, $p<.001$, $\eta^2=.962$. Regarding attitude, the experimental group showed significantly higher post-test ranks (Mean Rank=28.34) than the control group (Mean Rank=10.66), $U=12.50$, $Z=-4.966$, $p<.001$. Within the experimental group, 18 out of 19 students showed improved attitudes ($Z=-3.742$, $p<.001$). The BAS demonstrated excellent reliability ($\alpha=.970$). Student perceptions were overwhelmingly positive, with 84.2% liking the 5E method and 100% agreeing hands-on activities helped understanding. The study concludes that the locally adapted 5E instructional model significantly improves both conceptual understanding and attitude towards learning enzymes. Recommendations include improving the integration of the 5E model into the biology curriculum, providing teacher professional development, and replicating the DBR approach for other challenging science topics.

Keywords: *5E Instructional Model, Attitude, Conceptual Understanding, Design-Based Research, Enzymes*

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List of Abbreviations

Abbreviation	Meaning
ANCOVA	Analysis of Covariance
BAS	Biology Attitude Scale
BSCS	Biological Sciences Curriculum Study
DBR	Design-Based Research
ECT	Enzymes Concept Test
GEQIP	General Education Quality Improvement Programme
KR-20	Kuder-Richardson Formula 20
SPSS	Statistical Package for the Social Sciences
UNESCO	United Nations Educational, Scientific and Cultural Organization

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

Modern education has been interested in teaching thinking and refining its skills, so that the learners can implement the knowledge and information they obtain to achieve success they seek (Faris & Alathameen, 2021). The reason is that thinking is an indispensable need for peoples and societies; its value is no longer measured only by its natural resources, but also by minds used to formulate and develop knowledge, and the extent to which it accepts the amazing technological and informational changes that are taking place. This necessitate preparation of individuals who can adapt to scientific developments, and this were only come through developing teaching strategies to develop students' thinking skills.

In an attempt to promote meaningful learning in science, a substantial body of research has accumulated in the last few decades has examined the effectiveness of different teaching strategies on students' understanding of variety of science (Schroeder *et al*., 2007). One of the teaching strategies based on constructivist epistemology with a long history in science education is the learning cycle (Msel *et al*., 2009). The 5E (Engage, Explore, Explain, Elaborate, and Evaluate) Instructional Model is a specific, refined version of the broader learning cycle framework. It was developed by the Biological Sciences Curriculum Study (BSCS) to translate the constructivist phases of the original learning cycle into a clear, teacher-friendly model for lesson and curriculum design (Dodge, 2017). The learning cycle allows students to become active participants in the process of science as they construct understanding of scientific concepts (Grau *et al*., 2021). The 5E Instructional Model (Engage, Explore, Explain, Elaborate, and Evaluate) offers a constructivist, student-centered alternative that actively involves learners in building their own knowledge.

However, Ethiopian educational context, science subjects like biology are often taught through traditional, teacher-centered methods, which can lead to rote memorization and a lack of deep conceptual understanding (Azmi & Mohamed, 2014). This is particularly true for complex biochemical concepts like enzymes, which are abstract and challenging for students to grasp (Özmen & Ozmen, 2004). A core aim of educational interventions like the 5E model is to improve specific, measurable student outcomes. For this study, the primary dependent variables are conceptual understanding and attitude towards learning both of which are indicators of meaningful learning.

Conceptual understanding refers to the ability to comprehend, integrate, and apply scientific concepts in multiple contexts, going beyond memorization to include constructing meaningful relationships among ideas (Schroeder *et al*., 2007). It involves not only knowing facts but also understanding underlying principles and transferring knowledge to novel situations.A substantial body of research supports the efficacy of the 5E model in fostering deeper conceptual understanding across various science topics. For instance, a meta-analysis by (Schroeder *et al*., 2007) on U.S. science teaching strategies found that inquiry-based models, which share core principles with the 5E cycle, produced significant positive effects on student achievement. Similarly, research by (Sadi, 2010) on 11th-grade biology students in Turkey found that those taught with the 5E learning cycle achieved significantly higher scores on tests concerning the human circulatory system, indicating superior conceptual grasp. Inaddiion, the 5E model has proven more effective than traditional instruction in remediating misconceptions about photosynthesis and respiration (Joswick & Hulings, 2024). More recently, provided evidence for the long-term effects of the 5E model, showing that it promoted more durable conceptual learning compared to conventional methods (Grau *et al*., 2021).

Beyond conceptual understanding, the other key variable of the current study is students' attitude. Attitude in an educational context encompasses the feelings, beliefs, and values a student holds toward a specific subject. It includes three components affective , cognitive (, and behavioral. A positive attitude is a critical affective outcome linked to increased motivation, engagement, persistence, and ultimately, academic achievement (Osborne, Simon, & Collins, 2010). Regarding attitude, the 5E model's student-centered, exploratory approach has been shown to increase engagement, interest, and creative thinking skills, with studies demonstrating that it makes learning more enjoyable and relevant (Faris & Alathameen, 2021).

Despite this evidence, significant gaps in the literature justify the current study (Vaezi, 2019). First, while conceptual gains are well-documented, much research relies on standard achievement tests that may not fully capture nuanced reasoning or the persistence of misconceptions (Özmen & Ozmen, 2004) Enzymes are a threshold concept in biochemistry, poorly understood due to their abstract nature; therefore, targeted studies are needed to evaluate how the 5E phases concretize these concepts (Loertscher *et al*., 2014). Recent research confirms that explicit instruction in troublesome knowledge enhances conceptual understanding (Aptyka, 2025).

Second, there is a pronounced contextual gap. Although some studies on the 5E model have been conducted in Ethiopia (Ashagrie *et al*., 2023) these have largely focused on urban high schools with better resources, on grades 9 or 10, and on topics like cell biology (T. A. Tegegne & Kelkay, 2023). To the researcher's knowledge, no enough studys in Ethiopia has specifically investigated the 5E model's effect on Grade 11 students' conceptual understanding of enzymes under typical resource constraints and large class sizes. Thus, the current study fills this gap by focusing on an under-researched topic Grade 11, and Fasilo Secondary School in Bahir Dar.

Third, a methodological gap exists, as few studies employ a design-based research (DBR) approach to iteratively develop and refine the 5E model in a real-world classroom over time (Najib & Mohamad, 2025). Most existing studies use quasi-experimental designs that measure immediate outcomes but fail to capture iterative adaptation (Chigona *et al*., 2024). Recent scoping reviews confirm that DBR remains underutilized in educational intervention research (Yang & Lee, 2025).

Fourth, concerning attitude, studies often use generic scales that may not detect shifts in disposition toward a challenging topic like enzymes, and they rarely examine how cultural norms in Ethiopia influence student reception of the 5E model (Chigona *et al*., 2024). Research shows that attitude is topic-specific, yet most instruments measure general attitudes toward science (S. Henderson *et al*., 2025). Finally, the dynamic relationship between improved conceptual understanding and improved attitude within the 5E framework is often implied but not rigorously examined in an integrated manner (Wondmagegn *et a*l., 2025). While some studies suggest a reciprocal relationship, few have systematically explored how gains in conceptual understanding influence attitude changes during implementation of a constructivist model like the 5E (S. Henderson *et al*., 2025).

Recent comparative studies continue to call for integrated investigations that examine both cognitive and affective outcomes simultaneously (Williams *et a*l., 2025).

Hence, this study directly addresses these interconnected gaps by employing a DBR framework to investigate the impact of a locally adapted 5E unit on both conceptual understanding of enzymes and topic-specific attitudes at Fasilo Secondary School, Bahir Dar, Ethiopia. Design-Based Research (DBR) is a pragmatic methodology that aims to develop effective educational interventions through iterative cycles of design, enactment, analysis, and redesign in real-world settings (Anderson & Shattuck, 2012). Unlike purely experimental research that primarily tests a theory, DBR focuses on addressing complex educational problems and co-developing solutions with practitioners. Its core application is to generate both theoretical understanding (in the form of design principles) and practical tools (a refined instructional unit) that are contextually relevant and sustainable (Wang *et al*., 2005). By applying DBR, this study moves beyond simply testing the 5E model's efficacy to actively engineering a viable and effective version of it for the specific context of Fasilo Secondary School.

1.2. Statement of the Problem

A substantial body of research has demonstrated the significance of inquiry-based instructional models, particularly the 5E Instructional Model, in promoting meaningful learning in science education. In addition studies showed the significance of the 5E Instructional Model (Engage, Explore, Explain, Elaborate, Evaluate) to promote meaningful learning in science education (Polanin *et al*., 2024). The model's role in facilitating conceptual change by connecting new ideas to prior knowledge has been documented (Williams *et al*., 2025). The 5E model, particularly the exploratory phase, enhances student engagement and scientific reasoning in secondary biology classrooms (Polanin *et al*., 2024). The model improves both academic achievement and attitudes toward science among middle school students (Cakır, 2017). The 5E fosters durable understanding by linking scientific concepts to real-world phenomena in environmental science education (Journal & Sciences, 2010). Meta-analytic evidence confirms that inquiry-based approaches, which share core principles with the 5E cycle, produce significantly higher student achievement compared to traditional exposition methods (Wahyono & Susetyarini, 2021). The 5E model's five phases Engage, Explore, Explain, Elaborate, and Evaluate operationalize constructivist principles by actively involving learners in building their own knowledge rather than passively receiving information (Calvert *et al.*, 2017) Specifically, research has shown that the 5E model is effective in remediating misconceptions about abstract scientific concepts, promoting durable conceptual learning, and increasing student engagement and interest in science (Joswick & Hulings, 2024). Given this compelling evidence, the 5E Instructional Model represents a theoretically grounded and empirically validated approach for addressing persistent challenges in science education.

Accordingly, the Ethiopian education system has explicitly recognized the importance of student-centered, inquiry-based instruction in its official policy frameworks. The national curriculum frameworks, including the Education and Training Policy (Studies & Curriculum, 2019) and subsequent Curriculum Framework for Ethiopian Education (Adamu, 2024), advocate for active learning methodologies that shift away from traditional teacher-centered transmission models.The Ministry of Education has repeatedly emphasized that science education should develop students' problem-solving skills, critical thinking, and scientific inquiry abilities (Eshetu *et al.*, 2022). The General Education Quality Improvement Program (GEQIP) and subsequent reforms have called for the implementation of constructivist pedagogies, including inquiry-based learning, across all secondary school subjects (Mengistie, 2020). Despite these policy-level commitments to student-centered, inquiry-based instruction, there is a notable deficiency in how this instructional approach is actually utilized in Ethiopian classrooms. This gap negatively impacts both teachers and students, suggesting that the lack of application may hinder effectiveness of the science education (Ayilara *et al*., 2020).

In support of this, empirical evidence consistently documents the low implementation of inquiry‑based instruction, including the 5E model, in Ethiopian secondary schools (Chengere, 2025). Research found that while Ethiopian middle‑level science teachers recognize the value of inquiry‑based practical activities, significant gaps persist between these positive perceptions and actual classroom practice, with most teachers continuing to prefer teacher‑dominated approaches (Joseph, 2023). A significant disconnect between policy aspirations and teaching practices has been reported in Ethiopian upper primary schools, concluding that classroom instruction remains predominantly teacher‐centered despite official frameworks advocating for constructivist learning (W. A. Tegegne & Bizuneh, 2025). It has further been confirmed that Ethiopian secondary schools often rely on traditional, rote‐based laboratory methods that hinder science process skills development (W. A. Tegegne & Bizuneh, 2025).

Concurrently, evidence indicates low student learning achievement in Ethiopian secondary schools (Ashagrie *et al*., 2023). National Assessments have consistently revealed poor student performance in science subjects, with biology being no exception (S. Henderson *et al*., 2025). At Fasilo Secondary School in Bahir Dar city, where the current study was conducted, local performance data show that Grade 11 students consistently score poorly on enzyme‐related items. A preliminary Phase 1 DBR analysis identified widespread misconceptions among students and negative attitudes, with students describing the topic as difficult,confusing, and boring. In addition, with teachers confirmed that biological topics related to enzymes are a chronically challenging topic to teach effectively using existing .instructional processes profoundly affect students' conceptual understanding and attitudes toward science. From a theoretical perspective, traditional instruction is grounded in a transmission model of learning, where knowledge is passively transferred from teacher to student. This approach contradicts constructivist learning theory (Lourenço, 2012) which posits that learners actively construct knowledge by integrating new information with pre-existing cognitive frameworks. When instruction ignores students' pre-existing conceptions, it fails to challenge or modify them (Tian *et al*., 2020). Assimilation theory further emphasizes that meaningful learning requires linking new material to existing cognitive structures, a process traditional methods, with their focus on content coverage and memorization, fail to facilitate. Regarding attitudes, the affective filter theory (Joseph, 2023). suggests that negative emotions such as boredom, confusion, or frustration create mental blocks to learning. Empirically, studies show that students perceive traditionally taught abstract topics as difficultand, boring (Williams *et al*., 2025), leading to disengagement that undermines meaningful learning.Hence, the topic of enzymes is particularly difficult for students when taught using a conventional teaching approach due to its abstract, dynamic, and microscopic nature. Enzymes are invisible, their actions occur at the molecular level, and their function involves three-dimensional spatial interactions (active sites, substrates, and products) that are difficult to conceptualize without concrete models or dynamic visualizations *(*Cardak *et al*., 2008).

Therefore, it is essential to explore effective student-centered instructional methods that improve students' learning outcomes, such as conceptual understanding and attitude, in the Ethiopian context. Addressing these issues requires effective teacher training and professional development for successfully implementing student-centered instructional methods (Darling-Hammond, 2017). The 5E inquiry-based instruction offers a promising alternative that is theoretically and empirically aligned to address the specific cognitive and affective gaps identified in Ethiopian secondary schools (Negerie *et al*., 2026). The 5E model operationalizes constructivist and conceptual change principles through its five phases: Engage (to elicit prior knowledge and generate interest), Explore (to create cognitive conflict through hands-on experiences), Explain (to introduce formal terminology and connect to student discoveries), Elaborate (to apply knowledge to new contexts), and Evaluate (to assess conceptual change). By systematically moving students through these phases, the 5E model is designed to challenge existing misconceptions, promote meaningful cognitive restructuring, and foster positive attitudes through active engagement and relevance(Joswick & Hulings, 2024). Implementing such an approach in Ethiopian secondary schools has the potential to transform biology instruction from rote memorization to genuine conceptual mastery.

Numerous studies have emphasized the complexity of the enzyme topic and documented persistent student misconceptions. Research on biochemistry education has identified that students at both secondary and tertiary levels struggle with fundamental enzyme concepts, including the nature of enzymatic action, the specificity of the active site, the fact that enzymes remain unchanged after catalysis, and the distinction between activation energy and reaction thermodynamics (Villafañe *et al*., 2021). Before targeted instruction, students held "abstract models" of enzyme structure and interactions, with over 90% relying on simplistic lock‑and‑key diagrams and struggling to explain key concepts such as how enzymes lower activation energy (Konu Kadirhanoğulları & Özay Köse, 2024). Common misconceptions include beliefs that enzymes are "used up" during reactions, that enzymes "provide energy" for reactions, that each enzyme can catalyze any reaction, and that enzymes are living organisms (Dorsah & Acquaye, 2018). These persistent misconceptions are resistant to change through traditional instruction because they are rooted in intuitive, everyday experiences rather than abstract scientific models (Dorsah & Acquaye, 2018).

Hence, it is time to explore instructional methods that promote active involvement in learning leading to improved conceptual understanding and attitude. In complex biological topics such as enzymes. After reviewing the literature on studies of 5E inquiry-based instruction on students' learning (conceptual understanding and attitude) in Ethiopian secondary schools, no study was found that was designed to improve the effectiveness of 5E inquiry-based instruction specifically for the enzyme topic in the Ethiopian context. In addition while some studies have examined the effect of the 5E model in Ethiopia on other topics (Ashagrie *et al*., 2023) none have specifically targeted Grade 11 students' understanding of enzymes at a secondary school in Bahir Dar. Furthermore, no study has employed a Design-Based Research (DBR) approach to iteratively develop, refine, and evaluate how the 5E model fosters change for this specific challenging topic. To address this gap, the researcher initated to designed and implemented a DBR study to enhance the implementation of the 5E inquiry-based approach to help students master fundamental enzyme concepts and make the learning process meaningful.

1.3 Objectives of the Study

1.3.1 General Objective of the Study

The overall objective of the study was to investigate the effect of the 5E instructional model on Grade 11 students' conceptual understanding of and attitudes toward learning enzymes at Fasilo Secondary School, Bahir Dar, Ethiopia.

1.3.2. The Specific objectives of the study

1. To identify baseline conceptual understandings, common misconceptions, and attitudes regarding enzymes among Grade 11 students.

2. To identify the effective activities for the improvement of 5E- instructional model to enhance students' conceptual understanding and attitude in the enzyme topic.

3. To examine how secondary school students can be supported to learn about enzymes using the enhanced 5E instructional model

4. To assess students' perceptions of the enhanced 5E inquiry-based model and extract design principles for future biology curriculum adaptations.

1.4. Research Questions

The study was designed to offer valid and reliable answers to the following research questions:

1. What are the baseline conceptual understandings, common misconceptions, and attitudes regarding enzymes among Grade 11 students?
2. What localized, context-appropriate instructional activities can be designed and adapted within the 5E framework to address these specific challenges?
3. What is the iterative impact of the redesigned 5E unit on students' conceptual mastery and topic-specific attitudes?
4. How do students perceive the enhanced 5E inquiry-based model, and what design principles for future biology curriculum adaptations can be extracted from their perceptions?

1.5. Significance of the Study

The study titled " Designing to enhance 5E- inquiry-based instruction to improve students' conceptual understanding and attitude towards learning enzymes in Bahir Dar city, Northwestern, Ethiopia" holds significant importance for several reasons:

1. The research investigates how improvements in the 5E-inquiry-based instrution can enhance students' conceptual understanding and attitude in biology. By identifying effective activities in the teaching process, the study contributes to develop strategies to enhance students' conceptual understanding and retention of complex biological concepts.
2. By employing a Design-Based Research (DBR) framework this study were not only test the efficacy of the 5E model but also contribute a contextually adapted, ready-to-use instructional unit on enzymes for teachers at Fasilo Secondary School, thereby providing them with an evidence-based strategy to improve learning. Furthermore, it generated

localized empirical evidence on the effectiveness of constructivist pedagogy, addressing a critical gap in the literature for similar educational settings.

3. By highlighting the benefits of DBR implementation in 5E-model, the research can inform the design and implementation of more effective teaching strategies. The findings of this study would provide valuable insights for educators, curriculum developers, and policymakers.
4. This study is significant for the entire educational community. For students at Fasilo Secondary School, it offers the chance to truly understand enzymes not just memorize facts transforming a difficult topic into an engaging discovery that builds critical thinking skills and fosters a lasting, positive attitude, empowering them for future academic and career paths. For teachers, it provides a practical, ready to use toolkit and a powerful professional experience, moving beyond traditional lectures to evidence based, interactive teaching that re-energizes the classroom. For curriculum designers and policymakers in Ethiopia, the findings offer a locally tested blueprint for reform, demonstrating how to successfully adapt and scale student-centered models to strengthen STEM education nationwide. Finally, for the global research community, this work fills a critical gap by providing rich, contextual insights and a replicable Design-Based Research framework, laying a foundation for further studies and contributing practical design principles and theoretical understanding to the science of teaching and learning.

1.6. Delimitation of the study

This research is intentionally focused within specific boundaries to ensure it is both manageable and meaningful. The study is deliberately anchored within a defined scope across several key dimensions. Geographically and institutionally, the investigation is confined to Fasilo Secondary School in Bahir Dar, Ethiopia. While the findings and the developed instructional model were most directly applicable to this specific school community, the insights generated may offer valuable guidance for educators in similar regional contexts. Temporally, the study was conducted within the 2025 academic year, specifically aligned with the scheduled teaching period for the enzyme unit in the Grade 11 biology syllabus. Concerning the participants, the scope is strictly limited to Grade 11

Natural Science students; specifically, two intact classes comprising approximately 38 students. Topically, the research is exclusively centered on the concept of enzymes. It targets students' conceptual understanding of factors affecting enzyme activity such as temperature, pH, and substrate concentration and their attitudes toward learning this specific topic, rather than biology or science education as a whole. Finally, the methodological scope is defined by the Design-Based Research (DBR) framework, which prioritizes the iterative, collaborative development of a practical, context-sensitive teaching intervention over the pursuit of broadly generalizable findings typical of large-scale experimental trials. These deliberate delimitations clarify the study's focus and help set realistic expectations for the applicability and transferability of its outcomes.

CHAPTER TWO: LITERATURE REVIEW

2.1. Instructional Approaches

Instruction, at its core, refers to the deliberate arrangement of experiences to facilitate learning, encompassing the strategies, methods, and interactions employed by educators to promote student achievement (Design & Bajracharya, 2019). The choice of instructional approach fundamentally shapes the nature of learning, influencing not only what students learn but also how deeply they understand and can apply knowledge (File *et al*., 2004). Globally, instructional paradigms have historically been dominated by teacher-centered approaches, which position the teacher as the primary authority and transmitter of knowledge (Lutjens, 1998). These approaches, grounded in behaviorist learning theories Skinner (2016) often manifest as lectures, direct instruction, and rote memorization activities, emphasizing the passive reception of information by students (Knogler, 2014).

In response to the limitations of traditional pedagogy, the late 20th and early 21st centuries witnessed a significant global shift toward student-centered, constructivist approaches. Drawing on the foundational work of theorists like (Lourenço,2012), these approaches posit that learners actively construct knowledge by integrating new information with existing cognitive frameworks through experience and social interaction (Driver *et al*., 2026). Inquiry-based learning (Grau *et al*. 2021), problem-based learning(Banerjee, 2010),and project-based learning (Knogler, 2014) exemplify this paradigm., engaging students in authentic, complex tasks that require investigation, collaboration, and critical thinking (Fitriani *et al*., 2022). International organizations such as the OECD and UNESCO have actively promoted this shift, advocating for educational systems that prioritize skills like creativity, communication, and adaptability alongside traditional academic content (OECD, 2018; UNESCO, 2015). The OECD's Future of Education and Skills 2030 project, for instance, emphasizes student agency and interdisciplinary learning as essential for navigating a rapidly changing world (Sotáková, 2023).

Ethiopia's educational landscape mirrors these global trends and tensions. Since the early 2000s, the government has embarked on an ambitious reform agenda to improve educational quality and equity, most notably through the General Education Quality Improvement

Programme (GEQIP), implemented in phases since 2008. A cornerstone of recent reforms has been the adoption of a competency-based curriculum, officially prioritized in the 2024 education policy, which aims to shift pedagogy from content transmission to the development of practical skills and competencies (Fantino *et a*l., 2019).

However, the implementation of these reforms faces persistent challenges. Research indicates that classroom instruction in Ethiopia remains predominantly traditional and teacher-centered, particularly in secondary schools (Azmi & Mohamed, 2014). A recent study observing classrooms before an intervention found students spent over 50% of their time in passive, teacher-led instruction, with minimal opportunities for collaboration or active engagement (Info, 2024). In the Ethiopian context, the translation of curriculum policy into classroom practice is hampered by multiple factors: insufficient distribution of curriculum materials to schools, lagging textbook production, and teacher training that often emphasizes theoretical principles over practical strategies for implementing learner-centered pedagogy (Kite *et al*., 2023). The consequences of this implementation gap are evident in learning outcomes. Despite progress in access and equity with disadvantaged regions showing accelerated learning gains in recent years Chekol (2024). foundational learning levels remain critically low. Nationally, an astonishing 90% of ten-year-old students cannot read with comprehension, reflecting what the World Bank terms "learning poverty (World Bank, 2023). This disparity between policy aspirations and classroom realities underscores the urgent need for research that not only identifies instructional problems but also develops and tests contextually appropriate solutions (Knogler, 2014). It is within this nexus of global pedagogical shifts, national reform commitments, and persistent implementation challenges that the present study is situated, focusing specifically on the teaching and learning of enzymology at Fasilo Secondary School.

2.2. Theoretical Foundation of the Learning Cycle and the 5E Model

All through the last century, researchers offer alternative strategies to support meaningful learning in biological concepts in different countries and there have been different arrangements to active participation of students in biology instruction. The learning cycle can be defined as an activity oriented teaching methods and promote students meaningful understanding of scientific concept, explore and deepen that understanding, and then apply the concept to new situations (Cardak *et al*., 2008). Originating in an elementary science program called Science Curriculum Improvement Study (SCIS) by Robert Karplus learning cycle generally consists of three distinct phases: (1) exploration, (2) concept introduction, and (3) concept application (Msel *et al*., 2009). As long as the learning cycle has been used and researched for nearly four decades, science educators have extended the three phases into five, known as the 5E learning cycle: Engagement, Exploration, Explanation, Extension, and Evaluation (Msel *et al*., 2009) and into 7, known as 7E learning cycle (Msel *et al*., 2009). The 7E learning cycle expands the Engagement phase into Engagement and Elicit and Elaborate and Evaluate phases into Elaborate, Evaluate and Extend. In general, every learning cycle has at its core the same inductive instructional sequence. Briefly, the learning cycle begins with the active engagement of students in investigating the natural phenomena. During exploration, students engage in hands-on activities as the basis for developing a specific concept and related vocabulary. In this phase, teacher acts as a facilitator, providing materials and directions, guiding the physical process of the activities. After the exploration, the teacher promotes a discussion period in which students share their observations with classmates. This is the time in which the teacher connects student experiences to the target science concept including the identification of scientific vocabulary. Once the concept has been labeled, students engage in additional activities in which they apply newly gained knowledge to unfamiliar areas (Settlage, 1999).

Since 1960s, learning cycle been used effectively to teach of variety of science concepts, such as diffusion and osmosis (Odom & Kelly, 2000), plant nutrition (Sotáková, 2023),photosynthesis and respiration in plants (Balci *et al*., 2006), mitosis ecology (Lawson, 1991).

2.3. The 5E Instructional Model in Science Education

The theoretical strength of the 5E model lies in its structured yet flexible phases, which promote student-centered learning. The Engage phase stimulates curiosity, the Explore phase allows hands-on investigation, the Explain phase encourages articulation of understanding, the elaborate phase extends learning to new contexts, and the Evaluate phase provides ongoing assessment (Joswick & Hulings, 2024). This cyclical process supports deeper conceptual understanding and encourages positive attitudes toward learning (Faris & Alathameen, 2021).

2.4. Empirical Evidence on the Effectiveness of the 5E Model

In a study conducted by (Faris & Alathameen, 2021), the effects of the 5E learning cycle on tenth-grade biology students in Jordan were examined, focusing on achievement and creative thinking skills in the unit of viruses, viroids, and prions. The quasi-experimental design involved 65 students divided into experimental (5E strategy) and control (traditional method) groups. Results showed statistically significant improvements in both achievement and creative thinking skills (fluency, flexibility, originality) among the experimental group. This suggests that the 5E model not only enhances content mastery but also fosters higher-order thinking skills, which are essential for meaningful learning.

Similarly, (Sotáková, 2023) investigated the impact of the 5E model on fifth-grade students' achievement and retention in biology. The study found that students taught using the 5E strategy outperformed their traditionally taught peers in post-tests and demonstrated better retention of knowledge. This aligns with the findings of (Faris & Alathameen, 2021) who reported that seventh-grade students taught with the 5E model showed superior achievement and biological thinking skills compared to the control group. Since 1960s, learning cycle been used effectively to teach of variety of science concepts, such as diffusion and osmosis (Odom & Kelly, 2000), plant nutrition (Sotáková, 2023),photosynthesis and respiration in plants (Balci *et al*., 2006), mitosis ecology (Lawson, 1991).

2.5. The Specific Challenges of Teaching and Learning Enzymology

Enzymology presents a unique constellation of learning difficulties, making it a prime candidate for structured constructivist intervention. Literature identifies three primary contributing factors: the inherent abstract and conceptual properties of the discipline, variable teaching styles, and diverse student abilities (Akter *et al*., 2025) Crucially, understanding enzymology requires learners to reason through dynamic, causal mechanisms at a molecular level a form of systems thinking that traditional didactic lectures often fail to develop (Loertscher *et al*., 2014). Furthermore, enzymology is both integrative, requiring connections to chemistry, biology, and physiology, and deeply conceptual, relying on principles rather than isolated facts (Villafan *et al*., 2011). The 5E model, with its emphasis on exploration before explanation and elaboration, is designed to scaffold this complex reasoning.

A significant and recurrent theme in the literature is a barrier that limits the effectiveness of any evidence-based model: the widespread lack of formal pedagogical training among science educators. As (Mishall *et al*., 2025) note, most basic science and clinical faculty lack training in the science of learning or instructional design. Consequently, teaching practices are frequently based on intuition and personal experience rather than on research-grounded theory (Mishall *et al*., 2025).This gap means that even when aware of models like the 5E, instructors may implement them superficially, missing the essential constructivist sequencing and dialogic elements necessary for their success (Brucks & Nielsen, n.d.). This disconnects between educational research and classroom practice remains a critical impediment.

Enzymology is a difficult discipline for many learners to understand, yet it is the foundation for pursuing a career in health sciences. A previous survey study showed the most frequent factors contributing to the difficulty of learning enzymology are as follows: properties of the discipline, educators' teaching style, and the students' abilities (Michael, 2025). A learner must be able to reason through causal mechanisms and think about dynamic systems to understand enzymology. Additionally, learners need to recognize that enzymology is both integrative and conceptual in nature. An underlying issue is that most basic science and clinical faculty involved in medical education do not have formal training in the science of learning or instructional design (Khalil & Elkhider, 2025). This lack of preparation may result in suboptimal teaching, as instruction is based on intuition and experience rather than research and theory (Khalil & Elkhider, 2025; Levinson & Merrie, 2010).

2.6. The 5E Inquiry -Based Learning and Its effect on Learning Outcomes

The 5E Instructional Model is a systematic, constructivist framework designed to sequence learning experiences that guide students from initial curiosity to deep, applied understanding (Kenealy, 2013). This pedagogical journey unfolds through five distinct phases. It begins with Engage, where a teacher uses a provocative question or puzzling demonstration about enzymes to activate prior knowledge and spark curiosity, making the learning personally relevant and laying the groundwork for a positive attitude (Faris & Alathameen, 2021).Students then move to Explore, engaging in hands-on activities like testing the effect of temperature on enzyme activity where they manipulate materials and identify patterns without direct instruction, building the concrete experiential base essential for grasping abstract biochemical processes (Villafañe *et al*., 2021). In the Explain phase, the teacher strategically introduces formal scientific terminology and principles, encouraging students to articulate their understanding from their explorations; this crucial step connects direct experience to canonical explanation, helping to remediate misconceptions and solidify accurate conceptual models (Villafañe *et al*., 2021). Next, in Elaborate, students extend and apply their new understanding to a novel context, such as using enzyme kinetics to explain a digestive supplement or metabolic disease, thereby deepening conceptual understanding by requiring knowledge transfer and moving learning beyond rote memorization (Joswick & Hulings, 2024). Finally, Evaluate emphasizes formal checks for understanding through ongoing, formative assessments like presentations and reflective writing, creating a continuous feedback loop that helps both teacher and student monitor progress in conceptual mastery throughout the entire learning cycle (Bybee *et al*., n.d.).

2.6.1. Effect of 5E Model on Conceptual Understanding

For this study, conceptual understanding is defined as a learner's integrated mental model of a scientific concept that enables them to explain its principles, connect it to related ideas, and apply it to solve novel problems, moving beyond the recall of isolated facts (Grau *et al*., 2021). In the context of enzymes, this means students can accurately explain mechanisms like factors affecting activity (e.g., temperature, pH) and predict outcomes in new scenarios, demonstrating that rote memorization has been replaced by functional (Villafañe *et al*., 2021). Attitude in this educational context refers to the composite of a student's feelings, beliefs, and predispositions toward learning a specific subject, which influences their motivation, engagement, and persistence (Osborne *et al*., 2010). A positive attitude toward learning enzymes would be characterized by interest in the topic, a belief in its relevance and their own ability to understand it, and a wereingness to engage with challenging materia
The 5E model systematically builds conceptual understanding through a scaffold, experience first sequence that targets the architecture of knowledge itself. Its power lies in creating a cognitive need before providing explanations. By beginning with the Explore

phase where students investigate phenomena hands-on without initial instruction the model ensures that abstract concepts (like enzyme activity) are grounded in concrete, personal experience (Villafañe *et al*., 2021). This experiential foundation makes subsequent formal explanations in the Explain phase more meaningful and directly addresses the tenacious misconceptions that lecture-based methods often fail to correct (Joswick & Hulings, 2024).The learning is then solidified and expanded in the Elaborate phase, where students must transfer and apply their understanding to novel contexts, reinforcing robust mental models and moving beyond superficial memorization to deep, functional knowledge (Licayan, 2009).The integrated Evaluate phase, with its formative feedback, allows for continuous refinement of these conceptual models throughout the process (Çimer, 2012).

Empirical studies consistently show that the 5E model's inquiry-based, experiential sequence leads to superior conceptual gains compared to traditional instruction. For instance, a meta-analysis by (Schroeder *et al*., 2007). On U.S. science teaching found inquiry-based models like the 5E cycle significantly boosted student achievement. Specific to biology, (Sadi, 2010) found 11th-grade Turkish students taught with the 5E model showed significantly better understanding of the human circulatory system. More recently, (Grau et al., 2021) provided evidence that the 5E model promotes more durable, long-term conceptual learning, while (Joswick & Hulings, 2024) noted its particular efficacy in remediating persistent scientific misconceptions, a key indicator of deep conceptual change.

2.6.2. Effect of 5E Model on Attitude

Concurrently, the 5E model nurtures a positive attitude toward learning by fundamentally reshaping the classroom experience from a passive reception of information to an active, student-centered journey. The Engage phase immediately works on affect by hooking interest and making the topic personally relevant, which is a critical first step in fostering intrinsic motivation (Faris & Alathameen, 2021).The autonomy, collaboration, and sense of discovery inherent in the Explore and Elaborate phases promote feelings of ownership and competence. When students successfully make sense of their investigations and see their knowledge applied meaningfully, they experience mastery, which is a key driver of positive affect and continued engagement (Sotáková, 2023). Furthermore, by weaving assessment throughout the cycle (Evaluate), the model reduces the anxiety associated with high-stakes, end-of-unit testing, making the learning process itself feel more supportive, engaging, and less stressful. Therefore, while the model constructs knowledge cognitively, it also carefully cultivates the motivational and emotional dispositions that make students want to learn.

The model's student-centered design also positively influences affective outcomes. Research indicates that the active, exploratory nature of the 5E model increases student engagement and interest.(Faris & Alathameen, 2021), for example, reported that the model not only improved achievement but also enhanced creative thinking skills and made learning more enjoyable for biology students in Jordan. The structure of the cycle beginning with engaging phenomena and allowing for hands-on exploration fosters intrinsic motivation and a sense of ownership over learning, which is foundational to a positive academic attitude *(Osborne et al.*, 2010).

2.6.3 Previous Empirical Studies on the 5E Model in Biology Education

A growing body of empirical research has investigated the effectiveness of the 5E Instructional Model (Engage, Explore, Explain, Elaborate, Evaluate) within biology education, with studies consistently demonstrating positive outcomes. For instance, (Faris & Alathameen, 2021) found that 10th-grade biology students in Jordan taught with the 5E model showed statistically significant improvements in both academic achievement and creative thinking skills compared to a control group taught traditionally. Similarly, research by (Sadi, 2010) with 11th-grade students in Turkey indicated superior understanding of the human circulatory system among those experiencing the 5E cycle. These gains are often attributed to the model's structured yet flexible, inquiry-based approach that promotes active knowledge construction (Berie *et al*., 2022). More recent evidence suggests the 5E model not only boosts immediate achievement but also fosters more durable, long-term conceptual learning (Grau *et al*., 2021). Studies have also noted its efficacy in remediating specific, persistent misconceptions in topics like photosynthesis, a challenge analogous to that found in enzymology (Joswick & Hulings, 2024).

2.7. Synthesis and Identified Research Gap

Synthesizing the literature reveals a clear pathway forward. The 5E Instructional Model provides a validated, constructivist framework well-suited to address the conceptual difficulties of enzymology. However, its potential is unlocked only when coupled with comprehensive faculty development. Future efforts must focus on creating scalable and sustainable professional development that moves beyond one-time workshops to ongoing communities of practice where educators can design, implement, and reflect on 5E-based instruction (C. Henderson *et al*., 2011). Additionally, further research is needed to develop and validate 5E-specific assessment tools that measure the model's impact on the complex causal and systems reasoning that defines true understanding in enzymology *(Loertscher et al*., 2014).

Despite its proven effectiveness in various contexts, there is limited research on the application of the 5E model in Ethiopian secondary schools, particularly in teaching complex biological concepts such as enzymes. The complexity of enzymology as a subject is well-established in educational research, identifying it as a significant cognitive hurdle for learners. Notably, enzymes have been classified as a threshold concept in biochemistry, representing knowledge that is both transformative for understanding yet inherently troublesome, effectively acting as a gatekeeper to advanced scientific reasoning (Loertscher *et al*., 2014).This status stems from the requirement for dynamic, systems-level thinking; students must conceptualize enzyme activity not as static facts but as probabilistic interactions within complex biological systems, a skill poorly developed through rote memorization (Villafan *et al*., 2011). Consequently, this abstract and integrative nature leads to widespread and persistent student misconceptions regarding enzyme function and interaction, which are notoriously resistant to change through traditional instruction (Özmen & Ozmen, 2004).

The difficulty of mastering enzymology is further corroborated by perspectives from both learners and educators. From the student viewpoint, biological concepts like enzymes are frequently characterized as abstract and demanding integration of knowledge from multiple disciplines, making them particularly challenging to grasp (Çimer, 2012). This learner-reported difficulty aligns directly with faculty observations, as surveys of educators consistently rank enzymes and related metabolic topics among the most challenging areas to teach effectively in life science courses (Michael, 2025).This convergence of evidence from cognitive theory, assessment data, and stakeholder perspectives underscores that the challenge of teaching and learning enzymes is not merely perceptual but is rooted in the fundamental structure of the discipline, necessitating pedagogical approaches that explicitly address these deep-seated conceptual and reasoning difficulties. Enzymes are a challenging topic for many students due to their abstract nature and biochemical complexity. A design-based research approach, which integrates iterative cycles of design, implementation, and evaluation, could provide valuable insights into how the 5E model can be adapted to local educational contexts to improve both conceptual understanding and student attitudes.

2.7.2. Identified Gaps in the Existing Literature

Despite this robust evidence, several critical gaps justify the need for the current study. First, there is a pronounced contextual gap. The majority of cited studies are from contexts such as the United States, Jordan, and Turkey. There is a severe shortage of empirical research on the implementation and efficacy of the 5E model within Sub-Saharan African educational settings, particularly in Ethiopia, where factors like large class sizes, resource constraints, a dominant teacher-centered pedagogical tradition, and specific curriculum structures may significantly influence implementation and outcomes (Azmi & Mohamed, 2014) Second, a methodological gap exists. Many prior studies employ quasi-experimental designs that test a pre-defined version of the 5E model. Few utilize a Design-Based Research (DBR) approach, which is essential for iteratively adapting, implementing, and understanding how the model works and can be sustainably integrated within the unique ecosystem of a specific, real-world classroom (Anderson & Shattuck, 2012).Third, there is a topical and integrative gap. While studies show general benefits in biology, targeted research on its application to notoriously difficult threshold concepts like enzymology which requires dynamic, systems-level reasoning is limited (Loertscher *et al.*, 2014). Furthermore, studies often measure conceptual understanding and attitude in isolation; rigorous, integrated investigation into how the 5E model simultaneously influences both cognitive and affective outcomes for a specific, complex topic is needed.

2.7.3. How the Current Study Fills These Gaps

This study is strategically designed to address these interconnected gaps. To bridge the contextual gap, the research is firmly situated at Fasilo Secondary School in Bahir Dar, Ethiopia. It were not merely import the 5E model but were actively engineer a contextually adapted version through collaboration with local teachers, ensuring it is feasible and relevant within the local constraints and opportunities. To address the methodological gap, the study employs a Design-Based Research (DBR) framework. This involves iterative cycles of design, enactment, analysis, and redesign, moving beyond simply testing effectiveness to developing a deep, practical understanding of how to make the 5E model work in this specific setting and generating practical design principles for similar environments. Finally, to fill the topical and integrative gap, the investigation focuses explicitly on enzymes, a recognized threshold concept, and employs a mixed-methods approach to rigorously examine the intertwined development of conceptual understanding (through concept tests and misconception analysis) and attitude (through targeted surveys and interviews) within the same intervention. While international research supports the 5E model's effectiveness (Joswick & Hulings, 2024), no published studies have investigated its implementation for teaching enzymes in Ethiopian secondary schools. This study addresses that gap by employing a Design-Based Research (DBR) framework. It were commence with Phase 1: a structured needs assessment using diagnostic tests and surveys to empirically baseline students' conceptual understanding and attitudes, followed by collaborative workshops with teachers to co-create a contextually appropriate prototype 5E unit on enzymes. This approach moves beyond identifying the problem to actively developing a practical, evidence-based solution responsive to the local context.

Therefore, this study aims to contribute not only a validated, localized instructional tool but also rich, contextualized knowledge about implementing constructivist pedagogy to overcome a fundamental learning barrier in an under-researched educational context.

The overarching framework guiding this study is Design-Based Research (DBR) . DBR is a pragmatic methodology aimed at developing effective educational interventions through iterative cycles of design, enactment, analysis, and redesign in authentic classroom settings, simultaneously contributing to practical solutions and theoretical understanding (Tashakkori *et al*., 2010).

Therefore, this study aims to extend the existing literature by exploring the effects of the 5E instructional model on Grade 11 students' conceptual understanding and attitudes toward learning enzymes at Fasilo Secondary School in Bahir Dar, Ethiopia. By adopting a design-based research framework, this study seeks to contribute to both theoretical understanding and practical application of the 5E model in under-researched educational settings.

2.8. Theoretical Framework

This study is grounded in Constructivist Learning Theory, which posits that learners actively construct their own understanding and knowledge of the world through experiences and reflection (Lourenço, 2012). The 5E Instructional Model is a direct application of these constructivist principles, promoting active, inquiry-driven learning over passive information reception. Several foundational theories further inform the model's effectiveness. Piaget's Theory of Cognitive Development is reflected in the 5E cycle's structured phases such as Explore and Elaborate where students interact with materials, challenge existing schemas, and assimilate or accommodate new knowledge (Grau *et al*., 2021). Vygotsky's Social Constructivism emphasizes the role of social interaction and scaffolding, which aligns with the collaborative and guided discussions in the Explore and Explain phases, helping learners operate within their Zone of Proximal Development (Cole & Scribner, 1978). Dewey's Experiential Learning underscores learning through hands-on experience and reflection, mirrored in the Engage and Explore phases where students investigate phenomena before formal explanation (Duckworth *et al*., 2018). Additionally, Ausubel's Meaningful Learning Theory highlights the importance of connecting new information to prior knowledge, a process supported by the 5E model's Engage phase and Elaborate phase (Ausubel, 1968). Among these, Constructivism serves as the primary theoretical lens because the 5E model is explicitly designed to foster knowledge construction through inquiry, collaboration, and reflection. Its phases systematically create the conditions for conceptual change a central aim of constructivist pedagogy making it especially suitable for addressing persistent misconceptions in complex topics such as enzymology.

2.8.1. Conceptual Framework

The conceptual framework illustrates the relationship between the independent variable (the 5E Instructional Model) and the dependent variables (conceptual understanding and attitude toward learning enzymes). It also acknowledges the mediating role of the educational context (Fasilo Secondary School) and the Design-Based Research process, which ensures iterative refinement. Unlike a static linear model, this conceptual framework incorporates an iterative, cyclical relationship consistent with the DBR approach. Each implementation cycle provides feedback that informs refinements to the instructional design, which in turn influences student outcomes. This cyclical process continues until the intervention is optimized for the local context.

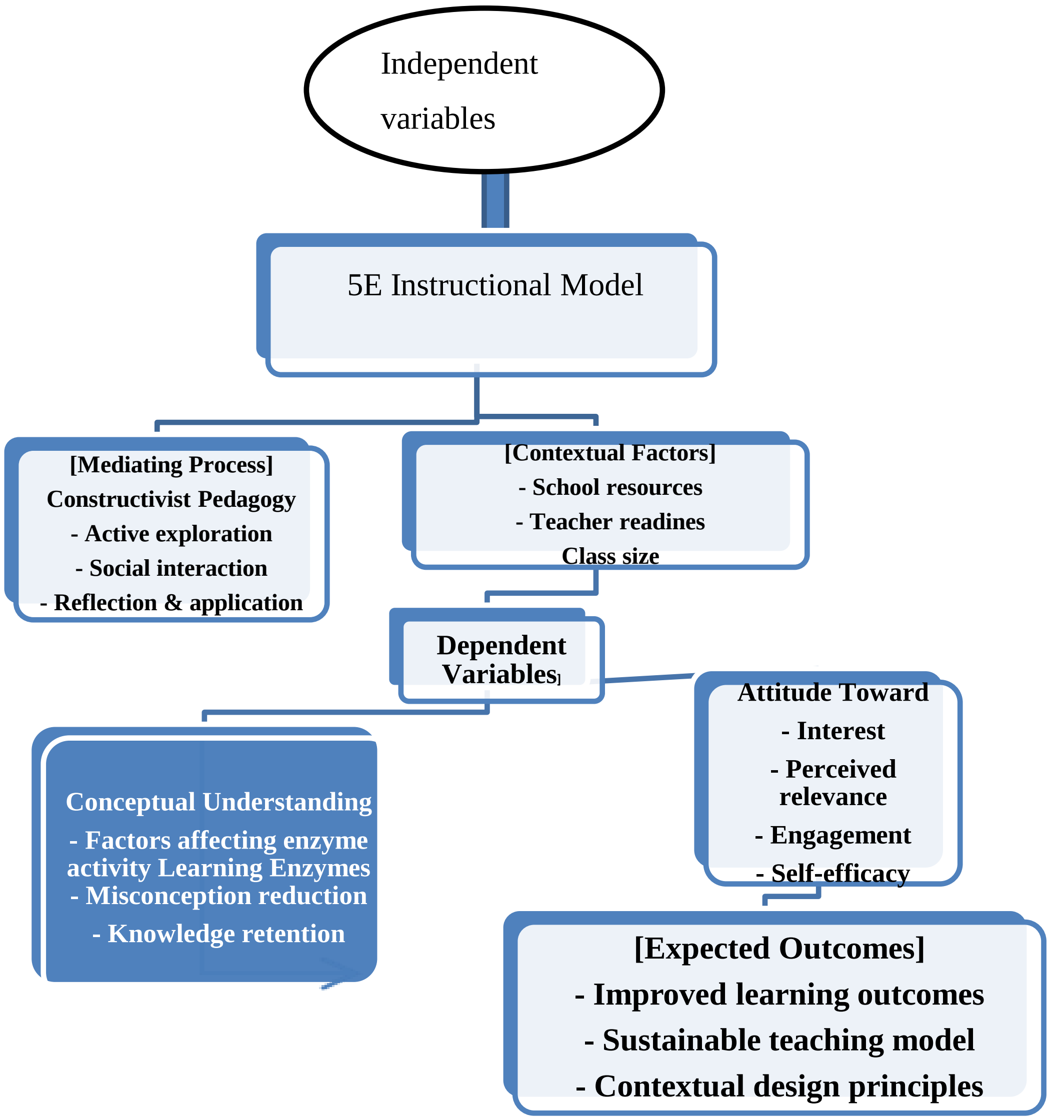


Figure 1 Conceptual Framework of the 5E Instructional Model and Its Influence on Students' Conceptual Understanding and Attitudes Toward Learning Enzymes.

CHAPTER THREE: METHODOLOGY

3.1. Research Paradigm

The research paradigm guiding this study is Pragmatism. Pragmatism is a philosophical framework that prioritizes practical, real-world solutions and endorses the use of multiple methods of inquiry to solve problems (Creswell & Inoue, 2025). Its central tenet is to focus on in a given context, valuing actionable outcomes and the consequences of ideas over adherence to a single, absolute truth (Morgan & Morgan, 2014). This paradigm is particularly suited to applied educational research where the goal is to develop effective interventions within authentic settings (Albertse, 2025; Kaushik & Walsh, 2019).

Pragmatism validates the study's emphasis on utility and practical application. The primary objective extends beyond merely testing the efficacy of the 5E model in the abstract. It is to generate a contextually adapted, usable instructional unit and a set of evidence-based design principles that teachers can apply (Henderson *et al*., 2011). Pragmatism legitimizes this goal of producing tangible, useful knowledge that directly informs and improves classroom practice.

Aligned with this pragmatic philosophy, the study formally commenced with Phase 1 of the DBR framework: the analysis of practical problems and the development of a prototype solution in collaboration with practitioners (Azmi & Mohamed, 2014). This phase involved a structured needs assessment, including a diagnostic concept test and attitude survey to empirically baseline students' understanding and perceptions, followed by collaborative design workshops with participating biology teachers. In these workshops, diagnostic data were analyzed to co-create a contextually appropriate prototype 5E Instructional Model unit on enzymes. This prototype was theoretically grounded in constructivist principles while being pragmatically adapted to the school's resources and constraints. By following this DBR approach, the study moves beyond merely identifying a problem to actively engaging in a rigorous, iterative process of designing, implementing, and refining a practical solution that is deeply informed by and responsive to the local educational context.

3.2. Research Design

This study employed a mixed methods, and an embedded design (QUAN-qual) (Anderson & Shattuck, 2012). In this design, a primary quantitative experimental framework is enhanced by the embedded, concurrent collection of qualitative data. The quantitative component, using pre and post-tests (the Enzymes Concept Test and Biology Attitude Scale), provides objective, generalizable measures of the intervention's impact on student outcomes. Simultaneously, the qualitative component comprising classroom observations, student interviews, and artifact analysis generates rich, contextual insights into the process of implementation, student engagement, and emergent classroom dynamics.

This specific mixed methods is particularly appropriate for the Design-Based Research (DBR) framework guiding this study for two key reasons. First, DBR requires not only testing whether an intervention works but, more importantly, understanding how and why it functions within a complex real-world setting (Anderson & Shattuck, 2012). The embedded qualitative data directly serves this explanatory purpose, uncovering the mechanisms behind the quantitative results. Second, DBR is inherently iterative, relying on formative feedback to redesign the intervention. The continuous flow of qualitative data during implementation provides the real-time, nuanced feedback necessary to inform the systematic refinements between cycles (e.g., from Phase 2 to Phase 3). Thus, this mixed methods design is not merely an add-on; it is structurally integral to fulfilling DBR's core aim of developing a contextually effective and theoretically informed educational solution.

The study followed five key phases. In Phase 1, the researcher worked with the school to understand the problem and design a first version of a 5E lesson on enzymes. In Phase 2, this lesson was taught to one class while another class learned using the usual method, and systematic observations were recorded. In Phase 3, all collected information (test results and student feedback) was analyzed to identify what worked and what did not, and the lesson was improved. In Phase 4, the improved lesson was taught to evaluate its effectiveness. Finally, in Phase 5, all findings were synthesized to create a clear set of guidelines that other teachers in similar schools can use to teach enzymes effectively.

3.3. Study Population and Sampling

A purposive sampling technique was used to select the participant classes. From the total of seven sections of Grade 11 intact classes available at Fasilo Secondary School, two intact classes, section ‘’A’’ with a total number of student 19 and ‘’B’’ with a total number of student 19 were purposively selected. The rationale for using purposive sampling at this stage is to ensure that the selected classes are suitable for the intervention and share key characteristics that enhance the validity of the comparison. The specific criteria for selection were include:

Similar class size: To control for the potential influence of class size on instructional quality and student engagement.

Shared teacher characteristics: Ideally, both classes were taught by the same biology teacher to minimize teacher-variable effects.

Scheduling compatibility: To ensure the intervention can be implemented without disrupting the school's regular timetable.

Willingness to participate**:** Based on the collaborative DBR approach, teacher willingness is essential.

Once the two intact classes are purposively selected, a simple random sampling technique was used to assign one class to the experimental group and the other to the control group. This was done through a straightforward method, a coin toss or drawing lots. E.g, the name of one class were written on a piece of paper and placed in a container with a paper for the other class; the first paper drawn were designated the experimental group, and the remaining class served as the control group. This random assignment at the group level helps to strengthen the internal validity by reducing the risk of selection bias, ensuring that any pre-existing differences between the groups are due to chance rather than systematic selection.

3.4. Data Collection Instruments

Several instruments, including Enzymes Concept Test (ECT), observation schedule, Biology Attitude Scale (BAS) questionnaire, observation and interview schedule were used.

3.4.1 Enzymes Concept Test (ECT)

The Enzymes Concept Test (ECT) was adapted from the established instruments (e.g., (Machová & Ehler, 2023) to measure conceptual understanding and identify misconceptions. This test was administered for both groups before and after the implementation of the intervention as a pre and posttests.

3.4.2. Biology Attitude Scale (BAS) Questionnaire

A Biology Attitude Scale (BAS) questionnaire was adapted from validated instruments in science education (Reid, 2006; Osborne et al., 2003; Prokop et al., 2007) to assess students' affective domain towards learning biology, with a specific focus on the topic of enzymes. Items were adapted to focus specifically on "enzymes" rather than general biology, following the topic-specific attitude measurement approach recommended by Henderson et al. (2025). This Likert-scale instrument measures key dimensions such as interest, perceived relevance, self-efficacy, and enjoyment related to the subject matter.

3.4.3. Classroom Observation Schedule

A structured yet flexible classroom observation schedule was used to document the implementation process, student engagement, and teacher-student interactions during the 5E lesson cycles. This qualitative instrument focus on capturing evidence of constructivist practices such as inquiry, collaboration, and hands-on exploration as well as noting challenges and the students responses. Observations were conducted primarily in the experimental group classroom to gather rich, contextual data on how the intervention unfolds in real time, which is crucial for the iterative redesign phase of the Design-Based Research.

3.4.4. Semi-Structured Interview Schedule

A semi-structured interview schedule was used to conduct in-depth interviews with a purposively selected subset of students from the experimental group after each implementation cycle of the 5E unit on enzymes. The interviews explored students' experiences, challenges, conceptual reasoning (e.g., lock-and-key model, factors affecting enzyme activity), and affective responses (e.g., interest, confidence) to the 5E model. These interviews provided qualitative insights that complemented the quantitative data from the Enzymes Concept Test (ECT) and Biology Attitude Scale (BAS).

Purposive sampling was used to select 6 interview participants from the 19 students in the experimental group for three reasons. First, to gather information-rich cases, students were selected based on their level of improvement on the ECT (high, medium, and low) to capture diverse perspectives (Patton ,2015). Second, to achieve maximum variation, students were selected to represent different attitude shifts on the BAS, different participation levels during the 5E phases, and both genders (Creswell & Inoue, 2025). Third, for feasibility within this DBR study, interviewing all 19 students would have been impractical given the need for rapid analysis and refinement between implementation cycles (Chigona *et al.*, 2024) Specific selection criteria include voluntary participation, representation of top 25%, middle 50%, and bottom 25% on the ECT pre-test, gender balance, and variation in observed classroom engagement.

3.4.5. Artifact Collection

A systematic collection of student-generated artifacts were serve as a key qualitative data source to triangulate findings and provide evidence of the learning process. This includes student worksheets completed during the Explore and Elaborate phases, outputs from collaborative group work (such as concept maps or posters), and individual reflection notes written during or after lessons. These artifacts are authentic products of the 5E instructional sequence and were collected from the experimental group throughout both implementation cycles. Analysis of these materials were provided a tangible evidence on students' conceptual reasoning development, application of knowledge, metacognitive awareness, and collaborative skills, offering a direct window into how the intervention shapes learning in practice.

3.4.6. Validity and Reliability of Instruments

The Enzymes Concept Test (ECT), content validity was ensured by adapting items from validated instruments and expert review, and reliability was measured using the Kuder-Richardson Formula 20 (KR-20). Similarly the Biology Attitude Scale (BAS) questionnaire was adapted from established scales and reviewed for relevance, with its internal consistency assessed via Cronbach's Alpha. The Classroom Observation Schedule was made credible by triangulating findings with other data, while an inter-rater reliability check with a second observer ensured dependability. For the Semi-Structured Interview Schedule, member checking with participants and inter-coder agreement with a researcher were strengthen validity and reliability. Finally, Artifact Collection supported validity through triangulation, and reliability was ensured using a code-recode procedure and peer debriefing to confirm consistent analysis.

3.5. Data Collection Procedure

Phase 1: Preliminary Design & Analysis

Administering pre-tests (the Enzymes Concept Test and Biology Attitude Scale) to both the control and experimental groups was methodologically essential for two reasons. First, it establishes a clear baseline, allowing the study to attribute any post-intervention differences to the 5E model rather than pre-existing group disparities. Second, it provides diagnostic insight into students' starting knowledge and attitudes, enabling a deeper analysis of how conceptual understanding and attitude were affected throughout the intervention. This approach not only measures overall effectiveness but also enriches the explanatory depth of the findings within the Design-Based Research framework.

Phase 2: Implementation Cycle 1

The first version of the 5E learning unit were implemented with the experimental group, while the control group continuedwith traditional instruction. During this enactment, data were collected concurrently through structured classroom observations, maintenance of a detailed researcher journal, and the ongoing analysis of student work (Cobb *et al*., 2003).

Activities Conducted During Implementation Cycle 1

1. Engage Phase

The class teacher asked a provocative question: "Why does your stomach not digest itself?" to activate prior knowledge. A demonstration using hydrogen peroxide with raw liver (producing bubbles) versus boiled liver (no bubbles) was shown to generate curiosity. Students wrote their initial ideas about enzymes on index cards as a preconception check.

2. Explore Phase

Students worked in small groups of five members to investigate how temperature affects enzyme activity using potato extract (catalase) and hydrogen peroxide at different temperatures (ice, room temperature, warm, and boiled). Groups mixed the materials, observed bubble formation, and recorded their findings in a data table.

3. Explain Phase

The researcher scored all tests, calculated mean scores and standard deviations, and conducted ANCOVA, Mann-Whitney U, and Wilcoxon signed-rank tests as appropriate for the data distributions. Interviews, observation notes, the researcher journal, and student worksheets were transcribed and analyzed using thematic analysis to identify recurring themes, challenges, and persistent misconceptions

4. Elaborate Phase

Students discussed a real-world problem: "Why do people with lactose intolerance need lactase supplements?" Students then predicted what would happen if a lactase supplement was heated, justifying their answer using the lock-and-key model.

5. Evaluate Phase

Students completed an exit ticket with three questions: (a) What is an enzyme? (b) What happens when an enzyme is boiled? (c) Draw and label the lock-and-key model.

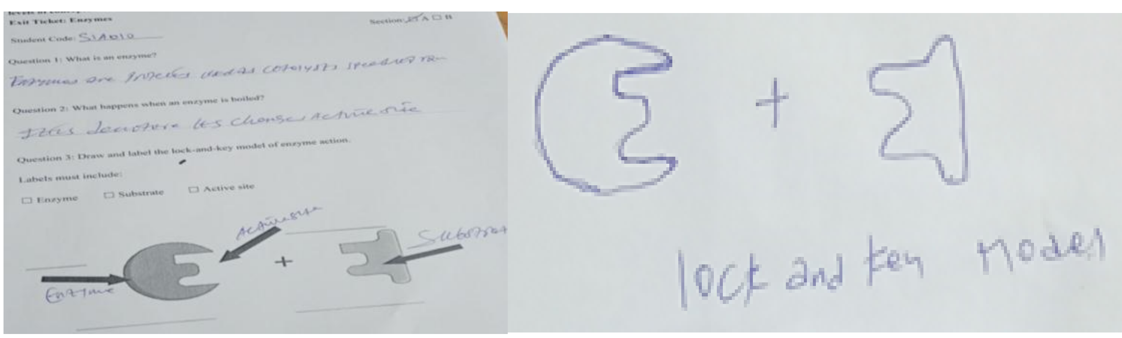


Figure 2: Exit ticket and lock and key model

Phase 3: Analysis and Redesign

This phase focused on the formative learning generated through the initial implementation, where analysis directly informed intervention refinement (Edelson, 2002). Following the first cycle, post-tests (ECT, BAS) were administered to both groups, and semi-structured interviews were conducted with selected students and the participating teacher. The researcher scored all tests, calculated mean scores and standard deviations, and conducted t-tests to compare within-group and between group differences. Interviews, observation notes, the researcher journal, and student worksheets were transcribed and analyzed using thematic analysis to identify recurring themes, challenges, and persistent misconceptions (e.g., "enzymes are used up"). Quantitative and qualitative findings were triangulated using a comparison matrix to identify areas of convergence and divergence. Strengths of the first prototype (e.g., hands-on investigation, lock-and-key model) and weaknesses (e.g., insufficient Explore time, lack of materials, quiet student non-participation) were compiled. The researcher met with the participating biology teacher to review findings, discuss practical suggestions, and agree on feasible refinements. Based on this analysis, the Because the normal class period is 40 minutes, the 5E phases were spread across three periods. Refinements for Cycle 2 included: Explore phase increased to 3 periods minutes total across two periods; temperature conditions reduced from four to three (ice, warm, boiled); pre-drawn data collection sheets; pre-assigned group roles, and for lock-and-key; "myth vs. fact" chart for misconceptions; and diagrams showing denaturation as shape change. The refined unit was documented as a complete lesson plan across three periods, and all materials were prepared for Cycle 2 implementation.

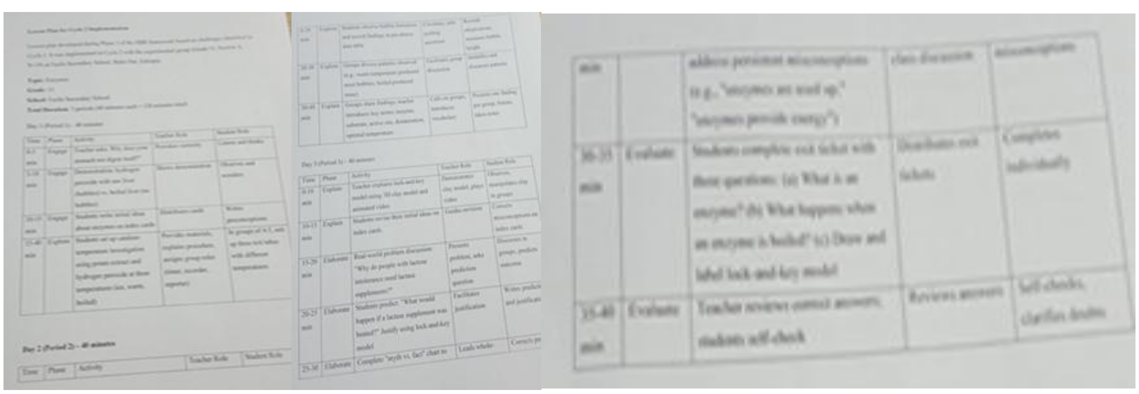


Figure 3 : 5E Lesson plan

Phase 4: Implementation Cycle 2

The refined 5E unit were implemented to test improvements and further validate the design. Data collection (observations, interviews, post-test) were repeated to assess the impact of the refinements. Emphasizes how DBR methods are tailored to study learning in authentic, complex settings (like a classroom) (Wang *et al*., 2005). The refinement activities were conducted during this cycle. First, the revised Explore phase was implemented by shortening the laboratory investigation from four to three temperature conditions (ice, warm, boiled), assigning pre-assigned group roles ,and using a simplified data collection sheet with pre-drawn tables. Second, enhanced instructional support was provided through a hands-on paper modeling activity where students cut and folded paper to represent enzyme-substrate interactions, a collaborative "concept sort" activity where students grouped cards with enzyme statements into "true" and "false" categories to address misconceptions, and a teacher-led think-aloud demonstration using a whiteboard animation to show how heat changes enzyme shape (denaturation). Third, repeated data collection for comparison included classroom observations documenting student engagement, semi-structured interviews with 6 selected students to gather feedback on improvements, and post-tests (ECT and BAS) administered to both experimental and control groups to compare outcomes with Cycle 1 results.

Phase 5: Final Analysis and Design Principle Formulation

A final comparative analysis of all data were conducted. Finally the study formulated a set of evidence-based design principles for using the 5E model in similar contexts.

Strategies to Minimize Contamination Between Groups

Several strategies were implemented to minimize contamination between the experimental and control groups. First, the experimental and control groups were in different physical classrooms with separate entrances. Second, the experimental group's 5E lessons and control group's traditional lessons were scheduled at different times of the day to prevent students from discussing content between classes. Third, while the same teacher delivered instruction to both groups to control teacher effects, the teacher followed strict protocols: for the control group, only traditional lecture/discussion methods were used; for the experimental group, the teacher followed the 5E lesson plan; the teacher was instructed not to discuss the 5E activities with the control group. Fourth, students were not informed that one group was receiving a "special" instruction method to prevent demotivation or cross-group discussion.

Finally, the researcher conducted all observations and assessments with both groups to ensure consistency in data collection.

3 .6. Data Analysis

Both quantitative and qualitative data analysis techniques were employed. For quantitative data, all statistical analyses were conducted using SPSS software (Version 26.0). First, descriptive statistics (mean, standard deviation, and percentage gain) were calculated for the experimental and control groups on the Enzymes Concept Test (ECT) and Biology Attitude Scale (BAS). Second, an Analysis of Covariance (ANCOVA) was conducted to compare the post-test scores of the experimental and control groups on the ECT, using the pre-test scores as a covariate to control for baseline differences and provide a more precise estimate of the intervention's effect (Clark & Plano, 2022). Third, due to pre-existing differences in attitude scores and the non-normal distribution of Likert-scale data, a Mann-Whitney U test was used to compare post-test attitude scores between groups. Fourth, a Wilcoxon signed-rank test was conducted to measure attitude change within the experimental group from pre-test to post-test. Concurrently, qualitative data from semi-structured interviews, classroom observations, and collected artifacts underwent thematic analysis to identify, code, and interpret recurring patterns, challenges, and insights related to the implementation and student experience (Braun *et al*., 2011).

3.7. Ethical Considerations

This study was adhered to strict ethical standards throughout its implementation. Formal written permission were first be obtained from the Bahir Dar University research ethics committee and the administration of Fasilo Secondary School (Cohen et al., 2022). Prior to data collection, informed consent were secured from all participating teachers and from the students' parents or guardians, clearly outlining the study's purpose, procedures, risks, benefits, and the voluntary nature of participation, including the right to withdraw at any time without penalty (Calvert *et al*., 2017).

CHAPTER FOUR: RESULTS

4. RESULTS

4.1. Pre-intervention Test Score Analysis of Students'conceptions of enzymes

4.1.1. Pre-intervention Students'conceptions of enzymes (Qualitative Findings)

The results of Levene's test for equality of variances revealed a non-significant difference in the variance of the two groups (Sig. = .982); therefore, equal variances were assumed. As displayed in Table 1, the ECT pre-test mean score of the experimental group was 4.158 (SD = 1.1062), and that of the control group was also 4.158 (SD = 1.1062). The independent samples t-test result indicated a statistically insignificant difference, $t(36) = 0.000$, $p = 1.000$. This confirms that the two groups were equivalent in their conceptual understanding of enzymes before the intervention.

As displayed in Table 1, before the intervention, most students had low conceptual understanding (mean 4.158/10) and held multiple misconceptions. From these, the most common conceptions were, being that boiling kills enzymes (70%), followed by enzymes being used up (60%) and enzymes providing energy (50%). This pre-intervention finding showed that most students' prior conceptions about enzyme related ideas are not correct conceptions, they are misconceptions.

Table 1: Pre-intervention Students' Conceptions About Enzymes

Misconception	Example Student Response	Frequency
Boiling "kills" enzymes	"Heat kills enzymes like it kills bacteria"	14/19
Enzymes are "used up" during reactions	"Enzymes disappear after they work"	12/19
Enzymes "provide energy" for reactions	"Enzymes give energy to speed up reactions"	10/19
Any enzyme can work on any substrate	"One enzyme can do many jobs"	8/19
Enzymes are living organisms	"Enzymes are small living things in the body"	6/19

4.1.2. Pre‑intervention Students'conceptions of Enzymes (Qualitative Findings)

In addition to the above quantitative findings, the qualitative data revealed the presence of some incorrect conceptions in the students mind before the intervention. For example, during Phase 1 DBR analysis, students' initial ideas about enzymes were collected through index cards (Engage phase) and pre-test responses. Thematic analysis revealed persistent misconceptions (Fgure 1).

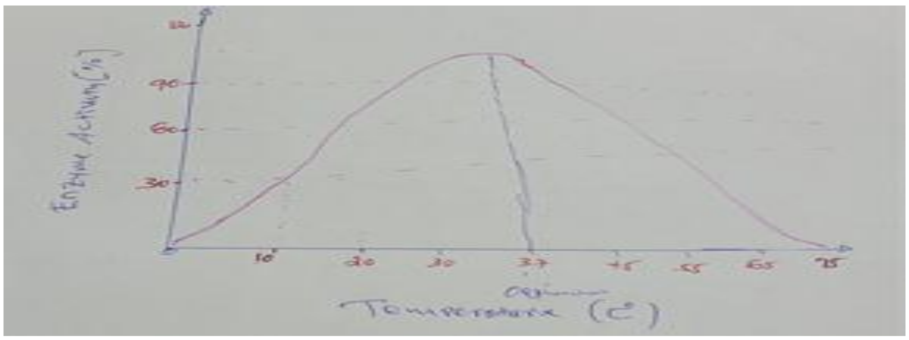


Figure 4: misconceptions of students

Figure 4 illustrates students' pre intervention understanding of the relationship between substrate concentration and reaction rate at different temperatures. The graph reveals a systematic misconception: while students correctly anticipated an initial increase in reaction rate with rising substrate concentration, their responses showed an unexpected decline at higher temperatures (85°C to 90°C). This pattern indicates that students incorrectly believed that very high temperatures decrease or reverse the effect of concentration. Scientifically, both higher temperature and higher substrate concentration increase reaction rates until enzyme saturation is reached. This misconception aligns with findings from previous studies (Dorsah & Acquaye, 2018)) and suggests that students hold fragmented, intuitive models rather than coherent scientific understanding.temperature and higher concentration increase reaction rates. Therefore, the figure does not demonstrate correct scientific understanding but instead reveals a systematic misconception about how temperature affects concentration-related processes.

4.2. Effective Activities during the 5E Instructional Model implimentation

4.2.1. Qualitative Findings about Effective Activities during the 5E Instructional

Data from classroom observations, researcher journals, semi-structured interviews with selected students (n=6), and teacher interviews were analyzed thematically. The following activities were identified as effective.

During Cycle 1 of the 5E instructional model implementation, each phase included specific activities that demonstrated clear evidence of effectiveness. In the Engage phase, the teacher used a provocative question e.g., Why does your stomach not digest itself ? which successfully sparked student curiosity, with 15 out of 19 students writing detailed initial ideas on index cards. During the Explore phase, students conducted a hands-on catalase-temperature investigation using potato extract and hydrogen peroxide, which resulted in high participation and active engagement; one student noted, I understood better when I saw the bubbles myself. In the Explain phase, the teacher presented a lock-and-key model diagram with interactive explanation, leading to 85% of students correctly labeling the active site and substrate on their exit tickets. The Elaborate phase involved a real-world problem discussion about lactose intolerance, which helped students make personal connections; one student remarked, "*Now I understand why my father takes lactase pills before drinking milk.*" Finally, the Evaluate phase used an exit ticket with three questions,and the visual drawing component proved effective in helping to identify remaining misconceptions among students. However, there were some challenges, such as, time shortage and less students' participation at the cycle 1 implimenttion phases.

4.2.2. Refined Activities in Cycle 2

Based on challenges identified in Cycle 1 (such as insufficient time, quiet students not participating, and the need for clearer visuals), several refined activities were implemented in Cycle 2. First, pre-assigned group roles were introduced, and observation notes showed that all students participated, with the teacher noting that even shy students had responsibilities and contributed. Second, a simplified data collection sheet with pre-drawn tables helped students record data more accurately, with fewer errors in temperature and bubble rate columns. Third, paper modeling of enzyme-substrate interaction using cut-andfold paper was used; one student explained, "*Folding the paper helped me see how the enzyme and substrate fit together. I will not forget the lock-and-key model"*.

Table 2: BAS (Biology Attitude Scale) Total Scores

Group	Pre-test Mean (SD)	Post-test Mean (SD)	Gain
Experimental	31.32 (7.34)	38.58 (4.62)	+7.26
Control	25.11 (6.13)	29.53 (3.63)	+4.42

Both groups showed improved attitude scores from pre-test to post-test. However, the experimental group (5E model) had a larger gain (+7.26) compared to the control group (+4.42). The experimental group's post-test mean (M = 38.58, SD = 4.62) was also higher than the control group's (M = 29.53, SD = 3.63). These descriptive results suggest the 5E model was more effective in improving students' attitudes toward learning enzymes.

4.3. Effect of the Enhanced 5E-Model implementation on the Students' Conceptual Understanding and Attitude

4.3.1. Descriptive Statistics of Conceptual Understanding and Attitude

To analyze the effect of the enhanced 5E-model implementation on the improvement of students conceptual understanding and attitude, a descriptive statistics were computed to summarize and compare the central tendency and variability of ECT and BAS scores for the experimental and control groups before and after the intervention.

Table 3: Analysis of pre-and post tests of Enzymes Concept Test and Biology Attitude Scale

Group		N	Minimum	Maximum	Mean	SD
Experimental	ECT Pre test score(0-10)	19	2.0	6.0	4.158	1.106
	ECT Post test score(0-10)	19	5.0	8.5	6.947	.984
	BAS total pre test(10 items)	19	22.00	50.00	31.3158	7.341
	BAS total post test(10 items)	19	33.00	50.00	38.578	4.622
Control	ECT Pre test score(0-10)	19	2.0	7.0	4.158	1.106
	ECT Post test score(0-10)	19	3.5	8.0	5.211	1.031
	BAS total pre test(10 items)	19	13.00	40.00	25.105	6.127
	BAS total post test(10 items)	19	21.00	40.00	29.526	3.626

Note: ECT = Enzymes Concept Test; BAS = Biology Attitude Scale

As shown in Table 3, both groups have identical mean pre-test scores on ECT Pre-test score (4.158) and almost identical standard deviations (1.106). This indicates random assignment or matching was successful with no prior difference in enzyme knowledge. However, the experimental group's mean ECT Post-test score (6.947) is substantially higher than the control group's (5.211). The gain (experimental = +2.79 points, control = +1.05 points) suggests the 5E model led to greater improvement. Standard deviations are similar between groups, indicating consistent effects**.**

Regarding the BAS total pre-test (10 items), the experimental group had a mean score of 31.32 (SD = 7.34), while the control group had a mean score of 25.11 (SD = 6.13). Unlike the ECT, this pre-existing difference in attitude was statistically significant. Therefore, the

Mann-Whitney U test was used to compare post-test attitude scores between groups, as presented in the following section.

4.4. Analysis of the Effect of the Re-designed Activities on the students' Conceptual understanding and Attitude

4.4.1. Analysis of the Effect of the Re-designed Activities on Conceptual understanding

4.4.1.1. Assumption Checking for ANCOVA on Conceptual Understanding

Before running the main ANCOVA, the homogeneity of regression slopes assumption was tested by including the interaction term Group * ECT_Pre.

Table 4: Homogeneity of regression

Source	F	df1, df2	Sig.
Group * ECT_Pre	1.022	1, 34	.319

Note: ECT_Pre = Enzymes Concept Test Pre-test Score

Since $p = .319 > .05$, (Table 4), the interaction is not significant, indicating the relationship between pre-test and post-test scores of conceptual understanding does not differ between groups. The assumption is met.

4.4.1.2. Main ANCOVA Results for Conceptual Understanding

A one-way ANCOVA was conducted to compare post-test scores of conceptual understanding (measured by ECT) using pre-test scores as a covariate.

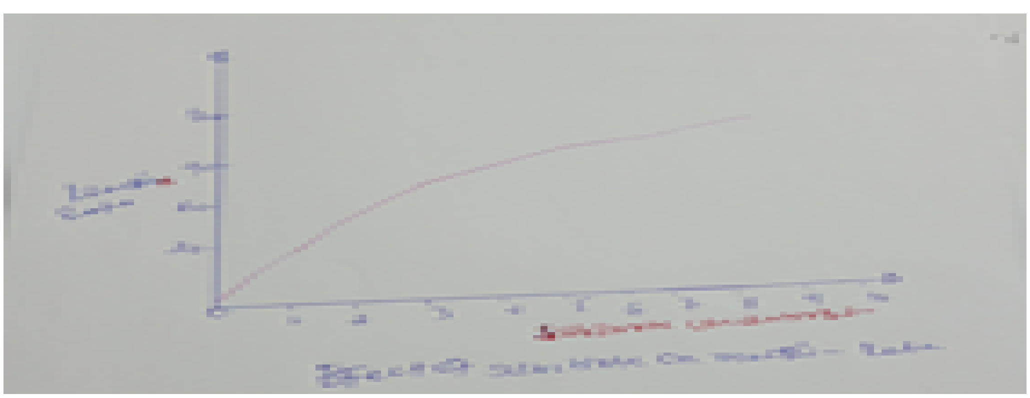


Figure 5 : Effect of substrate concentration

Table 5: Tests of Between Subjects Effects

Source	Sum of Squares	Df	Mean Square	F	Sig.	Partial (η^2)
ECT_Pre	35.465	1	35.465	1088.655	<.001	.969
Group	28.658	1	28.658	879.698	<.001	.962
Error	1.140	35	0.033			

Note: ECT_Pre = Enzymes Concept Test Pre-test Score

A one-way analysis of covariance (ANCOVA) was conducted to compare the post-test scores of the experimental and control groups on the Enzymes Concept Test (ECT), using pre-test scores as a covariate.

The main effect of the teaching method (Group) was statistically significant, F (1,35) = 879.70. F (1,35) = 879.70, $p<.001p<.001$, partial $\eta2=.962$. This indicates that after controlling for prior knowledge, students in the experimental group (5E model) performed significantly better on the post-test than those in the control group (traditional instruction). The effect size is very large, with the teaching method explaining 96.2% of the variance in post-test scores after accounting for the covariate.

The covariate (ECT pre-test) was also significant, F (1,35) = 1088.66. F (1,35) = 1088.66, $p<.001p<.001$, partial $\eta2=.969$,confirming that prior knowledge was strongly associated with post-test performance. Levene's test was not significant ($p>.05p>$), satisfying the assumption of equal error variances.

Table 6: Estimated Margin means (Adjusted)

Group	Adjusted Mean	Std. Error	95% CI Lower	95% CI Upper
Experimental	6.947	0.041	6.863	7.031
Control	5.211	0.041	5.126	5.295

Table 6 displays the estimated marginal means for the experimental and control groups. The experimental group (M = 6.947) outperformed the control group (M = 5.211), with nonoverlapping confidence intervals indicating a significant difference. This table demonstrates that the intervention had a positive effect on student outcomes.

After controlling for pre-test scores, the experimental group's adjusted mean (6.947) was significantly higher than the control group's (5.211), $F(1,35)=879.70$, $p<.001$, partial $\eta^2=.962$. The effect size is very large, with the teaching method explaining 96.2% of the variance in post-test scores.

4.4.2. Analysis of the Effect of the Re-designed Activities on Attitude

Due to the pre-existing difference in attitude and the non-normal distribution of Likert-scale data, a Mann-Whitney U test was used to compare post-test attitude ranks between groups.

4.4.2.1. Mann-Whitney U Test for Post-Test Attitude between Groups

Due to the pre-existing difference in attitude and the non-normal distribution of Likert-scale data, a Mann-Whitney U test was used to compare post-test attitude ranks between groups.

Table 7: Rank table Mann-Whitney U

Group	N	Mean Rank	Sum of Ranks
Experimental	19	28.34	538.50
Control	19	10.66	202.50

As shown in Table 7 the results of the Mann-Whitney U test comparing the experimental and control groups. The experimental group (N = 19) had a significantly higher mean rank (28.34) than the control group (N = 19, mean rank = 10.66), with U = 12.50, $p < .001$. This indicates that the experimental condition produced higher scores than the control condition.

4.4.2.2. Wilcoxon Signed-Rank Test for Attitude Change within Experimental Group

To determine if the experimental group's attitude significantly improved from pre-test to post-test, a Wilcoxon signed-rank test was conducted.

Table 8: Wilcoxon Signed-Rank Test

N	Mean Rank	Sum of Ranks	
Negative Ranks (post < pre)	0	0.00	0.00
Positive Ranks (post > pre)	18	9.50	171.00
Ties (post = pre)	1		
Total	19		

As shown from Table 9 the Wilcoxon signed-ranks test showed that 18 out of 19 participants improved from pre-test to post-test (positive ranks = 18, mean rank = 9.50), while no participants decreased (negative ranks = 0). This indicates a significant improvement after the intervention.

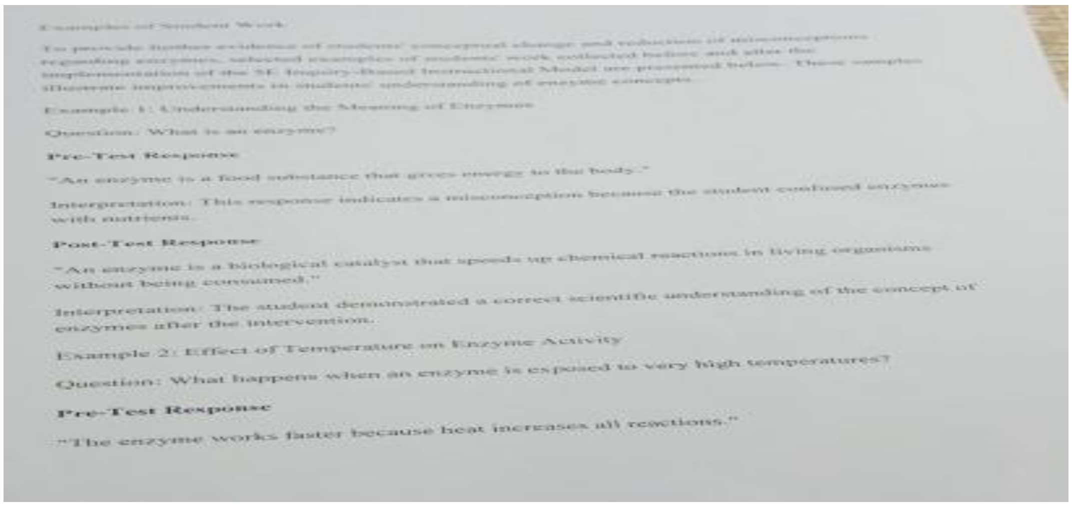
Table 9: Test statistics table for Wilcoxon Signed-Rank Test

Statistic	Value
Z	-3.742
Asymp. Sig. (2-tailed)	< .001 (p = 0.000)

As shown from Table 10 the Wilcoxon signed-ranks test was statistically significant (Z = -3.742, p < .001), confirming that the post-test scores were significantly higher than pre-test scores.

4.4.3. Qualitative Findings on the Effectiveness of the re-designed activities in the instructional process on Students' Conceptual Understanding and Attitude

Effect of the re-designed activities during the intervention period of cycle 2 was also evaluated by using a qualitative evidences. Hence, to address Objective 4, two perception questions were administered to the experimental group (n=19) after the intervention. As shown in Table 11, 84.2% of students (57.9% Agree + 26.3% Strongly Agree) liked the 5E way of learning, with no student disagreeing, indicating a positive attitude toward the re-designed activities. As shown in Table 12, 100% of students either agreed (63.2%) or strongly agreed (36.8%) that hands-on activities helped their understanding, demonstrating the perceived effectiveness of the re-designed activities on conceptual understanding. Therefore, the re-designed 5E-inquiry-based instructional method was effective in improving both students' attitude and conceptual understanding of enzymes.


Example 1: Understanding the Meaning of Enzymes

Question: What is an enzyme?

Pre-Test Response

"An enzyme is a food substance that gives energy to the body."

Post-Test Response

"An enzyme is a biological catalyst that speeds up chemical reactions in living organisms without being consumed."

Interpretation: The student demonstrated a correct scientific understanding of the concept of enzymes after the intervention.

Example 2: Effect of Temperature on Enzyme Activity

Question: What happens when an enzyme is exposed to very high temperatures?

Pre-Test Response

"The enzyme works faster because heat increases all reactions."

Figure 6: Example of student work

Figure 6 presents an example of student work from the experimental group. The pre test response shows a common misconception: the student incorrectly stated that enzymes provide "energy to the body." Following the 5E intervention, the post test response demonstrated improved understanding, with the student correctly identifying that enzymes lower activation energy and are not consumed during reactions. This example illustrates the conceptual change that occurred for many students in the experimental group.

4.4.3.1. Reduction in Misconceptions/ conceptual understanding/ After Cycle 2

Comparison of Misconception Prevalence Before and After Cycle 2 in Table 11 showed that "the re-designed activities were highly effective in resolving persistent misconceptions. he misconception that boiling 'kills' enzymes was completely eliminated (from 74% to 0%). the misconception that enzymes are 'used up' was reduced from 63% to 11%.

Table 10: reduction of Misconception Prevalence Before and After Cycle 2

Misconception	Before Cycle 1 (Engage Phase)	After Cycle 2 (Post-test)	Reduction
Boiling "kills" enzymes	14/19 (74%)	0/19 (0%)	74%
Enzymes are "used up"	12/19 (63%)	2/19 (11%)	52% r
Enzymes "provide energy"	10/19 (53%)	1/19 (5%)	48%
Any enzyme works on any substrate	8/19 (42%)	1/19 (5%)	37%

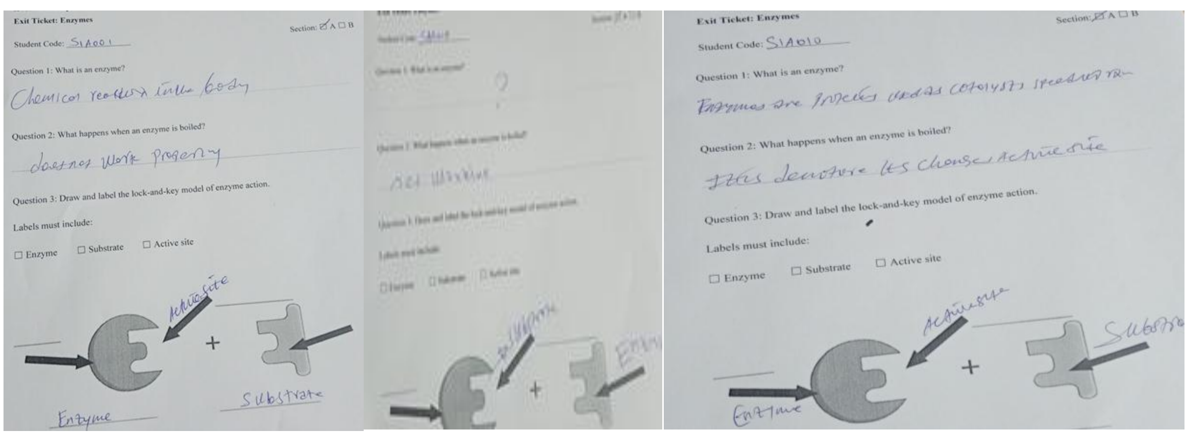


Figure 7: Exit tickets on enzymes

Figure 7 presents examples of student exit tickets from the experimental group. The responses demonstrate varying levels of understanding, with some students showing correct identification of key concepts while others continued to exhibit misconceptions. This variation highlights the importance of formative assessment within the Evaluate phase to identify students who require additional support and reinforcement.

4.4.3.2 Student Perceptions of the 5E Instructional Model

Frequency analysis was conducted on two perception questions administered only to the experimental group after the intervention. This finding relates to Objective 4 of the study: To analyze the effectiveness of re-designed activities in the implementation of 5E-inquiry-based instruction on students' conceptual understanding and attitude.

Table 11: Post Liked 5E way (For experimental group only)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Neutral	3	15.8	15.8	15.8
	Agree	11	57.9	57.9	73.7
	Strongly Agree	5	26.3	26.3	100.0
	Total	19	100.0	100.0	

Table 12: Post Hands-on helped understanding

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Agree	12	63.2	63.2	63.2
	Strongly Agree	7	36.8	36.8	100.0
	Total	19	100.0	100.0	

Regarding conceptual understanding, Table 12 shows that 100% of students either agreed (63.2%) or strongly agreed (36.8%) that the hands-on activities helped their understanding.

CHAPTER FIVE: DISCUSSION

5. Discussion of Findings

5.1. Conceptual Understanding of Enzymes

The first research question examined what conceptions of enzymes students had before the intervention. The pre-test results (mean = 4.158 out of 10, Table 1) showed that students had very low conceptual understanding and held many misconceptions. This finding supports previous literature that identifies enzymology as a difficult "threshold concept" that students struggle to understand Other studies have similarly found that both secondary and university students enter enzyme lessons with significant knowledge gaps This study identified several specific misconceptions that match patterns reported in other countries. First, 73.7% of students believed that boiling "kills" enzymes. One student said, "Heat kills enzymes like it kills bacteria." This is an example of anthropomorphic thinking treating non-living molecules as if they were alive. Research confirms that enzymes are proteins that change shape when heated, not living things that can die (Studies & Curriculum, 2019). The same misconception has been found in Ghana (Dorsah & Acquaye, 2018) and Turkey (Cardak *et al*., 2008). Second, 63.2% of students thought enzymes are "used up" during reactions. One student said, "Enzymes disappear after they work." This is incorrect because enzymes are catalysts that remain unchanged after the reaction. This misconception likely comes from everyday experiences with things that get consumed, like food or fuel(Linenberger & Bretz, 2015). Similar findings were reported in Indonesia, where 58% of students held this belief (Ademakinwa & Mohammed, 2024). Third, 52.6% of students believed enzymes "provide energy" for reactions. This violates basic thermodynamics. Enzymes lower activation energy but do not add energy to reactions (Williams *et al*., 2025). Students confuse how fast a reaction occurs with whether it is possible at all (Loertscher *et al*., 2014).

Fourth, 42.1% of students thought any enzyme can work on any substrate, and 31.6% believed enzymes are living organisms. These findings are consistent with studies from Turkey (Cardak *et al*., 2008).and Ghana (Dorsah & Acquaye, 2018). Together, these results show that students enter the enzymes unit with deep, persistent misconceptions that traditional teaching fails to correct (Joseph, 2023).

5.2. The Effective Activities for the Improvement of 5E Instructional Model to Enhance Students' Conceptual Understanding and Attitude

Regarding the second research question about effective activities for the improvement of the 5E instructional model, the Design-Based Research (DBR) framework allowed the researcher to refine the unit based on real classroom feedback. Three key supporting strategies emerged.

First, hands-on exploration must come before formal explanation. Students needed to test catalase activity at different temperatures to create concrete experiences. This created cognitive conflict that motivated learning (Lawson, 1991). Based on Cycle 1 challenges, the researcher increased Explore time across three periods and pre-assigned group roles. This iterative refinement is a key feature of DBR (Anderson & Shattuck, 2012). Second, collaborative discussion during the Explain phase required teacher scaffolding. Students shared their findings and then learned scientific terms. This social interaction helps students learn within their Zone of Proximal Development (Lourenço, 2012). The teacher noted that previously passive students became active explainers. Third, connecting enzymes to local contexts was very effective. Students discussed enzymes in traditional Ethiopian foods like injera fermentation and real health issues like lactose intolerance. One student said, "Now I understand why my father takes lactase pills before drinking milk." Research shows that students learn best when science connects to their daily lives (Machová & Ehler, 2023).

5.3. Effect of the 5E Model Implementation on Conceptual Understanding and Attitude

The ANCOVA results showed that the 5E model was highly effective in improving conceptual understanding. After controlling for pre-test scores, the experimental group's post-test mean (6.947) was significantly higher than the control group's (5.211), $F(1,35)=879.70$, $p<.001$, with a very large effect size ($\eta^2=.962$). This means that the intervention explained 96.2% of the variance in post test scores between groups after adjusting for the covariate. This finding matches international research. A meta-analysis found that inquiry-based models like the 5E cycle significantly improve student achievement in science (Banerjee, 2010). Other studies have shown that the 5E model improves biology learning in Turkey (Sadi, 2010) and helps correct misconceptions

(Joswick & Hulings, 2024). The model also promotes long-term retention of knowledge (Grau et al., 2021).Other studies have shown that the 5E model improves biology learning in Turkey (Sadi, 2010) and helps correct misconceptions (Joswick & Hulings, 2024). The model also promotes long-term retention of knowledge (Grau *et al*., 2021).

Qualitative data supported these results. One student said, "I understood better when I saw the bubbles myself." Another said, "I used to think boiling killed enzymes, but now I know it changes their shape." After the intervention, the misconception that boiling "kills" enzymes was completely eliminated (from 73.7% to 0%), and the misconception that enzymes are "used up" dropped from 63.2% to 10.5%. This confirms that hands-on exploration helps students build correct mental models (Villafañe *et al*., 2021).

The results also showed that the 5E model significantly improved student attitudes. The Mann-Whitney U test found that the experimental group had a much higher mean rank (28.34) than the control group (10.66), $U = 12.50$, $Z = -4.966$, $p < .001$. The Wilcoxon test showed that 18 out of 19 students in the experimental group improved their attitudes, with none showing a decline ($Z = -3.742$, $p < .001$).

These findings support the idea that positive emotions help learning, while negative emotions block it (Joseph, 2023). The 5E model's Engage phase sparked curiosity with a real-world question ("Why does your stomach not digest itself?"). The hands-on activities gave students a sense of discovery and ownership. Research from Jordan found that the 5E model makes learning more enjoyable and increases creative thinking (Faris & Alathameen, 2021). Student feedback was very positive. 84.2% of students said they liked learning with the 5E way, and 100% agreed that hands-on activities helped their understanding. This shows that when students experience success in building their own knowledge, their attitude toward science improves (Osborne *et al*., 2010).This study extends previous research by showing that even a difficult topic like enzymes can become interesting when taught with the 5E model (Joswick & Hulings, 2024).

5.5. Design Principles for Future Effective Implementation of the 5E Instructional Model

Design Principles for Future Effective Implementation of the 5E Instructional Model

Based on the findings of this study, the following design principles are recommended for future implementation of the 5E instructional model, particularly for teaching challenging science topics like enzymes in Ethiopian secondary schools.

Principle 1: Embed Hands-On Investigation Before Explanation

Instructional materials should embed hands-on laboratory investigations using low-cost, locally available materials before any formal scientific explanation. This creates concrete experiences and cognitive conflict that challenge students' existing incorrect ideas, thereby reducing persistent misconceptions and improving conceptual understanding. This was evidenced by the belief that boiling "kills" enzymes dropping from 73.7% to 0% and the belief that enzymes are "used up" dropping from 63.2% to 10.5%.

Principle 2: Connect Abstract Concepts to Local Contexts

Instructional materials should connect abstract enzyme concepts to familiar local examples and everyday experiences, such as injera fermentation, lactose intolerance, and digestive supplements. This makes abstract biochemical concepts personally relevant and meaningful, reducing the psychological distance between unfamiliar scientific ideas and daily life, thereby significantly improving students' attitudes toward learning. This was evidenced by the experimental group's higher mean rank (28.34) compared to the control group (10.66), with $U=12.50$, $p<.001$, and 84.2% of students reporting they liked the 5E way of learning.

Principle 3: Allocate Sufficient Time and Provide Structured Tools

The Explore phase should allocate sufficient time and include simplified data collection tools, such as pre-drawn tables and pre-assigned group roles. This reduces cognitive load and allows all students, including shy or slower learners, to manipulate materials, record observations, discuss findings, and build meaningful mental models without procedural frustration, thereby improving conceptual understanding. This was evidenced by the experimental group's post-test mean score (6.947) being significantly higher than the control group's (5.211), with a very large effect size (η^2=.962).

Principle 4: Combine Multiple Representations of Concepts

Instruction should combine multiple representations of the same concept, including hands-on experiments, paper modeling, visual diagrams, and myth-versus-fact charts. This reinforces the same scientific concept from various angles, catering to different learning modalities and strengthening students' mental models through cross-checking, thereby eliminating tenacious misconceptions. This was evidenced by the misconception that "enzymes provide energy" dropping from 52.6% to 5.3% and the belief that "any enzyme works on any substrate" dropping from 42.1% to 5.3%.

Principle 5: Embed Formative Assessment Throughout All Phases

Assessment should be embedded throughout all five phases using low-stakes tools such as exit tickets, drawing tasks, index card revisions, and group presentations. This provides continuous feedback to both teacher and student, allowing misconceptions to be caught and corrected immediately rather than remaining hidden until a final exam, thereby increasing student confidence and perceived effectiveness of learning. This was evidenced by 100% of students agreeing that hands-on activities helped their understanding and no student disagreeing that they liked the 5E way of learning.

Principle 6: Begin Each Lesson with a Provocative Question or Demonstration

Each lesson should begin with a provocative, real-life question or a surprising demonstration to create curiosity and cognitive dissonance. This motivates students to actively seek explanations during the Explore and Explain phases rather than passively waiting for answers, thereby producing immediate and sustained student engagement. This was evidenced by 18 out of 19 students in the experimental group showing improved attitudes from pre-test to post-test ($Z=-3.742$, $p<.001$) and no student showing a decline.

6. CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

Based on the findings of this study, the following conclusions are drawn.

First, regarding students' conceptions of enzymes, Grade 11 students entered the enzymes unit with deep-seated and widespread misconceptions. The pre-test mean score of 4.158 out of 10, combined with qualitative evidence showing that 73.7% of students believed boiling "kills" enzymes, 63.2% thought enzymes are "used up" during reactions, and 52.6% believed enzymes "provide energy" for reactions, confirms that enzymology is a threshold concept that traditional, teacher-centered instruction has consistently failed to remediate.

Second, regarding the effectiveness of the 5E model, the locally adapted 5E inquiry-based instructional model is highly effective in improving both conceptual understanding and attitudes toward learning enzymes. The experimental group taught with the 5E model achieved a significantly higher post-test mean (6.947) than the control group taught with traditional methods (5.211), $F(1,35)=879.70$, $p<.001$, with an extremely large effect size ($\eta^2=.962$). The experimental group also had significantly higher post-test attitude ranks (Mean Rank=28.34) than the control group (Mean Rank=10.66), $U=12.50$, $Z=-4.966$, $p<.001$. Student perceptions were overwhelmingly positive, with 84.2% liking the 5E way of learning and 100% agreeing that hands-on activities helped their understanding.

Third, regarding effective implementation, the iterative Design-Based Research (DBR) framework allowed for successful refinements between cycles, leading to the complete elimination of the "boiling kills enzymes" misconception (from 73.7% to 0%) and a substantial reduction in the "enzymes are used up" misconception (from 63.2% to 10.5%). Specific activities within the 5E model particularly the Explore phase using hands-on investigation and the Elaborate phase connecting enzymes to local contexts proved most effective in supporting student learning.

Limitations of the Study

This study has several limitations. First, the sample was limited to two intact classes (N=38) at a single school, which limits the generalizability of the findings to other contexts. Second, the study duration was relatively short (one unit). Long-term retention of conceptual gains and attitude shifts was not measured. Third, the experimental group had a higher pre-test attitude score, which, although statistically controlled for in the conceptual analysis, may have influenced the dynamics of the intervention. Finally, the Hawthorne effect (students behaving differently because they know they are being studied) cannot be entirely ruled out.

6.2. Recommendations

Based on the findings and conclusions of this study, the following recommendations are made.

For Biology Teachers: Biology teachers at Fasilo Secondary School should adopt the refined 5E instructional unit on enzymes developed in this study. Teachers should replace traditional lecture methods with the 5E model, especially the hands-on Explore phase using catalase activity at different temperatures, which proved highly effective in correcting misconceptions. Teachers should also connect enzyme concepts to local contexts such as injera fermentation and lactose intolerance during the Elaborate phase to make learning relevant and meaningful.

For School Administration: The school administration should support the implementation of the 5E model by ensuring laboratory materials, including potato extract, hydrogen peroxide, and basic glassware, are consistently available. The administration should also provide collaborative planning time for biology teachers to adapt additional challenging topics using the 5E framework.

For Curriculum Designers and Policymakers: Given the large effect size ($\eta^2 = .962$) demonstrating the superiority of the 5E model over traditional instruction, the Ministry of Education should promote the 5E instructional model as a practical framework to support Ethiopia's competency-based curriculum reform. Investment in teacher professional development programs focused on the 5E model and the development of locally relevant, low-cost instructional materials is strongly recommended.

For Teacher Education Institutions: Teacher education institutions, including Bahir Dar University, should explicitly teach the 5E instructional model in pre-service science teacher methodology courses. Student teachers should practice designing and implementing 5E lessons during their practicum placements to ensure they graduate with the necessary skills.

For Future Research: Future research should replicate this Design-Based Research study in other Ethiopian secondary schools with different grade levels and science topics to validate and refine the design principles generated here. Longitudinal studies are needed to assess long-term retention of conceptual understanding and attitude gains. Research focusing on the Evaluate phase of the 5E model to develop authentic, formative assessment tools would also be a valuable extension of this work.

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Appendices

Pre test

Section A: Multiple Choice Questions

Student Name: ______________________________ Section: 1. A 2 B

Student Code: ________________ Date: ________________

This section contains 10 questions. Each question is divided into two tiers: Tier I and Tier II.

How to Answer

For each question, you must provide two answers:

Tier I: Select the one correct option from A, B, C, or D.

Tier II: Select the one best reason for your Tier I answer from the numbered options 1–5.

1. Tier I: What are enzymes primarily made of?

   A. Carbohydrates

   B. Lipids

   C. Proteins

   D. Nucleic acids

1.1. Tier II: What is the reason for your answer?

   Carbohydrates are mainly used for quick energy, not catalysis.

   Lipids form membranes and are not involved in speeding up reactions.

   Enzymes are biological catalysts that are nearly always globular proteins.

   Nucleic acids (DNA/RNA) carry genetic information, though some RNA can be catalytic (ribozymes), most enzymes are proteins.

   Other reasons --

2. Tier I: The part of an enzyme where the substrate binds is called the:

   A. Allosteric site

   B. Active site

   C. Binding domain

   D. Activation center

2.1. Tier II: What is the reason for your answer?

   The allosteric site is for regulatory molecules to bind, not the main substrate.

   The active site is a specific groove or pocket formed by the folded protein where the substrate fits.

"Binding domain" is a general term, but in enzymology, the specific catalytic region is the active site.

The activation center is not a standard term for the substrate binding location.

Other reasons --

3. Tier I: Which of the following statements about enzymes is TRUE?

A. Enzymes are used up during chemical reactions.

B. Enzymes increase the activation energy of reactions.

C. Enzymes are specific to their substrates.

D. Enzymes work best at any temperature.

3.1. Tier II: What is the reason for your answer?

Enzymes are regenerated at the end of a reaction.

Increasing activation energy would slow a reaction down, not speed it up.

The shape of the active site allows only specific complementary substrates to bind.

Enzymes have an optimum temperature; extreme temperatures denature them.

Other reasons --

4. Tier I: What happens to an enzyme at very high temperatures (above 60°C)?

A. It works faster

B. It becomes denatured

C. It produces more products

D. It changes its substrate

4.1. Tier II: What is the reason for your answer?

High temperatures provide more kinetic energy (this is true *until* denaturation).

The heat breaks the hydrogen bonds holding the protein's 3D structure, changing the active site shape.

The reaction rate increases until the enzyme is destroyed.

Enzymes do not "change" their substrate; they are specific.

Other reasons --

5. Tier I: The lock and key model of enzyme action suggest that:

A. The enzyme changes shape to fit the substrate

B. The substrate changes shape to fit the enzyme

C. The active site has a fixed shape complementary to the substrate

D. Multiple substrates can fit any enzyme

5.1. Tier II: What is the reason for your answer?

This describes the Induced Fit model (A).

Substrates do not change shape to fit; they are the "key."

The "lock" (enzyme) has a rigid, pre-formed shape that perfectly matches the "key"(substrate).

Enzymes are specific; they don't fit multiple substrates (that violates specificity).

Other reasons ---

6. Tier I: Which factor does NOT affect the rate of enzyme activity?

A. pH

B. Temperature

C. Substrate concentration

D. Color of the enzyme

6.1. Tier II: What is the reason for your answer?

pH affects the charge and shape of the active site.

Temperature affects kinetic energy and denaturation.

Substrate concentration affects how often enzymes collide with substrate.

Color is a physical property of the molecule but has no impact on catalytic function.

Other reasons ---

7. Tier I: At optimum pH, an enzyme functions:

A. At its slowest rate

B. At its maximum rate

C. Not at all

D. Only in acidic conditions

7.1. Tier II: What is the reason for your answer?

At optimum pH, the enzyme's shape is perfect for substrate binding.

Extreme pH values denature the enzyme.

Enzymes have specific pH optima (e.g., pepsin likes acid, trypsin likes alkaline); "optimum" means maximum efficiency.

Other reasons ---

8. Tier I: When the substrate concentration increases continuously while enzyme concentration remains constant, the reaction rate will:

A. Increase indefinitely

B. Increase then decrease

C. Increase until it reaches a maximum plateau

D. Remain constant throughout

8.1. Tier II: What is the reason for your answer?

Eventually all active sites are occupied (saturated).

The enzymes are working as fast as they can.

Adding more substrate cannot speed up the reaction because there are no free enzymes to act on it.

Other reasons --

9. Tier I: Enzymes catalyze reactions by:

A. Increasing activation energy

B. Decreasing activation energy

C. Being consumed in the reaction

D. Changing the free energy of products

9.1. Tier II: What is the reason for your answer?

Lowering the activation energy allows more molecules to react at a given temperature.

Enzymes lower the energy barrier for the reaction.

Enzymes do not alter the starting point or end point (free energy of reactants/products), only the path between them.

Other reasons --

10. Tier I: Which of the following is an example of an enzyme?

A.Glucose

B.Catalase

C.Starch

D. Oxygen

10.1. Tier II: What is the reason for your answer?

Glucose is a monosaccharide (sugar).

Catalase is a specific enzyme that breaks down hydrogen peroxide.

Starch is a polysaccharide (carbohydrate).

Oxygen is a gas/element.

Other reasons --

Post test

Question 11

Tier I: What is the role of enzymes in chemical reactions?

A. They provide energy for the reaction

B. They slow down the reaction rate

C. They speed up the reaction without being used up

D. They change the products of the reaction

Tier II: What is the reason for your answer?

Enzymes are catalysts, so they lower activation energy but are not consumed.

Enzymes do not provide energy; they only facilitate the reaction.

Enzymes are specific to their substrates and do not change products.

Other reasons: ________________________________

Question 12

Tier I: Which of the following best describes the "induced fit" model of enzyme action?

A. The active site has a rigid, fixed shape

B. The enzyme changes shape slightly to fit the substrate

C. The substrate changes shape to fit the enzyme

D. The enzyme and substrate do not interact

Tier II: What is the reason for your answer?

This is an updated version of the lock and key model.

The active site molds itself around the substrate for a better fit.

The substrate is unchanged during this process.

Other reasons: ________________________________

Question 13

Tier I: Why does enzyme activity decrease at very low temperatures?

A. The enzyme denatures

B. The substrate freezes

C. Molecules move too slowly for effective collisions

D. The active site changes shape permanently

Tier II: What is the reason for your answer?

Low temperatures reduce kinetic energy, so collisions are less frequent.

Denaturation occurs only at high temperatures, not low temperatures.

The enzyme is still functional but works slower.

Other reasons: ________________________________

Question 14

Tier I: What happens to an enzyme when the pH is too acidic or too basic?

A. It works faster

B. It becomes denatured

C. It changes its substrate

D. It produces more products

Tier II: What is the reason for your answer?

Extreme pH disrupts hydrogen bonds and ionic bonds in the enzyme.

The active site shape is altered, preventing substrate binding.

The enzyme's structure is changed permanently.

Other reasons: ________________________________

Question 15

Tier I: Which of the following statements about enzyme specificity is TRUE?

A. One enzyme can catalyze many different reactions

B. Enzymes are specific to one substrate or type of reaction

C. Enzymes can work on any substrate

D. Specificity is not important for enzyme function

Tier II: What is the reason for your answer?

The shape of the active site determines which substrate can bind.

Enzymes evolved to catalyze specific reactions efficiently

Non-specific enzymes would cause uncontrolled reactions.

Other reasons: ________________________________

Question 16

Tier I: What is the effect of increasing enzyme concentration (while substrate is unlimited)?

A. Reaction rate decreases

B. Reaction rate increases

C. Reaction rate stays the same

D. Reaction stops completely

Tier II: What is the reason for your answer?

More enzymes mean more active sites available for substrate binding.

The reaction rate is proportional to enzyme concentration.

The reaction will proceed faster until substrate is limited.

Other reasons: ________________________________

Question 17

Tier I: What are enzyme inhibitors?

A. Substances that speed up enzyme reactions

B. Substances that slow down or stop enzyme reactions

C. Substances that change the enzyme's substrate

D. Substances that provide energy to enzymes

Tier II: What is the reason for your answer?

Inhibitors bind to enzymes and prevent them from working.

Competitive inhibitors compete for the active site.

Non-competitive inhibitors change the enzyme's shape.

Other reasons: ________________________________

Question 18

Tier I: Which of the following is a biological importance of enzymes?

A. They allow reactions to occur at body temperature

B. They prevent all chemical reactions

C. They are only found in plants

D. They are not necessary for life

Tier II: What is the reason for your answer?

Without enzymes, reactions would be too slow to sustain life.

Enzymes lower activation energy so reactions happen quickly.

Our body temperature would not support reactions without enzymes.

Other reasons: ________________________________

Question 19

Tier I: What is the optimal temperature for most human enzymes?

A. 0°C

B. 25°C

C. 37°C

D. 60°C

Tier II: What is the reason for your answer?

INSTRUMENT 2: Biology Attitude Scale (BAS)

Section B: Attitude Toward Enzymes Questionnaire

Dear students, this questionnaire is prepared for the partial fulfillment of the MEd thesis at Bahir Dar University, College of Education and School of Teacher Education (Biology Education). Therefore, the questionnaire could not have any conflict with anyone. The questionnaire has two parts; the first part is the preliminary section, which contains the general information of the respondents. The second part contains the main body of the questionnaire, which is intended to assess the attitude of the students.

Amlaku MEd Candidate at BDU

Biology Attitude Scale (BAS)

Instructions: Please indicate your level of agreement with each statement below by circling the number that best represents your opinion. There are no right or wrong answers. Answer honestly based on your feelings about learning biology, specifically the topic of enzymes.

Scale:

1 = Strongly Disagree

2 = Disagree

3 = Neutral

4 = Agree

5 = Strongly Agree

Part II: Interest and Enjoyment

No.	Statement	SA	A	N	D	SD
1.	I look forward to my biology classes.	◻	◻	◻	◻	◻
2.	Learning about enzymes is interesting.	◻	◻	◻	◻	◻
3.	I enjoy doing experiments related to enzymes.	◻	◻	◻	◻	◻

Part 2: Perceived Relevance and Importance

No.	Statement	SA	A	N	D	SD
4.	Understanding enzymes is important for understanding how my body works.	◻	◻	◻	◻	◻
5.	What I learn about enzymes is useful in everyday life.	◻	◻	◻	◻	◻
6.	Knowledge of enzymes will help me in future science studies.	◻	◻	◻	◻	◻
7.	Enzymes are relevant to health and medicine.	◻	◻	◻	◻	◻

Part 4: Engagement and Participation

No.	Statement	SA	A	N	D	SD
8.	I actively participate during enzyme lessons.	◻	◻	◻	◻	◻
9.	I like working in groups during enzyme activities.	◻	◻	◻	◻	◻
10.	I prefer to listen rather than do hands-on activities. (R)	◻	◻	◻	◻	◻

Part 5: Perception of Teaching Method (Post-test Only - Experimental Group)

No.	Statement	SA	A	N	D	SD
11.	I liked the way we learned about enzymes in this unit.	◻	◻	◻	◻	◻
12.	The hands-on activities helped me understand enzymes better.	◻	◻	◻	◻	◻

Scoring Guide (For Researcher Use Only):

- Total Score Range: 10-50 (pre/post) or 13-65 (with post-intervention items)
- Positive Attitude: Higher scores indicate more positive attitude toward learning enzymes.
- Subscales:

- ✓ Interest: Items 1, 2, 3
- ✓ Perceived Relevance: Items 4, 5, 7
- ✓ Self-Efficacy/Confidence: Items 6, 8, 10

- Collaboration: Item 9

INSTRUMENT 3: CLASSROOM OBSERVATION SCHEDULE

Section A: General Information

Item	Details
Observer Name:	______________________________
Date:	______________________________
School:	Fasilo Secondary School
Grade/Section:	Grade 11, Section _____
Lesson Topic:	______________________________
Time Start:	______________________________
Time End:	______________________________
Number of Students:	_____ Male: _____ Female: _____
Cycle Number:	□ Cycle 1 □ Cycle 2
5E Phase Observed:	□ Engage □ Explore □ Explain □ Elaborate □ Evaluate

Section B: 5E Phase Implementation Checklist

Instructions: For each phase being observed, check (✓) whether the indicator is observed and add comments.

ENGAGE Phase

Indicator	Yes	No	Comments/Evidence
1. Teacher activates students' prior knowledge about enzymes	□	□	
2. Teacher uses a question/demonstration to spark curiosity	□	□	
3. Students show interest/ask questions	□	□	
4. Activity connects enzymes to real-life situations	□	□	
5. Teacher creates a "need to know" about enzymes	□	□	

EXPLORE Phase

Indicator	Yes	No	Comments/Evidence
1. Students engage in hands-on investigation/experiment	□	□	
2. Teacher provides materials and guidance (not direct answers)	□	□	
3. Students work collaboratively in groups	□	□	
4. Students record observations/data	□	□	
5. Students identify patterns or relationships	□	□	

EXPLAIN Phase

Indicator	Yes	No	Comments/Evidence
1. Students share their observations/ findings	□	□	
2. Teacher introduces scientific terminology/vocabulary	□	□	
3. Teacher connects student experiences to formal concepts	□	□	
4. Students articulate understanding in their own words	□	□	
5. Teacher addresses misconceptions that emerged	□	□	

ELABORATE Phase

Indicator	Yes	No	Comments/Evidence
1. Students apply enzyme concepts to new situations	□	□	
2. Activities extend understanding (real-world problems)	□	□	
3. Students make connections to other topics	□	□	
4. Higher-order thinking questions are used	□	□	
5. Students engage in problem-solving activities	□	□	
6. Time allocated: _____ minutes (Suggested: 10-15 min)	□	□	

EVALUATE Phase

Indicator	Yes	No	Comments/Evidence
1. Formative assessment occurs throughout the lesson	□	□	
2. Students demonstrate understanding (orally/in writing)	□	□	
3. Teacher provides feedback to students	□	□	
4. Students self-assess or peer-assess	□	□	
5. Assessment aligns with learning objectives	□	□	

Pre-Interview Protocol

Part A: General Perception of Enzymes

1. What comes to your mind when you hear the word "enzymes"?
- ✓ Can you tell me more about that?
- ✓ Where did you learn that?

2. Do you think enzymes are important? Why or why not?

- ✓ Can you give me an example?
- ✓ How do they relate to your daily life?

3. What do you find most interesting about enzymes?

- ✓ Is there anything specific that catches your attention?

4. What do you find most difficult or confusing about enzymes?

- ✓ Can you describe a specific concept that is challenging?

Part B: Learning Experience with 5E Model (Experimental Group Only)

5.How would you describe the way we learned about enzymes in this unit?

- ✓ How was it different from your usual biology classes?
- ✓ What did you like about it?

6. Tell me about the hands-on activities we did.

- ✓ Which activity did you enjoy most? Why?
- ✓ Did the activities help you understand better?

7. How did you feel when you were exploring before the teacher explained?

- ✓ Did you like discovering things on your own?
- ✓ What did you learn from that experience?

8. What did you think about working in groups?

- ✓ Did group work help you learn?
- ✓ Were there any challenges?

9. How would you compare this way of learning to the usual lecture method?

- ✓ What are the differences?
- ✓ Which way do you prefer? Why?

10. Did this way of learning change how you feel about enzymes?

- ✓ In what way?
- ✓ Do you find enzymes more or less interesting now?

Part C: Conceptual Understanding

11. Can you explain to me what enzymes do in our bodies?

- ✓ How do they work?
- ✓ Can you give an example?

12. Imagine you have an enzyme and you heat it to very high temperatures.

- ✓ What do you think happens?
- ✓ Why? • What does "denature" mean?
- ✓ Why does temperature affect enzymes?

13. Why do you think our stomach has a different pH than our mouth?

- ✓ How does pH affect enzyme activity?
- ✓ What would happen if the pH changed?

14. If you had more substrate than enzyme, would the reaction keep going faster? Why or why not?

- ✓ What limits the reaction rate?
- ✓ Can you explain what happens when enzymes are saturated?

15. Is there anything about enzymes that you still don't understand or would like to know more about?

- ✓ What questions do you still have?
- ✓ What would help you understand better?

Part D: Attitude and Engagement

16. How confident do you feel about your understanding of enzymes?

- ✓ What makes you feel confident or not confident?
- ✓ What helped you learn best?

17. Do you think learning about enzymes is useful?

- ✓ How could it be useful?
- ✓ Can you connect it to careers or real life?

18. How often do you participate during enzyme lessons?

- ✓ What makes you want to participate?
- ✓ What might prevent you from participating?

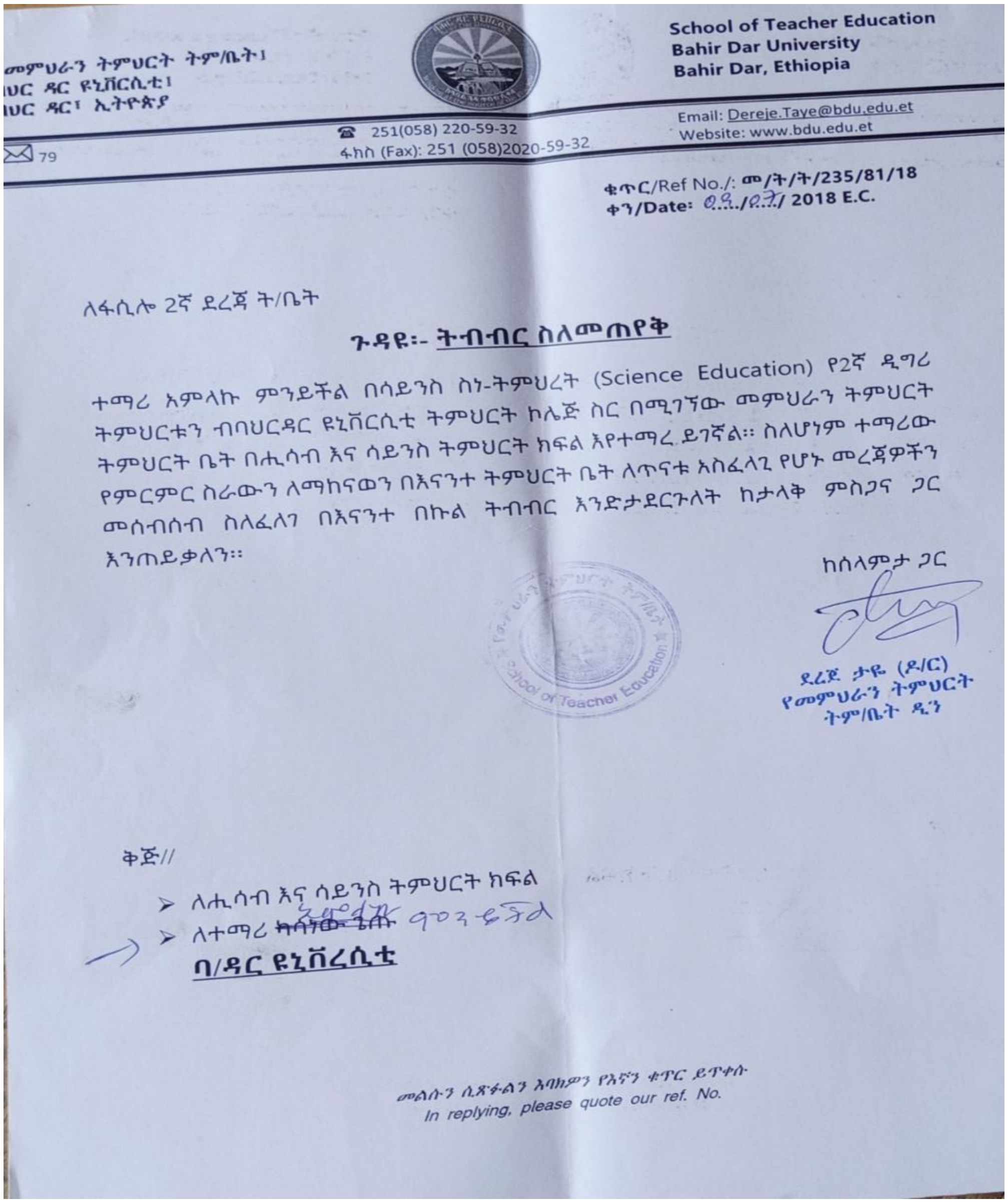
19. Would you like to learn other biology topics in a similar way?

- ✓ Which topics?
- ✓ Why?

20. If you could change one thing about how we learned enzymes, what would it be?

- ✓ What would you add or remove?
- ✓ How would that help you?

Clearance Letter



መምህራን ትምህርት ትም/ቤት፤
ባህር ዳር ዩኒቨርሲቲ፤
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School of Teacher Education
Bahir Dar University
Bahir Dar, Ethiopia

☎ 251(058) 220-59-32
ፋክስ (Fax): 251 (058)2020-59-32
✉ 79

Email: Dereje.Taye@bdu.edu.et
Website: www.bdu.edu.et

ቁጥር/Ref No./: መ/ት/ት/235/81/18
ቀን/Date: 09./07./ 2018 E.C.

ለፋሲሎ 2ኛ ደረጃ ት/ቤት

ጉዳዩ:- <u>ትብብር ስለመጠየቅ</u>

ተማሪ አምላኩ ምንይችል በሳይንስ ስነ-ትምህረት (Science Education) የ2ኛ ዲግሪ ትምህርቱን ብባህርዳር ዩኒቨርሲቲ ትምህርት ኮሌጅ ስር በሚገኘው መምህራን ትምህርት ትምህርት ቤት በሒሳብ እና ሳይንስ ትምህርት ክፍል እየተማረ ይገኛል። ስለሆነም ተማሪው የምርምር ስራውን ለማከናወን በእናንተ ትምህርት ቤት ለጥናቱ አስፈላጊ የሆኑ መረጃዎችን መሰብሰብ ስለፈለገ በእናንተ በኩል ትብብር እንድታደርጉለት ከታላቅ ምስጋና ጋር እንጠይቃለን።

ከሰላምታ ጋር

ደረጀ ታዬ (ዶ/ር)
የመምህራን ትምህርት
ትም/ቤት ዲን

School of Teacher Education

ቅጅ//

- ለሒሳብ እና ሳይንስ ትምህርት ክፍል
- ለተማሪ ~~[illegible]~~ አምላኩ ምንይችል
  <u>**ባ/ዳር ዩኒቨረሲቲ**</u>

መልሱን ሲጽፉልን እባክዎን የእኛን ቁጥር ይጥቀሱ
In replying, please quote our ref. No.