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Enhancing achievement, problem-solving, and critical thinking of secondary school biology students through problem-based scenarios integrated with indigenous knowledge

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Enhancing achievement, problem-solving, and critical thinking of secondary school biology students through problem-based scenarios integrated with indigenous knowledge

By

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Dissertation submitted in partial fulfillment of the requirements for the degree of doctor of education in biology

Principal Advisor: Bizuayehu Kerisew (Ph.D.)

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January 2026

BAHIR DAR

Declaration

This is to certify that the dissertation entitled "Enhancing students' academic achievement, problem-solving and critical thinking skills in biology through problem-based scenarios and indigenous knowledge: a design-based research approach" submitted in partial fulfillment of the requirements for the Degree of Doctor of education in Biology in the mathematics and scince education department, College of education, Bahir Dar university is a record of original work carried out by me and has never been submitted to this or any other institution to get any other degree or certificate. The assistance and help I received during the course of this investigation have been duly acknowledged.

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Name of the candidate	Signature	Date

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Approval of dissertation for defense

I hereby certify that I have supervised, read and evaluated this dissertation titled **"Enhancing achievement, problem-solving, and critical thinking of secondary school biology students through problem-based scenarios integrated with indigenous knowledge"** By KirosTareke prepared under my guidance**.** We recommend this dissertation be submitted for oral defense.

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Principal Advisor Signature Date

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Co-Advisor 1 Signature Date

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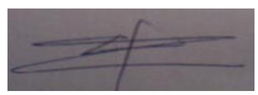
Approval of dissertation for defense result

As members of the board of examiners, we examined this dissertation proposal titled **"Enhancing achievement, problem-solving, and critical thinking of secondary school biology students through problem-based scenarios integrated with indigenous knowledge"** By Kiros Tareke. We hereby certify that the dissertation is accepted for fulfilling the requirements for the award of the degree of doctor of education in biology.

Board of examiners



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Abstract

Critical thinking and problem-solving are essential 21st-century skills; however, they remain underdeveloped in Ethiopian secondary education, where biology instruction is often dominated by rote learning, low academic achievement, and limited integration of indigenous knowledge. These constraints reduce students' ability to apply biological concepts to real-life contexts. This study examined the effectiveness of problem-based scenarios (PBS) integrated with Ethiopian indigenous knowledge in enhancing Grade 10 students' academic achievement, critical thinking, and problem-solving skills in human biology. Using a design-based research approach with mixed methods, the study was conducted over eight weeks in three biology classes. One classs received problem based scenarios with incorporating indigenous knowledge, while the other received problem based scenario alone, the control class received conventional instruction. Data were collected through pre- and posttests, interviews, student reflections, and classroom observations, and analyzed using SPSS and iterative qualitative coding. Results showed that Intervention 2 produced the largest and most consistent statistically significant gains ($p \leq .043$) in academic achievement, critical thinking, and problem-solving skills compared with Intervention 1 and the control group. Students demonstrated improved ability to generate practical, culturally relevant solutions to complex health-related scenarios. Gender had no significant main effect, although small interaction effects between gender and intervention were observed. The findings indicate that integrating problem-based scenarios with indigenous knowledge effectively enhances critical thinking, problem solving skills, and academic achievement in biology. To maximize impact, policymakers should institutionalize indigenous knowledge–integrated, problem-based biology instruction through curriculum reform, equitable digital access, and sustained teacher professional development. Educators should address technical constraints. Further research is recommended to refine instructional tools and improve inclusivity and learner engagement.

Key words: problem scenario, Indigenous knowledge, critical thinking skills, problem solving skills, academic achievement,

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List of acronyms and abbreviations

AA — Academic achievement

CCTST – California Critical Thinking Skills Test

CCTT – Cornell Critical Thinking Test

CG – Control Group

CI – Conventional Instruction

CIRC – Cooperative Integrated Reading and Composition

CTEET – Critical Thinking Embedded Essay Test

CTS – Critical Thinking Skills

DBR – Design-Based Research

ESDP – Educational Sector Development Program (Ethiopia)

ETP – Education and Training Policy (Ethiopia)

FRISCO – Focus, Reason, Inference, Situation, Clarity, Overview (Indicators of Critical Thinking by Ennis)

GTP I – Growth and Transformation Plan I (Ethiopia's first national development plan)

HBSH – Human Body System and Health

HCTA – Halpern Critical Thinking Assessment

IK – Indigenous Knowledge

PBS – Problem-based scenarios

PBL – Problem-Based Learning

PBPS – Paper-Based Problem Scenarios

PISA – Programme for International Student Assessment

PK – Prior Knowledge

PSS – Problem-Solving Skills

SBL – Scenario-Based Learning

STAD – Student Teams Achievement Divisions

STEM – Science, Technology, Engineering, and Mathematics

TIMSS – Trends in International Mathematics and Science Study

CHAPTER ONE: INTRODUCTION

Introduction

The introductory chapter presents the rationale for the study and outlines the structure of the thesis. It begins by providing background information that highlights the key issues leading to the formulation of the problem statement. The chapter then details the research problem, study objectives, and guiding research questions. It also explains the significance of the study, emphasizing the importance of enhancing students' academic achievement (AA), problem-solving skill (PSS), and critical thinking skills (CTS) in biology through PBS and indigenous knowledge (IK) using a design-based research approach. Additionally, the chapter outlines the study's delimitations and limitations, defining the scope and boundaries of the research. To ensure clarity and consistency, operational definitions of key terms frequently used in the study are provided. Overall, the introduction establishes a strong foundation for the thesis and sets the stage for an in-depth examination of the research topic.

1.1. Background of the study

Education is a structured process of developing knowledge, skills, values, and habits through teaching, training, and research. Educational theories, grounded in philosophy, psychology, and pedagogy, guide how learning happens and how to optimize outcomes. Pragmatism views education as an adaptable, PSS process (Dewey, 2024). Cognitivism focuses on mental processes like thinking and memory (Piaget & Cook, 1952), while constructivism emphasizes active knowledge-building through experience (Dewey, 1938; Vygotsky & Cole, 1978). Pedagogical theories like progressivism and experiential learning advocate for hands-on, reflective learning (Kolb, 2014).

Within this theoretical landscape, education aims not only to transmit information but also to cultivate essential 21st-century competencies, particularly PSS and CTS. These skills naturally emerge from educational models that encourage inquiry, reflection, and active engagement. The learning environment strengthens CTS by enabling students to question assumptions, analyze evidence, evaluate alternatives, and refine explanations, while PSS skills are developed through applying knowledge to complex situations, generating practical solutions, and iteratively adjusting strategies based on feedback and outcomes. Although scholars agree that these competencies are crucial for modern life and work (Trilling & Fadel, 2009), defining them precisely and determining the most effective instructional methods remain ongoing challenges (Lai, 2011). Ultimately, the interplay of educational theory and practice shapes how learners develop the cognitive tools needed to think critically and solve problems creatively.

Critical thinking and PSS skills are key goals of 21st-century education (Trilling & Fadel, 2009), though defining and teaching them remains difficult (Lai, 2011). Originating from Socratic questioning (Ps *et al*., 2023), CTS has been described as conception (Ennis, 1987), reasoning and evaluation (Facione, 2011), and a set of cognitive skills and dispositions (Kuhn, 2015; Lai, 2011). It supports PSS, decision-making, and inference (Abrami *et al*., 2015; Halpern, 2014). Contemporary scholars view it as deep, reasonable, and careful thinking (Ennis, 2018a), a context-dependent process involving multiple perspectives and evaluative judgment (Addy *et al*., 2014; Anwar *et al*., 2020; Mahanal *et al*., 2017; Williams, 2017), and the ability to assess accuracy, examine evidence, and engage in higher-order evaluation (Pasquinelli *et al*., 2021).

Despite extensive efforts to define CTS, its integration into teaching, learning, and assessment remains limited. Research often overlooks kindergarten and elementary levels (Lopez *et al*., 2023), even though CTS is emphasized across global curricula (Ongesa, 2020). Significant implementation gaps persist: deficiencies have been reported among learners in the Philippines (Cruz & Dominguez, 2020; Lugtu, 2018), secondary teachers in Norway (Austin & Throndsen, 2018), and academic communities in Thailand (Ploysangwal, 2018). Similar issues appear among higher education interns (Zayapragassarazan & Chacko, 2019) and graduates in Kenya (Ongesa, 2020). Adolescents also struggle with evaluating evidence and detecting bias in media (Ku *et al*., 2019; Nygren, 2019), and Ethiopian preparatory students show weak or absent CTS (Sisay, 2019).

Students' low perceptions and limited practice of CTS hinder sustainable skill development (Kafri, 2022). Studies further reveal unclear student understanding of CTS expectations (Islamiyah & Fajri, 2020), while employers continue to report graduates' deficiencies (Liyanage *et al*., 2021; Wynekoop & Nakatani, 2023), often blaming exam-driven, rote-focused education systems Ongesa, 2020).

Arbitrary teaching, theoretical instruction without application, and poorly defined assessments further impede students' growth (Latorre-Cosculluela *et al*., 2020). Overall, efforts to strengthen CTS remain limited, with persistent gaps in pedagogy, instructional strategies, and assessment practices (Bouygues, 2018; Gunawardena & Wilson, 2021).

Alongside CTS, PSS is a core cognitive skill essential for student success. Students develop this ability by creating goal-directed plans (Mayer, 2002), and it is widely recognized as a key outcome of 21st-century education. Once viewed as a simple, laboratory-based activity, problem solving is now understood as a complex process involving deliberate and prioritized cognitive actions aimed at achieving a desired goal (Frensch & Funke, 2014). Early perspectives treated it as mechanical and decontextualized, but cognitive learning theories revealed it to be a multifaceted mental activity requiring diverse skills and strategies. Today, it is defined as the capacity to engage in cognitive processing to understand and resolve problem situations (Ramalingam *et al*., 2017).

Problem solving skill involves a range of higher-order thinking skills—such as reasoning, analysis, synthesis, and abstraction—that must be effectively coordinated. Closely connected to decision making, CTS, and creativity, it begins with identifying and clarifying a problem, designing and implementing a solution, and then monitoring progress (Rahman, 2019). Because PSS is vital in everyday life, classroom activities that emphasize it help students prepare for real-world challenges (Tan, 2021). From an early age, such activities equip learners with strategies for identifying and analyzing problems, supporting lifelong learning and adaptability (Ramani & Brownell, 2014). Effective PSS also requires regulating routine skills and applying principles to explain new situations or predict outcomes. As Hooda and Devi (2018b) note, it demands persistent effort at both conscious and unconscious levels, which contributes to individual differences in managing challenges.

Cognitive theory distinguishes between well-defined and ill-defined problems, highlighting that individuals bring different perspectives and abilities to PSS tasks. Engaging students in authentic

PSS activities leverages these differences and fosters higher-order thinking and deeper learning (Middleton, 2020). Such tasks often require prediction, data analysis, and applying principles to establish cause-and-effect relationships, thereby strengthening reasoning. Research shows that strong PSS enable individuals to handle complex issues more effectively than intelligence alone, underscoring the need to nurture these skills in all learners from an early age (Lalzawmliana, 2023).

Problem solving skill allows students to apply classroom knowledge to new contexts and is central to AA, idea generation, and lifelong learning. A key purpose of education is to equip students with the ability to transfer knowledge and strategies to personal and community life. When students develop strong PSS, they make better decisions, reduce errors, and perform practical tasks more effectively (Rahman, 2019).

In line with the goal of helping students transfer classroom knowledge to new situations, research shows that structured PSS strategies can further strengthen this ability. Polya's four-step model—understanding the problem, devising a plan, implementing it, and reflecting—has been widely applied in mathematics (Maulyda *et al*., 2019). Similarly, Wood's six-step model—defining, exploring, planning, implementing, checking, and evaluating—supports systematic PSS in engineering (Mourtos *et al*., 2004). Both models highlight the importance of CTS in effective learning (Al-Najar *et al*., 2019). However, despite their success in other fields, these approaches remain underused in science education, particularly in high school biology.

This gap is significant because AA—traditionally measured through exams and grades but now understood to include deeper understanding, concept application, CTS, and PSS (Darling-Hammond, 1997), relies heavily on students' ability to engage in structured, higher-order thinking. Thus, integrating established PSS models into science instruction could meaningfully enhance students' overall academic performance and readiness for future challenges.

Studying AA alongside PSS and CTS is essential because these cognitive skills strongly influence performance. Students who can analyze information, reason effectively, and solve problems demonstrate higher academic success (Abrami *et al*., 2015). AA also reflects the effectiveness of instructional strategies and curricular interventions that aim to cultivate 21st-century skills (Savery, 2019).

Focusing on AA provides a measurable outcome for evaluating the impact of PSS and CTS on learning. It not only indicates knowledge acquisition but also demonstrates students' ability to transfer learning to new contexts and apply it meaningfully (Zohar & Dori, 2003). In science and biology education, high AA is closely linked to students' capacity for inquiry, reasoning, and application of principles to real-world problems, making it a vital variable for research on cognitive skill development.

However, achieving these outcomes remains challenging, as persistent gaps in students' AA, CTS and PSS highlight the need for more effective instructional strategies. In science education, attention has increasingly shifted toward argumentation-based inquiry (States, 2013). A focus also reflected in Ethiopia's updated primary and secondary curricula. Despite this emphasis, implementation remains weak due to low teacher motivation, limited student engagement, and misalignment between policy and classroom practices (Mahammoda & Sahin, 2019).

Earlier studies showed that scaffolding, reflection, problem-based learning, and collaborative learning promote CTS by building autonomy, encouraging metacognition, and exposing learners to multiple perspectives (Vygotsky, 1978). Recent research continues to confirm the positive impact of instructional methods on CTS (Ho *et al*., 2023). Collaborative learning, inquiry into authentic problems, structured dialogue, mentoring, and Socratic questioning enhance dispositions and deepen reasoning (Abrami & Waddington, 2015). Evidence also suggests implicit approaches are often more effective than explicit instruction (Bellaera *et al*., 2021). These findings call for teachers to adapt their practices, and for curricula and research to incorporate teachers' perspectives and contextual realities (Cáceres *et al*., 2020).

Student-centered instructional approaches, particularly problem-based learning (PBL), have been shown to promote more meaningful learning than teacher-centered methods (Muganga & Ssenkusu, 2019; Shamsuddeen & Amina, 2016). Originating in medical education under the constructivist paradigm, PBL has been adapted across grade levels, from elementary to high school (Drăghicescu *et al*., 2014; Merritt *et al*., 2017; Savery, 2019). By engaging students in authentic, open-ended problems, PBL fosters CTS, evidence-based decision-making, PSS, and the application of scientific principles to real-life contexts (Akben, 2020; Park *et al*., 2020; Thakur & Chauhan, 2021). Biology learning, in particular, benefits when problems are linked to everyday experiences (Bernstein, 2018).

Globally, curricula increasingly emphasize 21st-century skills, including CTS and PSS, through authentic learning environments (Priyadi & Suyanto, 2019). Informal settings—such as museums, science centers, farms, and natural environments—offer autonomy, promote scientific literacy, and foster high-level cognitive skills (Cabbar & Senel, 2020; Lavie Alon & Tal, 2015). These experiences complement classroom PBL by providing opportunities for knowledge transfer and real-world PSS.

Building on this shift toward authenticity and applied learning, scenario-based learning (SBL), incorporates realistic problems or storylines, further enhances students' engagement and ability to apply knowledge (Karabulut & Bayraktar, 2018). Well-designed scenarios motivate learners, promote reflection, and bridge theory-practice gaps, developing transferable skills in reasoning, decision-making, and PSS (Mianehsaz *et al*., 2023). Despite evidence of its effectiveness across disciplines, SBL remains underutilized in biology education, presenting an opportunity to strengthen higher-order thinking skills in this domain.

This need for meaningful, context-rich learning experiences also aligns with growing interest in integrating IK into instructional approaches such as PBL and SBL. Indigenous knowledge connects students' prior experiences to new concepts, helping them construct meaningful mental models and link theory to real-life applications (Demssie *et al*., 2020a; Hou & Li, 2014). In Ethiopia, integrating IK—such as traditional uses of plants and animals in healthcare—creates meaningful biological contexts that enhance CTS through evidence evaluation and comparison of traditional and scientific explanations, strengthen problem-solving skills through real-life health challenges, and improve AA by deepening understanding and application of biological concepts, while reinforcing cultural relevance and respect (Archila *et al*., 2021).

Despite policy reforms emphasizing active, learner-centered approaches, Ethiopian students' biology performance remains low due to overly theoretical curricula, limited PSS opportunities, and minimal integration of cultural knowledge (Alemu *et al*., 2024). Large-scale assessments like PISA and TIMSS indicate that students perform below regional and global averages, highlighting the need for instructional strategies that develop higher-order thinking, PSS, and AA (Alemu *et al*., 2021).

Integrating PBL, SBL, and IK may offer a pathway to enhance CTS, PSS, and AA simultaneously, making learning meaningful, transferable, and aligned with the goals of 21st-century education. This study, therefore, seeks to examine the impact of problem-based scenarios (PBS) on secondary school biology students' CTS, PSS, and AA.

1.2. Statement of the problem

Biology has increasingly become central to addressing many of the most pressing global issues of the 21st century. The field offers insights into understanding climate change, conserving biodiversity, ensuring food and water security, promoting sustainable energy use, and improving health and disease management (Council *et al*., 2009). For this reason, students are not only expected to acquire factual knowledge but also to develop higher-order skills that enable them to analyze problems, evaluate evidence, and apply biological principles to real-world situations.

In advanced education systems around the world, there is a growing emphasis on preparing students as problem-solvers who can transfer classroom learning to authentic contexts (Darling-Hammond *et al*., 2020). Rather than memorizing content for examinations, students are increasingly expected to interpret data, assess the credibility of scientific claims, and design innovative solutions to societal problems (Knowledge, 2012). This shift reflects broader calls for 21st-century competencies, such as CTS, creativity, collaboration, and communication, which are essential for personal and professional success in the global knowledge economy (Voogt & Roblin, 2012).

However, in many developing countries—including Ethiopia—biology education remains largely content-driven. The curriculum emphasizes the transmission of factual information rather than the cultivation of thinking skills. As a result, many students graduate with limited capacity to apply what they have learned to their lives, communities, or the broader national context

(Fried *et al*., 2020). This gap underscores the urgent need to re-examine the way biology is taught in Ethiopian schools (Teshome & Ordofa, 2023).

Ethiopia has implemented several curriculum reforms over the past decades, aiming to align its education system with modern pedagogical principles. Despite these efforts, the curriculum remains heavily content-laden and exam-oriented (Wondemtegegn & Mekonnen, 2022). Textbooks and teaching materials typically focus on transmitting large volumes of information, often presented in a fragmented manner. Students are expected to memorize definitions, classifications, and processes rather than engage in PSS, inquiry, or application-oriented learning.

Such an approach creates several challenges. First, students struggle to see the relevance of biology to their daily lives, reducing motivation and engagement. Second, the emphasis on recall over reasoning prevents learners from developing skills in analysis, evaluation, and synthesis—skills central to higher-order learning. Third, the pressure to prepare for high-stakes national examinations pushes both teachers and students to prioritize rote learning strategies, leaving little room for exploration, creativity, or critical inquiry (Dunworth & Sanchez, 2018).

Evidence from national assessments confirms this problem. For example, the 2009 baseline national learning assessment revealed that grade 10 and grade 12 students scored far below the expected standards, with composite mean scores of only 36% and 47.8% respectively across core subjects (Ababa, 2014). These scores highlight the inability of students to master the competencies outlined in the curriculum. More importantly, they reflect the limitations of a system that overloads students with content while providing minimal opportunities for reflective and application-based learning.

The Ethiopian government has undertaken several policy reforms intended to improve education quality and relevance. Among these is the 70:30 admission policy, which prioritizes natural and computational sciences over the social sciences in higher education. This policy was intended to produce a scientifically literate workforce capable of driving national development. However, despite such reforms, students' performance in biology and other sciences has not significantly improved (Dunworth & Sanchez, 2018).

One major reason is the disconnection between policy intentions and classroom realities. While the curriculum and policy documents highlight the importance of student-centered pedagogy, classroom practice remains largely teacher-dominated. Teachers often rely on lectures, note-taking, and textbook-based exercises, leaving students as passive recipients of knowledge rather than active participants in learning. The persistence of exam-driven teaching further discourages experimentation with innovative pedagogies, as both teachers and students fear that non-traditional methods may compromise examination results approaches (Mekonnen *et al*., 2024; Wodaj & Belay, 2021).

As a result, students often complete their secondary education without the skills required to transfer knowledge into practice. Their inability to apply biological concepts to everyday challenges weakens their preparation for both higher education and the labor market. In turn, this undermines the broader goal of producing citizens who can contribute to solving pressing national issues such as food insecurity, public health crises, and environmental degradation (Scott *et al*., 2022).

Teachers play a critical role in shaping the learning environment and in modeling PSS processes for students. However, in Ethiopia, many biology teachers lack the skills, training, and motivation to implement learner-centered approaches effectively (Kebede *et al*., 2025). Most teacher training programs emphasize content mastery rather than pedagogical innovation. Consequently, many teachers struggle to create interactive classrooms that encourage inquiry, collaboration, and CTS.

Furthermore, teacher practices are often constrained by systemic factors, including large class sizes, inadequate resources, and pressure to cover the syllabus. Under such circumstances, teachers default to traditional lecture methods. The reliance on one-way delivery not only discourages student participation but also deprives learners of opportunities to practice PSS, engage in discussions, or apply concepts to real-life scenarios (Iwan *et al*., 2024).

Research shows that Ethiopian teachers rarely use questioning techniques that stimulate higher-order thinking (Adebiyi, 2023a). Instead, they tend to focus on factual recall questions, reinforcing a cycle of memorization. Additionally, teachers often avoid open-ended tasks or investigative activities, fearing they may consume too much time or fall outside the scope of examinable content. Such practices hinder the development of critical competencies needed for the 21st century.

Another challenge lies in the limited integration of IK into the biology curriculum. Ethiopian classrooms often rely on Western-oriented curricula, which, while scientifically rigorous, are frequently disconnected from students' lived experiences and cultural contexts (Demssie *et al*., 2020a). As a result, learners find it difficult to connect what they study in textbooks with their communities' practices, challenges, and opportunities.

For example, many Ethiopian communities have long relied on traditional knowledge about medicinal plants, agricultural practices, and ecological stewardship. These practices represent rich opportunities for contextualizing biology concepts in ways that are relevant and meaningful to students. However, such IK is rarely incorporated into teaching and learning materials. The neglect of culturally relevant knowledge makes biology seem abstract and alien, thereby reducing its perceived value and applicability.

The exclusion of IK also undermines efforts to promote sustainability and national development. By failing to connect modern science with traditional wisdom, the education system misses an opportunity to equip students with holistic PSS that are both scientifically valid and culturally appropriate (Mekonen *et al*., 2023).

A growing body of research indicates that Ethiopian biology classrooms continue to be dominated by traditional, lecture-based teaching methods. Students rarely engage in experiments, collaborative tasks, or inquiry-based projects. Consequently, they remain disengaged, unmotivated, and poorly prepared to apply their learning beyond the classroom (Kebede *et al*., 2025).

Student disengagement is further reflected in declining performance on national examinations and classroom assessments. Despite increased enrollment in secondary education, overall achievement levels have stagnated or declined. Many students demonstrate weak understanding of core biology concepts and rely on rote memorization strategies. Their inability to solve novel problems or apply knowledge in unfamiliar contexts reveals the inadequacy of current instructional practices (Sengul *et al*., 2020).

This situation poses serious risks for the future workforce and for the country's ability to meet its developmental goals. Without interventions that strengthen CTS, PSS, and applied learning, Ethiopia risks producing graduates who lack the competencies needed for innovation, sustainability, and global competitiveness (Darling-Hammond *et al*., 2020).

Internationally, scenario-based learning (SBL) has gained attention as an effective strategy for enhancing students' engagement, CTS, and PSS. In SBL, students are presented with realistic scenarios that require them to apply conceptual knowledge, evaluate alternatives, and propose solutions. This approach mirrors the way problems are encountered in real life, making learning more authentic and meaningful.

Research has shown that SBL can be effective in both primary and higher education contexts. For example, virtual SBL environments have been used in biology laboratories to simulate experiments and PSS processes (Muhamad *et al*., 2012). While these approaches show promise, concerns remain about their authenticity and accessibility in low-resource settings. Moreover, studies suggest that while SBL has been widely adopted in fields such as medicine, engineering, and chemistry, its use in secondary school biology remains limited, particularly in developing countries (Seren Smith *et al*., 2018).

Given Ethiopia's reliance on traditional lecture-based teaching and the urgent need to foster CTS, SBL represents a promising avenue for innovation. Paper-based problem scenarios (PBPS), in particular, offer a cost-effective and context-appropriate version of SBL that does not rely on advanced technology. By situating biology concepts in real-life scenarios—such as disease outbreaks, agricultural challenges, or environmental issues—PBPS can encourage students to analyze problems, connect theory with practice, and develop solutions collaboratively (Adebiyi, 2023b).

Despite global evidence supporting the effectiveness of SBL, there is a lack of research examining its application in Ethiopian secondary school biology classrooms. While studies highlight the challenges of rote learning, exam orientation, and limited PSS opportunities, few interventions have been systematically tested to address these issues. In particular, there is little evidence on how paper-based scenario learning might enhance Ethiopian students' CTS, PSS, and engagement in biology.

This gap highlights the need for empirical research to evaluate the effectiveness of PBS in the Ethiopian context. Such a study is not only timely but also necessary to inform curriculum development, teacher training, and educational policy. By providing evidence of how PBS influence student learning, this research can contribute to improving the quality of biology education and preparing students to tackle real-world challenges (Probst, 2022).

In summary, biology education in Ethiopia faces significant challenges: content-driven curricula, exam-oriented teaching, limited teacher capacity, exclusion of IK, and declining student engagement. At the same time, global trends emphasize the need for education systems to prepare learners who can think critically, solve complex problems, and apply knowledge in meaningful ways. Scenario-based learning offers a promising strategy to address these challenges, yet its potential in Ethiopian secondary schools remains underexplored.

Therefore, this study seeks to investigate the impact of PBS on students' PSS and CTS skills in secondary school biology. By addressing this research gap, the study aims to provide insights that can guide teachers, curriculum developers, policymakers, and researchers in enhancing the relevance and effectiveness of biology education in Ethiopia.

1.3. Objective of the study

The main objective of this study is to enhance AA, PSS, and CTS of secondary school biology students through PBS and IK using a design-based research approach.

1.4. Specific objectives of the study

The specific objectives are:

1. To develop and implement a biology instructional tool that integrates PBS with IK in classroom settings.
2. To evaluate the effectiveness of the PBS in enhancing students' AA, PSS and CTS.
3. To evaluate the effectiveness of integrating PBS with IK in improving students' AA, PSS and CTS.
4. To examine the extent to which gender influences students' performance in PSS, CTS, and AA.
5. To iteratively refine the PBS–IK instructional tool through successive cycles of the design-based research framework.

1.5. Research questions

1. How can a biology instructional tool that integrates PBS with IK be designed and implemented effectively in classroom settings?
2. To what extent does the use of PBS enhance students' AA, PSS and CTS in biology learning?
3. To what extent does the integration of PBS with IK improve students' AA, PSS, and CTS compared to PBS alone or conventional instruction?
4. To what extent does gender influence students' performance in AA, PSS and CTS when learning biology through PBS instruction?
5. How does iterative refinement through successive cycles of the design-based research framework improve the effectiveness and usability of the PBS–IK instructional tool?

1.6. Significance of the study

This study is significant for students as it creates opportunities to engage with authentic biological problems that link conceptual knowledge to real-life situations. Through PBS, learners actively apply biological principles to meaningful contexts, strengthening conceptual understanding and enhancing their ability to transfer learning beyond the classroom. Such experiences support deeper learning and prepare students to address every day and community-related challenges using scientific reasoning.

The PBS approach also supports the development of essential 21st-century competencies by promoting active engagement, self-directed learning, analytical reasoning, and structured problem-solving. By participating in scenario-based tasks, students learn to examine situations, weigh alternatives, and justify decisions based on evidence. These processes cultivate adaptive thinking and equip learners with the capacity to approach academic and real-world problems systematically and responsibly.

Integrating indigenous knowledge (IK) into biology learning further enhances the relevance and impact of PBS. Grounding scientific concepts in local cultural practices, environmental conditions, and community experiences enables students to critically examine multiple forms of knowledge and make informed judgments. Exposure to IK encourages learners to integrate traditional insights with scientific explanations, fostering creativity, ethical awareness, and sustainable decision-making in addressing biological and societal challenges.

The study is also significant for teachers and instructional practice. It highlights the role of teachers not only as transmitters of content but as facilitators of meaningful learning experiences that promote reasoning, inquiry, and application. By adopting context-based and scenario-driven pedagogies, teachers can create learning environments that stimulate student engagement and support higher-order cognitive development.

Beyond the classroom, the findings provide valuable evidence for curriculum developers, teacher educators, and policymakers seeking to improve the quality and relevance of biology education. The study contributes to ongoing efforts to design curricula and instructional strategies that align with competence-based education goals and national development priorities. Overall, it underscores the importance of integrating authentic problem contexts and indigenous knowledge to enhance meaningful learning in secondary school biology.

1.7. Scope of the Study

This study examines the influence of PBS integrated with IK on grade 10 students' biology learning outcomes. It focuses specifically on students' AA, CTS, and PSS, recognizing grade 10 as a critical stage for the development of higher-order cognitive abilities.

The scope of the study is limited to selected secondary school biology classes and to instructional activities designed around context-based problem scenarios. The investigation considers a defined set of variables, namely instructional approach, AA, CTS, and PSS. Other instructional strategies, learner characteristics, and contextual factors that may influence learning are beyond the scope of this study.

The study is further delimited to the design, implementation, and evaluation of structured learning scenarios embedded within regular biology instruction. It does not aim to assess the effectiveness of broader pedagogical reforms or curriculum changes. Instead, it seeks to generate empirical evidence on how contextually grounded scenario-based instruction can support students' cognitive development and academic performance in biology.

1.8. Limitation of the study

One limitation of this study lies in the emergent nature of the design-based research approach; this requires collaboration among a diverse research team and the involvement of multiple stakeholders. While such diversity enriches the study with varied perspectives, it can also create challenges in coordinating teamwork, ensuring consistency, and managing data collection effectively across different phases of the research. Another limitation arises from the fact that the study was conducted in natural classroom settings, using intact classes assigned by randomly selected groups. Although this enhances ecological validity by reflecting real teaching and learning conditions, it restricts the extent to which the findings can be generalized to other schools with different organizational structures, student compositions, or learning environments. Moreover, measurement of CTS and PSS using open-ended essays may be influenced by rater subjectivity, writing ability, and the limited number of items, potentially constraining the assessment of students' full reasoning and PSS capacities. Consequently, the results should be interpreted with caution, acknowledging that variations in school contexts may influence the broader applicability of the outcomes.

1.9. Operational definitions of the terms used

To ensure clarity and consistency, the following key terms are operationally defined as they are used in this study:

Problem-based scenario: it refers to an instructional approach in which students learn biological concepts through carefully designed real-world scenarios. These scenarios are intended to create meaningful problem contexts that encourage inquiry, collaborative discussion, and the application of knowledge rather than rote memorization.

Critical thinking skills: CTS is defined here as the capacity to analyze and evaluate information systematically. Specifically, it involves clarifying concepts and ideas, making inferences supported by evidence, offering advanced explanations of terms and relationships, and developing effective strategies or tactics for problem resolution.

PSS: it refers to a learner's ability to approach and resolve challenges effectively. This includes identifying and defining the problem, generating potential solutions, selecting and implementing the most appropriate strategy, and reflecting on or evaluating the effectiveness of the solution.

Problem-based scenarios: they are instructional tools purposefully designed to capture students' attention and engage them in higher-order thinking. These scenarios provide structured opportunities for students to practice both CTS and PSS in relation to biology content.

IK: it refers to the experiential, cultural, and ecological understandings that students acquire from their families, community practices, and local environment. It encompasses traditional ways of knowing, PSS approaches, and practical wisdom that can be integrated with formal science learning to enrich understanding and application.

CHAPTER TWO: LITERATURE REVIEW

Introduction

This chapter examines literature related to the philosophical, theoretical, and pedagogical foundations of the study. It explores the relevance, guiding theories, and practical approaches for improving academic performance, CTS, and PSS through PBS and IK as they pertain to the present research. The chapter further reviews existing studies on PBL, SBL, PBS, and IK, highlighting prior findings that are directly connected to the variables examined in this investigation. It concludes by outlining the conceptual and theoretical framework that supports the study, offering an overview of how the central concepts are interrelated.

2.1. Educational philosophy

Philosophy of education is a branch of philosophy that considers the nature and the aims of education, from both a theory perspective and a practical perspective. Thus, progressivism view, the driving force of this dissertation involves learning by doing which encourages CTS and PSS as well as the teachers encourage the students to intrinsically want to learn by interesting them through activities that are related to their life and their prior knowledge. According to (Tippett & Lee, 2019a) study with a title of 'Looking Back to Move Forward: Understanding progressive education in the 21st century', the original progressive education movement was largely focused on primary and secondary education, emphasizing the education of "the whole child," and "learning by doing". Based on this study, each pedagogy exhibits distinguishing characteristics by focusing on a particular aspect of learning that would fit under the umbrella of progressive education. In progressive education various pedagogies that characterize the landscape of progressive education in the 21st century, primary pedagogies and approaches may be best understood in the context of five organizing characteristics: experience, sequence, action, participation, and reflection.

For progressive education, experience serves as the source from which knowledge emerges. Because progressive education is concerned with the emergence as opposed to transmission of knowledge, the learner must undergo a transformative experience. The nature of the transformation lies in the way the learner is changed by knowledge gained and the way that existing knowledge is changed through the learner's contributions. Experience pertains to individual learners as well as teachers and collectives. While experiential learning focuses specifically on the aspect of experience as the conduit of knowledge acquisition, other forms of learning focus on particular types of experience for the production of specific outcomes.

The theme of experience is also central to pedagogies of applied learning. However, the common thread among applied learning approaches is the opportunity to apply what has been learned, in the classroom or elsewhere, during an experience that will allow the learner to build upon their knowledge base. Beyond simply transferring theory into practice, applied approaches intend to provide the opportunity for learners to develop new knowledge from the experience of application; unforeseen achievements or setbacks are examples of how new knowledge is cultivated through *experience* in applied learning settings. One way of understanding the reason for the phrase “progressive education” is the notion of progression of thought when learning something new. Conversely, progressive pedagogies treat knowledge as a moving target, situated by context, and emerging through the learning process. Progressive pedagogies are useful for developing personal skills while expanding one’s knowledge (Kokotsaki *et al*., 2016).

Learning by doing is a central characteristic of progressive education. Although learning is a valuable end in itself, action remains key to both the learning process and learning outcomes. The final step of progressive learning models generally involves putting new knowledge to use. Action learning, in contrast, involves learning that begins with the recognition of what is not yet known, and the project of learning occurs through the mutual endeavor to solve a problem. Progressive approaches to education challenge the strict teacher-learner dichotomy by utilizing knowledge from life experience, emphasizing the ability of teachers to learn with and from students, and prioritizing the student’s interests and creativity in the learning process. In more clarification, the focus in both problem- and project-based learning is for participants to achieve a shared goal through collaboration (Kokotsaki *et al*., 2016). According to Olugbenga (2021), progressive education has strong emphases on PSS and CTS. It has also influenced by three main psychological paradigms namely behaviorism, cognitivism and constructivism (Tippett & Lee, 2019a).

2.1. Constructivism

Constructivism believes that knowledge is constructed through one's own personal experiences and interactions with the outside world. Thus, the learners take up an active role in the construction of knowledge and teachers facilitate this endeavor. Constructivism is best utilized when learners take control of the learning situation, such as problem- based learning. As learners engage themselves in an activity like this, they develop an understanding of the importance of the problem, comprehend the relevance of the topic and construct knowledge through their experience. Constructivism allows teachers to carry out project - based learning which allows students to learn by doing and applying ideas. Students engage in real- world activities that are similar to the activities that adult professionals engage in. It has also allowed the teacher to use discovery method to motivate students that help them to retain information and teach them how to learn. As the students attempt to deal with the problem, they not only learn the basics concepts involved but also acquire skills to gain knowledge (Tippett & Lee, 2019a).

2.2. Progressive learning theory

Progressive education draws on Piaget's theory of cognitive development, which emphasizes the active role of learners in constructing knowledge (Piaget & Inhelder, 2008), and Vygotsky (1978)'s perspective on socially situated learning, particularly the role of the zone of proximal development. It also reflects long-standing traditions that value experience and reflection as foundations for learning. This approach highlights child-centered methods where learners build understanding through exploration, discovery, and interaction within their cultural and social contexts. Contemporary learning theories further stress the influence of prior knowledge, social interaction, and culture on learning processes, as well as the importance of reflection, effort, and reasoning in skill development. Thus, progressive education views learning as an active, contextual process that integrates cognitive, social, and cultural dimensions (Tippett & Lee, 2019a).

2.3. Theoretical background

Learning is an acquisition of knowledge (Mayer, 2002). In the analysis of the revised Bloom's taxonomy of educational objectives, Mayer analyzed that learning is not only acquiring knowledge but also being able to use knowledge in a variety of new situations, which promotes retention and transfer of knowledge, meaningful learning. Likewise, Yunianta *et al* strongly recommended that this meaningful learning should be intentional(Vallori, 2014; Yunianta *et al*., 2012). This implies that in fact information can be retained in unplanned way without meaning, but meanings can be built in planned, formal and systematic situations.

According to Mayer (2002) learning is not taking place if students able to remember very few of the key terms and facts or cannot list the major components in the questions asked to recall part of the lesson. Conversely, it is happening if they can answer the questions and use the information asked to remember and diagnose or solve problems. Rote learning or retention is an outcome resulted when students possess a relevant knowledge but is unable to use that knowledge to solve problems. Whereas, meaningful learning is occurring when students use the information that they remember in the lesson to solve problems, generates many possible solutions, and transfer to new problems and new learning situations.

In addition to define a learning, Mayer analyzed the revised Bloom's cognitive taxonomy by summing up the six cognitive process categories into two core cognitive processes, retention (Remember) and transfer (Understand, Apply, Analyze, Evaluate, and Create). In other words, a knowledge that students remembered but not use it to solve problems is meaningless. Thus, remembering knowledge is essential for meaningful learning and PSS when that knowledge is used in more complex tasks. In are tension goal, students identifying and retrieving relevant knowledge using their remembering as a means to an end.

While in instruction goal is to promote transfer, students understand and constructing meaning from instructional messages by interpreting, exemplifying, classifying, summarizing, inferring, comparing, explaining and building connections between the new knowledge to be gained and their prior knowledge. Then, they can apply procedures to solve problems through implementing on unfamiliar tasks and analyze conceptual understanding of the problem and procedure. Finally, students evaluating by critiquing that lies at the core of CTS or judging the solution of a problem based on specified or student-determined criteria and standards (Castillo *et al*., 2018; Mayer, 2002).

Based on the suggested learning theory, learners in schools are anticipated to actively engage to achieve these cognitive goals in such a way that they transfer or use the acquired knowledge to solve new problems, answer new questions, or facilitate learning new subject matter (Castillo *et al*., 2018). Moreover, meaningful learning requires a meaningful task, which emerges from authentic context that have more meaning. Therefore, learning in such real life, new, different and useful contexts make students to engage in solving simple, complex and ill-structured problems (Dringenberg & Purzer, 2018; Hong & Kim, 2016).

The main function of school is to enable all students to acquire knowledge that takes them beyond their experience; to enable them to lead a flourishing life and to help others. In other words, it is used to prepare students for a life of autonomous, and successful engagement in worthwhile relationships, activities and experiences. Conversely, students can learn science informally outside the school setting to develop skills, dispositions, practices and knowledge (Khaddage *et al*., 2016). Even Mujtaba *et al* suggested that community institutions such as museums and zoos able to support young people's learning and interest in science better than schools working in isolation (Mujtaba *et al*., 2018). Similarly, Porozovs *et al* reported that students believe that biology lessons could be more interesting when learn in laboratory, research, experiments as well as conducting lessons in the open air(Porozovs *et al*., 2015). However, they are not equally accessible to all students in educational levels. Therefore, it needs some contexts to learn in meaningful ways formally in schools.

Formal learning may require contexts that can bring life experiences into classrooms discussions. Context is a situation which trigger students' preconceptions, that is the starting point for meaningful learning (Broman *et al*., 2018; Vos, 2014). Because, real-world contexts provide questions and problems to stimulate learning scientific concepts (Sutaphan & Yuenyong, 2019). When the context be a realistic situation from students' own lives, it helps to present a lesson from different aspects and relationships, then the lesson becomes concrete for them. Likewise, designing such context is a stimulating factor for students to think about new questions, problems, and phenomena, and to develop solution strategies (Cabbar & Senel, 2020; Lee & Hannafin, 2016; Purwati & Prasetyanti, 2019; Zhong *et al*., 2022). Thus, associating the topics of biology, life science, with daily life will increase the perpetuity of information. Sternberg argue that learning best takes place in the context in which it is going to be used (Sternberg, 2014). Similarly, knowledge is best acquired and more fully understood when situated within its context. These contexts and their use can be described by scenarios, which can be framed as an open ended problem scenario reflected in a real-world situation (Cukurova *et al*., 2018).

Scenarios are narratives that tell a story describing one or more tasks in a specific environmental situation in which real life problems take place. They help students to achieve the determined objectives of the instruction in specific processes and stimulate students to inquire and practice what they have learned (Karabulut & Bayraktar, 2018). Scenarios also focus on the activities and the context whereby the learners are asked how to go forward from them. Learning through this way requiring students to use authentic contexts, ill-structured or complex problems. In the process students can apply CTS and PSS in a safe, and real-world context.

Moreover, scenarios can provide many feedback opportunities to students, based on the decisions they make at each stage in the process whereby students feel probable situations they may encounter in real-life (Baile & Blatner, 2014; Koivisto *et al*., 2017); provide students a chance to reflect or evaluate their values (Çeliker, 2021; Ribchester & Healey, 2019); fills the gap between theory and implementation (Ahmad, 2019). Likewise, problem-based scenario method with experiment certainly contributed to the biology self-efficacy and CTS tendency (Çeliker, 2021). Overall, scenario with an embedded problem may elicit students' thinking, discussion, research, and learning to meet the learning outcomes (Oh *et al*., 2018).

Even though contexts and scenarios are suggested for meaningful learning, biological sciences are focusing on experiencing more learning in simulation than real world problems. For instance, it tends towards modelling modules strategies supported by educational technologies and virtual tools such as personal computers, advances computer applications and educational software (Elkhidir, 2020; Potkonjak *et al*., 2016). The use of these modellings, simulations and interactive learning strategies integrated with multi-media technology and interactive cloud computing models have led to simulate students on real biological problems to better understand concepts and improve their achievement (Elkhidir, 2020; Satyaprakasha & Sudhanshu, 2014). Although these technologies are so helpful in learning through simulation, science education in developed countries is fail to provide students with a deep understanding of science in the twenty-first century (Kelley & Knowles, 2016; Tytler, 2020) due to inaccessible of them.

In the same way students could not connect knowledge obtained in the school with their day-to-day lives to solve real problems (Kurup *et al*., 2021). Thus, science curricula and instructional methods have to design in accordance to real life situations. Recently, studies revealed that the system and curriculum of education in countries of the world have been focused to attain the needs of the 21st century learning skills and enrich students with classroom environments (Barcelona, 2014; Santoso *et al*., 2022). Schools also have to change in line with big aspects of life (Ayyıldız *et al*., 2022; Wibawanto *et al*., 2021). Overall, real world tasks need to be prioritized to improve students' achievement, to equip them with higher order thinking and PSS in science (Dessie, 2015).

According to past existed literatures direction and suggestions, science education in Ethiopia was started in 1947 and developed through educating all citizens in areas of science and technical fields. Afterwards, the global, national, and local contexts enforced the country to establish Education and Training Policy (ETP) in 1994. Through this policy implementation process, the country has designed Educational Sector Development Program (ESDP) in 1998. Since then up to 2018 the policy has given emphasis for the development of PSS capacity of students (Zerai *et al*., 2019).

Furthermore, in the first Growth and Transformation Plan (GTP I) of Ethiopia, Science education has taken as an instrument of supplying PSS to transform the economy from agriculture-led to industry-led activity. Curriculums designed on this basis have also incorporated practical skills that enhance the development of learners' PSS and creative thinking skills. For more emphasis a program called STEM (Science, Engineering and Mathematics) has been introduced to secondary and preparatory schools, in which students have enrolled to learn higher-order thinking skills in science, technology, engineering, and mathematics subjects. In addition, the program and the curriculum of science and technology have been aligning with the applying of

70/30 graduate mix policy, 70% natural science and 30% social science enrolments in high school and higher education (Negussie *et al*., 2019; Teferra *et al*., 2018; Vidergor, 2018).

Even though such efforts have made to improve quality science education, the present education system does not prepare students to be critical thinkers (Teferra *et al*., 2018). Similarly, the curriculum lacks quality, it has not given due attention for PSS; does not orient the learning process on practice, and it is too theoretical and fails to prepare students to hire on occupations. The contents incorporated in the textbooks are also too bulky which has not been leaving enough space for students to reflect their learning, to enable deep learning, to engage in identifying tasks, to inspire and aspire on activities.

Accordingly, teachers use inadequate equipping of laboratory and local materials which results in less student motivation to practical activity and preference in science education (Muleta & Seid, 2016). This makes society reluctant to learn children scientific knowledge (Ndalichako, 2014). As a result of this, learning outcomes of the students are very low; they do not have the expected knowledge, attitudes and skills. For instance, graduates of secondary education lack competence in integration of knowledge, skills and the necessary values. They focus only on factual knowledge, thereby they fail to master basic skills of leaning (Negussie, 2018; Reda & Gebre-Eyesus, 2018).

The most thoughtful and minimum learning concern is students' achievements that have been seriously affected. For instance, a program for international student assessment (PISA) and trends in international mathematics and science study (TIMSS) results have shown that the achievements of Ethiopian average scores for Mathematics, language, and science are much lower than PISA average scores of other participating countries in Africa (Tesema, 2021). Similarly, Ethiopia's grade 4 and 8 students' samples' scale means scores for the pilot TIMSS mathematics and science results are far below the lower average recommended by the benchmark score of 400 (Mullis & Martin, 2017). Overall, Ethiopia has been challenged yet to build a quality science education system in 21st century (Barnes *et al*., 2018; Sbhatu, 2021). In order to meet these needs of 21stcentury, literatures have suggested to learn in PBL whereby problems stimulate students' creative and CTS abilities (Goradia, 2018).

2.4. Critical thinking skill

Mainly CTS can be defined in philosophical, psychological and pedagogical views. The philosophical approach considers the critical thinker as a standard-bearer of thinking, adequacy and accuracy (THAMPI & Yongsorn, 2023). The ideal critical thinker in the philosophical approach is reflective and reasonable. For instance, Bloom's taxonomy tries to create a more hierarchical educational approach towards CTS, but Bloom has been critiqued for the limitations of dispositions and lack of clarity. Ennis *et al*. (1985) believes that CTS provides better clarity than the higher-order thinking skills put forward by Bloom.

Because, higher-order thinking does little to help develop education, teaching or curriculum. But it is helpful as a reminder that reminds the student and teacher community about the higher task and thinking skills. Ennis also argues that the terms in Bloom's taxonomy are too vague and do not provide any assessment criteria. In the pedagogical approach the definitions may be influenced by the pedagogical methods used by the teachers. For instance, inspiring and engagement process can increase CTS (Maker, 2021).

Critical thinking skill is defined as different skills required to judge the correctness and accuracy of information (Pasquinelli *et al*., 2021). In the same way it is the examining evidence, comparing incidents and then concluding (Alsarayreh, 2021), reason, analyze, synthesize and evaluate information (Facione, 2011). In more clear way, Ennis has defined it as reasonable and reflective thinking focused on deciding what to believe or do (Ennis, 2018a). In other words, it is thought as the ability to take responsibility and evaluate observations, communications, information, and arguments (Cojocariu & Butnaru, 2014; Ghaemi & Mirsaeed, 2017; Giri & Paily, 2020; Linina & Vevere, 2021).

Overall, it is a purposeful judgment that requires self-regulation, resulting in interpretation, analysis, evaluation, and inference of information (Ghanizadeh, 2017; Kitsantas *et al*., 2019). Accordingly, CTS skills are multiple skills such as analysis, comparison, interpretation, judgment, classification, arrangement, and the skills of checking and verifying information (Alsarayreh, 2021; Alwadai, 2014; Kong, 2014; Van Laar *et al*., 2017).

In relation to the definitions, critical thinkers believe that thinking deeply and reasonably are the best way to decide what to believe, and they tend to use these methods in a variety of appropriate situations (Paul & Elder, 2019). Unlike other empirical evidence, Jansen and Moller claimed that CTS are an integral part of both higher and lower order thinking i.e. skills to generate information (lower order thinking) and using those skills to guide behavior (higher order thinking) (Jansen & Möller, 2022). Overall, critical thinkers ought to go through the six levels of cognitive thinking defined by Bloom (Darwazeh & Branch, 2015).

Critical thinking skills refer to six elements or the indicators developed by Ennis abbreviated as FRISCO (Focus, Reason, Inference, Situation, Clarity and Overview) in which, first students focus on questions or issues that are available to make a decision about what is believed (Harjono & Doyan, 2021; Indrawatiningsih *et al*., 2019; Makhrus *et al*., 2021; Mirunnisa & Razi, 2021). Second, they know the reasons that support or oppose decisions made based on relevant situations and facts. Third, they make reasonable or convincing conclusions to find solutions, considerations of the interpretations and evidence. Fourth, students understand the situation and keeping it in mind that may help to clarify the question and know the meaning of the relevant key parts. Fifth, they explain the meaning or terms used.

Finally, students review and thorough examination of the decision taken. This helps students to learn (Ongardwanich *et al*., 2015), to enhance AA (Carter *et al*., 2017) and to solve complex problems. Because, the purpose of CTS is to overcome problems found in everyday life (Foster & Yaoyuneyong, 2016; Paul & Elder, 2019).

Through CTS students review the ideas produced, make a tentative decision about what action to be taken to solve the problem or what belief about the issue is most reasonable, then evaluate and refine that solution (Murawski, 2014). Since the ultimate intent of CTS is PSS, critical thinkers tend to see the problem from many perspectives, to consider many different investigative approaches, and to produce many ideas before choosing a course of action. In addition, they use their imaginations while analyzing problems and issues (Ali & Anwar, 2021; Anis & Anwar, 2020; Drapeau, 2014; Herrington *et al*., 2014; Yayuk & As' ari, 2020).

However, students are learning biology to memorizing facts, figures, and processes which does not promote or have low CTS (Wilson, 2017). For instance, in laboratory reports Addy *et al*. (2014) claimed that weaknesses in the CTS habits of students who never fully understand the objectives of the experiment, cannot ascertain how to relate the observed data to their hypotheses and scientific literature, and unable to draw appropriate conclusions; or relate experimental results to the appropriate objectives (Addy *et al*., 2014; Forawi, 2016; Khalaf & Mohammed Zin, 2018; Liu *et al*., 2014). Thus, to foster students' CTS in learning, it needs to expose them to topics or themes that are controversial (Nganga *et al*., 2020). Because, students learn to think gradually through habits that are trained in the form of formulating problems and answering questions that need explanation (Saputro, 2021).

2.5. Assessing and measuring CTS

According to the variations of CT definitions, diverse assessments of CTS have been developed and validated. For instance, some of the most widely used and recognized tests are the Watson-Glaser Critical Thinking Appraisal (WGCTA), California Critical Thinking Skills Test (CCTST), Cornell Critical Thinking Test (CCTT), and Halpern Critical Thinking Assessment (HCTA). However, the majority of CT tests, including the above CT tools used to assess general CT skills, do not consider specific subject-matter skills. This is a major limitation of the existing CT assessment practice because it emphasizes general CT skills. In sum, there is a general lack of experience among educators and researchers in testing CT skills in specific science domains (Tiruneh *et al*., 2016).

In addition to emphasizing general CT, assessments in the literature have tended to employ objective type test instruments. For instance, the WGCTA, CCTST and CCTT measure the ability to think critically with multiple-choice questions, while the HCTA measures with scenarios requiring short answers or ratings (Tiruneh *et al*., 2016). However, progressing investigations suggest that essay questions are standardized, authentic and appropriate for measuring CTS (Sobocan *et al*., 2022). Specifically, open-ended essay questions are more effective than closed-ended questions in encouraging students to clarify their thinking, knowledge, and rationale for their thoughts (Connor Desai & Reimers, 2019; Fajari, 2021a;

Febri, 2019; Firda & Tutut, 2022; Miterianifa *et al*., 2021; Purwati *et al*., 2022; Takus *et al*., 2021).

However, researchers and teachers consider essay instruments to be tiresome for providing comments and marks in large class sizes. As a result, they use objective test items to find a single correct answer. In particular, assessments in high schools focus only on objective items such as multiple-choice questions in which students memorize concepts or procedures (Carpenter & Toftness, 2017; McDermott *et al*., 2014) rather than thinking critically. By doing so, they expose students to guessing answers and hinder their critical-thinking skills (DAMI & Hadjer, 2022; St Hilaire & Carpenter, 2020). On the whole, an objective type of assessment format may be inadequate for measuring critical-thinking skills. Therefore, critical-thinking assessment researchers suggest that teachers must assert answers competently to represent the relevant information using essay questions (Ennis, 2018a; Sobocan, 2021).

Although multiple-choice measuring tools cannot assess information and decisions for action on a problem, some researchers have attempted to develop them as biological critical-thinking measuring instruments at the college level (Rosenbaum *et al*., 1991) and high school level (Anwar & Permata, 2020). Furthermore, forced construct response tests or reasoned multiple-choice tests have been employed in research as critical-thinking test instruments, but they measure only one aspect of CTS, reasoning (Ennis, 1993). Rating scales such as Likert and self-concept short scales have also been administered as critical-thinking assessments in research (Marlina, 2020; Noviyanti *et al*., 2019; Putri *et al*., 2021; Umam, 2020). However, these types of questions measure requesting agreements on opinions, attitudes, perceptions, self-assessments, and views of students (Suwandi *et al*., 2019) that impede the freedom of response and cannot indicate the thinking abilities of students (Ennis, 2018a; Sobocan, 2021).

Indeed, unlike multiple-choice studies, few studies have designed essay test instruments for high school students (Mahanal *et al*., 2017; Ristanto *et al*., 2020) or peer assessment tools for undergraduate students (Anwar, 2020). However, the instruments are concerned with different biological content at higher education levels. In summary, adequate emphasis and clear-cut critical-thinking test instruments have not yet been developed for biology. Similarly, no one can obtain consistent open-ended critical-thinking test tools for published stocks.

A variety of studies on CTS have suggested that the design of CTS instruments must be developed based on CTS definitions and indicators (Fitria *et al*., 2018; Hidayati & Sinaga, 2019; Purwaningsih *et al*., 2020). For instance, (Ennis *et al*., 1985) has developed five indicators, namely, elementary clarification, basic support (credible the source), inference, advanced clarification and strategies and tactics of information. (Facione, 2011) constructed six indicators: interpretation, analysis, inference, evaluation, explanation, and self-regulation. However, (Facione, 2011) focuses on a problem in adult students in higher education, while Ennis emphasizes adolescents in elementary and high schools. Thus, the present study attempted to develop a critical-thinking ability essay instrument by taking (Ennis *et al*., 1985)'s indicators as a criterion. In the critical-thinking essay question, students may expect to clarify information more than its presence, and indicators may measure the clarity of information and the decisions to take action.

In addition to indicators, scholars have been interested in embedding CT within specific subject matter instructions (Abrami & Waddington, 2015; Tiruneh *et al*., 2014). In particular, (Ennis, 1990) suggested that having adequate knowledge and understanding in one domain urges the performance of CT skills rather than knowledge of general CT. Moreover, (Davies, 2013) claimed that the ability to think critically is highly dependent on in-depth and specific content knowledge that is required for competent performance in various thinking tasks. in addition to skills and dispositions, as part of good CTS, Ennis and Facione emphasize the importance of background knowledge, IK in this case.

The need for domain-specific background knowledge in general is closely tied to the question of whether CTS is generalizable and applicable across a range of domains or if it is domain-specific. Therefore, to nurture students in such provocative essay measuring instruments (Fajari, 2021a; Nganga *et al*., 2020; Saputro, 2021), students must be exposed to contexts that are effective for examining skills (!!! INVALID CITATION !!!), analyzing, interpreting, inferring and explaining information (Danil *et al*., 2023; Kumala *et al*., 2022; Mafarja *et al*., 2022; Rusnayati *et al*., 2019; Sobocan, 2021; Suyana *et al*., 2019). Moreover, the development of critical-thinking assessment tools must rely on realistic or meaningful contexts, which are fundamental and powerful concepts in a discipline to be assessed (Sobocan, 2021). On the whole, this study has constructed an open-ended test tool to measure biological CTS through indicators of CTS.

2.6. Teaching and learning in CTS

Despite various studies have been making large efforts on how to teach and incorporate CTS in daily classroom activities, much is still left to be done with regard to helping students and teachers internalize the true essence and disposition of CTS (Debele, 2008). Although the majority of teachers claiming CTS to be their priority, they could not give clear description of what it is, what traits it refers to, or how they incorporate activities in their classrooms that help students develop their CTS.

However, certain teaching and learning approaches have been suggested in literatures, some of them are leading learners towards CTS. For instance, explicit instruction, providing clear explanations, modelling CTS processes, and guiding learners through practice opportunities that target specific dispositions (Abrami *et al*., 2015). Scaffolding instruction has also provided structured support to learners as they develop their CTS and dispositions. Moreover, reflection instruction leading to greater self-awareness and refining CTS (El Soufi & See, 2019).

According to Abrami *et al*. (2015), effective strategies for teaching general and content-specific CTS at all educational levels and across all disciplines are opportune learners for dialogue, expose them to authentic or situated problems and mentoring (Abrami & Waddington, 2015). The opportunity for dialogue, especially whole-class teacher-led discussions as well as teacher-led group discussions, improve the acquisition of CTS. Moreover, exposing students to authentic issues stimulates inquiry, particularly when this includes role-playing and applied PSS improves CTS outcomes.

Besides, though one-on-one mentoring did not generate strong results on its own, the combination of mentoring with dialogue and authentic issues yields larger effects. In other words mentoring might serve as a catalyst for CTS in combination with other effective strategies (Abrami & Waddington, 2015). Whereas, some other researches support the efficacy of these strategies include the study that presents students with case studies calling for CTS in subject-specific issues and problem-based learning, which overlaps with the use of authentic issues

(Ennis, 2016). Apart from this, the APA panel have suggested that learners should be exposed to simple situations that require them to exercise CTS. Throughout this process, learners should receive constructive feedback, be coached and motivated to become better and more independent critical thinkers. In short, CTS should be a part of the curriculum at all levels, from K-12 through college (Ma *et al*., 2023).

Refined instructional approaches have emphasized to enhancing instead of leading towards CTS. For example, problem-based learning (PBL), is an instructional approach that presents learners with authentic, complex PSS problems that enhances CTS dispositions. Furthermore, reviews of the CT teaching strategies such as collaborative learning activities show that there are various methods and activities that can be used to enhance students CT skills (Arifin *et al*., 2020; Dakabesi & Luoise, 2019; Erdogan, 2019; Nargundkar *et al*., 2014)..

Many other studies have tried to investigate the role of integrating technology to enhance CT skills. Nevertheless, there is still much room to better understand the impact of using different pedagogical strategies and technology in enhancing student CT(Alsaleh, 2020). Informally people have been learning how to be good critical thinkers for eras. For instance, they have been observing and evaluating sights and sounds in the forest to find food and avoid dangers, aware how thoughts produce bodily reactions to improve decision making, and discussing politics with a disagreeable to counter arguments. Luckily, formal instruction can also lead to predictable gains in CTS (Facione *et al*., 2020). Therefore, both formal and informal learning have to be considered in CTS in science education, particularly in biology.

In biology the more simulations and problem-based learning become part of the teaching strategy to enhance learners’ CTS on complex biological processes (Elkhidir, 2020). In addition to PBL, certain instructional strategies that have been conducted to enhance CTS in biology include collaborative learning (Ramdani & Susilo, 2022); cooperative integrated reading and composition (CIRC)-based scientific approach at elementary students (Ristanto *et al*., 2020). Moreover, instructional approaches supposed to learn CT in high school biology include directed investigation and discussion strategy (Alsarayreh, 2021) and thinking empowerment by questioning (Nur *et al*., 2023).

Biological CT learning strategies at higher education encompass analogy strategy (Suryanda *et al*., 2020) argument-driven inquiry and reading, questioning and answering (Amin *et al*., 2020), problem-based learning (Agustina *et al*., 2024; Don, 2020), reciting and analyzing the problem, and narrating, doing, assessing and implement the solution (Arsih *et al*., 2021), and open ended questions, inquiry-based learning, concept mapping, and dialogue (Jamil *et al*., 2024). However, based on the review, integration of instructional approaches on CT is very scarce. Thus, this dissertation needs to develop CT instructional scenarios and link them with problems.

2.7. Problem Solving Skills

PSS are learning outcomes or kind of expert thinking which are essential to look the demands of the 21st century that have strong desire to solve problems in real-life (Wismath & Orr, 2015). PSS help students to think reflectively in conceptualizing and understanding problems, designing to find the solutions, implementing solutions as well as evaluating the effectiveness of solutions used to solve problems (Jasman & Mahanal, 2024). It can be developed through the students practice to solve problems faced in day-to-day life (Amalia *et al*., 2017; Aslan, 2021; Khoiriyah & Husamah, 2018).

In addition to this, PSS can be developed with practical work, skills and attitudes (Chen *et al*., 2015; Karampelas, 2021, 2022). When students are presented with problems, they access their prior knowledge, establish a problem space, search for new information to help reach their PSS goals, then they may restructure existing representations (A. Alrahlah, 2016). These skills enable students to identify issues in real-life situations, make evidence-based decisions, and take appropriate actions (Pease *et al*., 2020). Moreover, PSS insures students to find the issues in real life situations, make evidence based decisions and take appropriate action (Boss & Krauss, 2022).

Problems in education can be structured on unstructured, the structured problems are clearly defined, have only one correct answer with the help of the formulas and have memorized without having the need to think in-depth and make interpretations (Broman & Parchmann, 2014; Tekkumru-Kisa *et al*., 2015). In contrast, unstructured or an ill-defined problems are complex that cannot be solved with a simple answer, but encountered in daily life (Hesse *et al*., 2015; Perusso & Baaken, 2020). Unstructured problems can be defined as authentic, real-world problems, or an ill-defined problems with multiple possible solutions that cannot be solved by simple answers (Riyanto & Putri, 2019; Siew & Ambo, 2018). In short, complex problems cannot be solved merely by recalling facts from memory or by using a simple algorithm. Instead, complex problems require that problem solvers engage in a wider variety of scientific practices, processes and skills (Leak *et al*., 2017).

A problem in PBL is the starting point for learning that they may face it in their future life (Ali, 2019). Thus, when the starting point for learning is a problem, a query or a puzzle, and situated in real life contexts, students better able to form connections between the science and real life (Karakoç & ALACACI, 2015; Kelley & Knowles, 2016). Moreover, the real problems adopted in PBL stimulate students to vigorously construct new knowledge that relates strongly to their prior knowledge and experience (Dolmans *et al*., 2015; Priyadi & Suyanto, 2019). These real-world problems have a potential, that trigger them to analyze the problem and evaluate their learning (Dewi & Primayana, 2019; Hasanah, 2020a; Utomo *et al*., 2020). Likewise, students can use problems as context for an in-depth investigation of what they need to know and support their perception of subjects that they may use them in their real life (Hwang, 2014). In summary, if students are to successfully struggle with authentic, complex biological problems as scientists and citizens, they need practice solving such problems (Reiser, 2018).

Even though PSS are as such the 21st century focus of learning outcome, studies conducted to improvise it in all disciplines are too limited. For instance, some studies have conducted at secondary schools on effect of PSS on mathematics achievement (Hooda & Devi, 2018a, 2018b; Lalzawmliana, 2023); PSS and AA on mathematics with gender (Prema & Sathiskumar, 2021); PSS with reference to gender (Ramzan, 2020), PSS and scientific attitude with gender (Miachieo & Ratna, 2021), PSS and creativity (Kumar, 2020) in high school students; PSS with gender on nursing students (Dawngliani *et al*., 2019) and between gifted and ordinary students (Wahyuni & Dahlan, 2020).

Some other study have done on the relationship between PSS, achievement, motivation, metacognitive and attitudes in students (Yunus *et al*., 2021). Indeed, investigations have carried out on PSS and AA in biology (AKINWUMI, 2021; Bilici & Yilmaz, 2024; Demirhan & Şahin, 2021; Fıtrıanı *et al*., 2020; MERCAN & KÖSEOĞLU, 2022). However, the focus of the studies varies in terms of aspects such as effects of Kolawole's PSS and examining the scientific creativity of biology teacher candidates. Studies have also concentrated to effects of single instructional methods including the effects of using collaborative digital storytelling, different kinds of hands-on modeling activities, integrated problem-based learning, predict, observe and explain on PSS. Therefore, to address this gap, the present dissertation aimed to assess the impact of problems and scenarios integrated problem-based scenario methods on PSS and AA in biology.

2.8.Problem based learning

Problem based learning is an instructional strategy that can help students to understand how to apply knowledge. In history it was first introduced in medical schools for testing the knowledge of graduates at higher education (Savery, 2015). Later on it has been adapted in elementary and high schools (LaForce *et al*., 2017). It is a student-centered constructivist learning approaches and inquiry-based instructional model in which students engage with an authentic, ill-structured, disordered or open-ended real-world problem that have no one right answer. In this model students to confront the problem and develop viable solutions, gain new information through self-directed learning that lead them to the development of PSS capabilities (Choiriya *et al*., 2019; Ge & Chua, 2019; Ge *et al*., 2015) and CTS (Virtanti *et al*., 2021).

Problem-based learning allows students to facilitate students' knowledge construction and engage in higher-level thinking (Chernobilsky *et al*., 2017). In addition, it identifies the need of learners to develop PSS (Ali, 2019; Savery, 2015; Tan, 2021). Furthermore, it can transfer skills and knowledge from classroom to work; theory to practice; promote students to develop self-directed, self-assessment, collaborative learning skills, high order thinking, encourages a deep learning approach up to life (A. Alrahlah, 2016; Evendi *et al*., 2022; Fukuzawa & Cahn, 2019; Savery, 2015; Tan, 2021).

This learning model help students to develop flexible, non-factual knowledge that motivates them to learn on their own real-life scenario (Ng *et al*., 2014). Likewise, it is increasing students' engagement, metacognitive growth, and long-term knowledge retention of the learned information and the learner to associate the learned topics with real life situations (Gholami *et al*., 2021; Horak *et al*., 2021; Shimizu *et al*., 2019). On the whole, it is used as a potential strategy to develop students' character in the 21st century learning (Bahri *et al*., 2021; Ridho *et al*., 2021). This offers an ideal climate to address the cultivation of skills and knowledge through emphasizing active student learning and authentic assessment techniques (Tan, 2021).

Indeed, problem based learning can employ real or simulated problems that can produce changes in knowledge (Banic & Gamboa, 2019; Savery, 2015). However, real world problems are more preferable for meaningful learning environment in biology education (Lee *et al*., 2014). Because, biology is best learned if it associated with day to day life and one's surrounding which contributes towards maximum involvement of the students (Thakur *et al*., 2018). Investigations claimed that students learn biology through PBL by solving realistic, complex, and open-ended problems whereby they improve their cognitive achievement (Clark & Mahboobin, 2017).

In addition to achievement, PBL has already been implemented in students' CTS and PSS (Birgili, 2015; Choi *et al*., 2014). However, the investigations on PSS have focused only at higher education and on pre-service teachers (Zeliha, 2017), too much on mathematic subject (Jimenez, 2020; Mutange, 2020; Simamora & Saragih, 2019; Wahyuni & Dahlan, 2020), neglected at lower education and it has not adjusted with certain learning goals and students' characteristics (Nehm, 2019; Reiss, 2018; Waarlo *et al*., 2018). Besides, biology teachers often pay insufficient attention to these skills. Likewise, since personal and situational factors and internal and external factors influence, PS has been underrepresented in the instructional design literature and most textbooks (Riegel *et al*., 2022).

In fact, the PSS instructional method has been suggested frequently in the policy document of Ethiopia, its implementation has not revised continuously for a better result, lacks iteration and the situations likely to hinder the development of those skills (Teferra *et al*., 2018). Therefore, it is important to equip students with PSS and empower them to challenge problems based on their experience (Harahap, 2023; Iwan *et al*., 2024).

Meaningful learning in science education have focused towards aspects such as pedagogy, interest, motivation, attitudes, understanding, academic success, and permanence of information (Agustian *et al*., 2022; Chang *et al*., 2022; Li *et al*., 2021). Some other studies on PSS have been concentrated on effectiveness of different instructional methods such as problem-based modules

(Acquandoh *et al*., 2022), blended problem-based learning approach (Pimdee *et al*., 2024), collaborative, process-based, experimental learning, context-based, lecturing, concept mapping, and computer-assisted methods (Aguilera & Perales-Palacios, 2020; Guerrero-Roldán & Noguera, 2018; Potvin *et al*., 2020).

Moreover, few studies in biology education have concerned on CTS and PSS (Anazifa & Djukri, 2017; Arsih *et al*., 2021; Asyari *et al*., 2016; Elkhidir, 2020; Magsino, 2014; Marthaliakirana *et al*., 2022; Miterianifa *et al*., 2019; Orozco & Yangco, 2016; Temel, 2014; Zakiyah *et al*., 2021). However, certain researches have asserted that learning with real-world problems is more effective in science education (Simanjuntak *et al*., 2021). Particularly, for biology education these problems serve as critical learning triggers for students that might encounter in their future lives (Tan, 2021).

Investigation caried out on PSS in the past 5 years had attempted to examine effect of instructional methods in different subject maters such as social studies in high school (Surur *et al*., 2020) and English language teaching at higher education (Kök & Duman, 2023). More significantly, PSS instructional strategies have scrutinized in teaching mathematics at all educational level (Ahdhianto *et al*., 2020; Juandi & Tamur, 2021; Khalid *et al*., 2020; Roorda *et al*., 2024). They have also applied in educational technology (Lu & Xie, 2023) and in online flipped classrooms (Pimdee *et al*., 2024) at higher education.

In science education, PSS instructional methods such as problem-posing approach at higher education (Akben, 2020), PBL (Magaji, 2021), flipped classroom technique (Alias *et al*., 2020) and collaborative PSS strategies in high school (Setiawan *et al*., 2020) supposed to be effective. Similarly, in biology education instructional strategies such as mini research learning (Widiantie *et al*., 2021), local-based teaching materials (Kundariati *et al*., 2022) and creative PSS strategy at higher education (Fatmawati, 2020), integrated PBL (Fıtrıanı *et al*., 2020), worksheets-based (Elkhidir, 2020) design thinking process learning model (Jasman & Mahanal, 2024), student teams achievement divisions (STAD), Remap-STAD in high school (Agustina *et al*., 2024) and PBL (Obochi, 2021; Taharu & Aba, 2020) have found to be effective for PSS learning.

Based on the review in the past 5 years, PSS investigations are limited in science education in general and biology education in particular. Even though the scrutinization of the impact of problem-based learning on biology learning is scarce, it can impact learners' PSS when it is integrated with simulated aspects or conditions. The more escalating is that it is effective when it bases on problems situated in real-life contexts whereby students connect scientific concepts with real-life situations. This approach enables students to link prior and acquired knowledge with new information, guiding them towards PSS goals. A study has also shown that students learn biology more effectively through PBL by solving realistic, complex, and open-ended problems (Webster *et al*., 2022). Therefore, real-world problems may be preferable for meaningful learning in biology education that can be associated easily with biological information or scenarios in day-to-day life.

Students in problem-based learning with scenarios can engage in problem-based activities, formulate problem statements, collect and analyze data; practice skills of analysis, integration, application and work out practical case-based scenarios (Douglass & Morris, 2014; Nguyen *et al*., 2020a; Wyness & Dalton, 2018). Problem-based learning emphasizes more on student activities to make them interact more with objects and events so that they gain understanding (Nasution *et al*., 2016). These situations or scenarios provide students to think critically and analytically, to find and use appropriate learning resources and provide stimulus and realistic thinking. Besides, applying scenarios including daily life problems helps to stimulate students' understanding on how to find information that are linked to problem through searching, discussing, and choosing the most appropriate solution to a problem (Haridza & Irving, 2017; Hung & Amida, 2020; Mehraj, 2019).

In PBL students can solve problems through an independent, cooperative, and collaborative learning process (Andreu-Andrés, 2015). They have to regulate themselves and be responsible to the group learning process such as dialogue, collaboration role play, work sharing and presenting solutions. Not only has this but they also assumed the roles of scientists as they pursue to find solutions to the problem (Miller *et al*., 2018). Similarly, they can rotate group roles such as leader, recorder, board writer, or members, during their group discussions (Hou, 2014).Their learning begins with the problem scenario established from real life and introduced at the start of a unit of instruction.

Afterwards students focus on problem in which they read through the scenario and identify unfamiliar terms or concepts, inquire into the problem situation (Tan, 2021). Then they identify and define the central problem to be clear and structured (Bahri *et al.*, 2021). Hence, they determine what they need to know in different contexts and situations (Hmelo-Silver *et al.*, 2018; Hou, 2014). This helps to notice what has been learned when a similar problem or situation is encountered later in professional practice (Lamon, 2020). Finally, they identify further learning issues, synthesized to explain the observations in the problem scenario, organize prior and new learning around the problem scenario (Tan, 2021). Then devise solutions to learn basic concepts in the context of a real-world example. This use of real-world examples helps students with the transference of knowledge from the classroom to the work and other settings (Stefaniak, 2020).

2.9. Problem solving skills assessment

Measurement of secondary school students' PSS in biology context has hold using an essay-shaped test instrument integrated with PSS indicators (Putra *et al.*, 2024). A concept mastery integrated with PSS of pre-service biology teacher in human physiology courses have also measured with the instrument an essay test (Amanda *et al.*, 2021). In research the instruments used to collect the data of the study on PSS in biology have also with an essay test (Fıtrıanı *et al.*, 2020). A study conducted on geography at higher education has also asserted that essay tests have used to measure students' skills in solving problems (Sari *et al.*, 2021).

In science education, essay questions have considered as scientific reasoning and PSS indicators at higher education (Kundariati *et al.*, 2022; Yasir *et al.*, 2020). Moreover, in biology essays have been used as PSS in the biology classroom at higher education (Kundariati *et al.*, 2021) and in high school (Jasman & Mahanal, 2024). Overall, essay test instrument is apt to measure PSS of students in high school. Accordingly, this dissertation has adapted open-ended essay questions to measure learners' PSS.

2.10. Scenario-based learning

Learning and seeking for knowledge is required for humans to satisfy the curiosity of a meaningful existence, and to increase the level of independence and efficiency (Ettore & Constantin, 2018). Fiorella and Mayer (2015), introduced learning as a generative activity of making sense of information as learners actively try to make sense of the instructional materials presented to them. This comes with the evidence that learning occurs when learners apply appropriate cognitive processes to incoming information (Fiorella & Mayer, 2015a).

In situated learning theory to SBL learning approach is understood as the ‘existing knowledge’ and ‘experience’ of the learner before assimilating new knowledge. Because SBL is a learning model whereby real-life events or near-fact storylines that are crafted in scenarios and pose as problems for the learners to attempt and solve. Storylines of a scenario or an event are the narratives and coherent sequence of plots. The more interesting and understanding the storylines of SBL, the more immersed are the learners in the learning activities (Adebiyi, 2023a).

The scenario can engage learners in a deep reflection; this will charge them to try to make meaning out of the presented situation based on their existing experience. Moreover, past events and imagination could enable learners to start developing CTS facts to form a rational judgment (Adebiyi, 2023a). Scenario-based learning approach deals with the simulating of real-life occurrences and plausible events. Hence, it increases level of active engagement. Learning engagement is a state in a learning process that determines the quality of attention, focus, and the ability to exercise CTS. The ability of an individual learner to continue analysing every scene as the learning proceeds will keep them on track, and occupied in the learning activity. This active engagement of learners in a learning process enhances their PSS (Adebiyi, 2023a).

Stories and fabricated cases are potentiality enhancing the cognitive functions of the learners and charge them to reflect and take actions accordingly based on the context of the story. Therefore, scenario-based learning is a learning approach that depends on using stories, past events, and imaginations. Scenario-based learning facilitates the effective application of knowledge to the real-world situation which is the economic value of education at large (Adebiyi, 2023a). For example, it saves resources incurred to be wasted through try and error attempts, this can enable the learners to develop their skills at the proficiency levels.

Moreover, scenario-based learning is a modern learning approach that involves the activity of simulating near-fact or real-life events as learning contents that are targeted towards enhancing the cognitive skills of learners. Facts are more likely to be remembered easily if they are part of a story as extracted from the web address (Banulescu-Bogdan, 2018). They also stimulate students to put into practice what they have learned (Karabulut & Bayraktar, 2018); provide meaningful solution and interaction between learners (Miller *et al*., 2014); improve learners' detail and deeper understanding, creative thinking, imagination and contains planning for the future by regarding the mental process (Drapeau, 2014; Pritchard, 2017). Scenarios develop competencies such as understanding complex situations, questioning, and seeing multiple perspectives (ŞAŞMAZÖREN *et al*., 2022). They are essential for catching students' attention. In short, stories, people and events in scenarios increase students' curiosity, make them think about their reasons, and keep students' motivation at a high-level while reaching the gains (Çeliker, 2021).

Teachers like SBL, because it helps them reach their goals better; provides a vast number of benefits and can dig active mood in passive learning; could help learners to eliminate negative insight as well as their negative perception of dull teaching strategies too; lead to improve student progress and performance, can eliminate passiveness and create. They learn how to express their ideas, opinions, and emotions in a more natural and authentic way. Furthermore, Scenario-based learning requires students to think critically and creatively about how to respond to a given situation (Mariappan, 2023)

Scenario-based learning at higher education is a learning principle that puts more emphasis on context rather than content (Adebiyi, 2023a; Ahmad, 2020). Most of the contexts in SBL are story-based contents that are educative enough to capture the mind of the learners and put them immensely in the learning process (Adebiyi, 2023a). The SBL and related activities may even help to bridge the theory-practice gap in teacher education; provides authentic and complex learning experiences that prompt student to consider ways of acting and PSS in everyday teaching situations; enhance students' self-efficacy and cognitive classroom readiness at higher education (Bardach *et al*., 2021) (Klassen *et al*., 2021).

Scenario-based learning approaches have the potential to introduce preservice teachers to the culture of the workplace, achieve graduate standards, develop their professional identity, and to increase the confidence and preparedness for the teaching placement and for subsequent professional practice (Klassen *et al*., 2021). This implies that SBL, has emphasized only to higher education such as enhancing student-teachers' TEFL practices in inclusive education classes (Shaaban & Shaat, 2022); improving communication skills in the classroom (Mariappan, 2023). improving statistics teaching and learning at the postgraduate level (Zamri *et al*., 2020) and enhance student satisfaction and academic chievement in online learning (Mamakli *et al*., 2023). Likewise, it is more effective than reflective learning for AA (Mamakli *et al*., 2023). However, some studies have reported that gender does not impact students' PSS (Wahyudiati, 2021).

Even though some studies have found that SBL increase students learning skills in science education, they emphasized only on health science at higher education. For instance, SBL improve knowledge and skills in medical students (Mianehsaz *et al*., 2023); increase self-confidence on nursing students’ (Rashwan, 2023), develop patient safety skills among nursing trainee (Yilmaz *et al*., 2020); can influence on the core competencies of nursing students (Sadeghi *et al*., 2023) and promote nursing students’ learning (Svellingen *et al*., 2021).

Based on the content of the target aimed to be gained, scenarios are categorized into skills-based, problem-based, speculative-based and issues-based scenarios (Caltabiano *et al*., 2018). However, in this context, studies have suggested that problem-based scenario is more apt for learning biology at all levels (Çelike, 2021). Because, they function as the simulation need for students to use authentic contexts to solve problems. They have involved students working their way through a storyline based on an ill-structured or complex problem, in the process students must apply their subject knowledge, CTS and PSS in a safe real-world context. Thus, learning best takes place in the context in which it is going to be used (Sternberg, 2014). On the other hand the problem scenario is of crucial significance when it engages the students’ interest and skillfully written (Bean & Melzer, 2021). Scenario-Based learning (SBL) is an innovative pedagogical approach where authentic scenarios are used to support active learning strategies such as problem-based, case-based learning, role-play, and simulation (Adebiyi, 2023a). Thus, empirical evidences asserted that scenarios are primary instructional materials for PBL, which are basically stories in which real life problems take place.

Scenarios can provide educational environment in which students are solving genuine work tasks or problems (Herrington *et al*., 2014). Learning based on scenarios is requiring first the transferring of thought into the action, second turning the action into life, and finally the individual acquiring this information from their own life (Çeliker, 2021). Therefore, scenarios should be prepared in such a way that they must attract the interest of students, be relevant to real life, and should not be very difficult or very complicated. Similarly, a well-designed scenario may provide students a chance to reflect, lets them exhibit, test, and evaluate their values (Ribchester & Healey, 2019).

Moreover, scenarios have to give opportunity for students to determine their current information and the information they need to know and to learn how, where and through which method they can obtain such information for the problem (Akben, 2019). Consequently, these scenarios facilitate learning through realistic experiences and provide meaningful solutions and intrinsically motivate students to learn and solve problems. The stories, characters, and events of scenarios increase curiosity and provoke deeper thinking; inspire students to solve problems and authenticate problems to construct solutions and offer authentic contexts for constructing solutions (Çeliker, 2021). Apart from this, scenarios also challenge students to display and reflect on their work, as well as to test and evaluate their values (Ribchester & Healey, 2019). In short, scenarios with daily life problems encourage students to determine methods for obtaining information to solve problems.

Throughout PBS approach, students are at the center of the learning process engaging in problem-based activities, formulating problem statements, collecting data and practice skills for analysis, integration and application, through practical case-based scenarios (Nguyen *et al*., 2020b). PBS improve various skills, activate imagination and make the learning and teaching process enjoyable for teachers and students. Additionally, they help students specialize in their lives and others (Çeliker, 2021). Problem-based learning supported by scenarios helps students to develop flexible knowledge that motivates them to learn in real-life contexts. It also increases engagement, metacognitive growth, and long-term retention of knowledge, enabling learners to relate topics to real-life situations. Entirely, it is a potential strategy to develop students' character for 21st-century learning, which emphasizing active learning, teamwork, and authentic assessment techniques (Bahri *et al*., 2021).

In addition to enhancing PSS, the problem-based scenario method positively impacts AA (Huang & Wang, 2020). Over all, Scenario-based learning (SBL) uses interactive scenarios to support active learning strategies such as problem-based learning. It involves students working their way through a storyline. Students must apply their subject knowledge, CTS and PSS in a safe and real-world context. In an interactive scenario, the individual is taking charge of the scenario, and takes responsibility for the actions and consequences.

2.11. Problem-based scenarios

In problem-based approaches, students pursue specific open-ended problems where they are required to identify what they know already about the problem; draw upon working knowledge; locate that knowledge in the discipline area; construct knowledge; apply these collections to a series of challenges; react appropriately to problems as they arise and, arrive at considered solutions based on reasons that can be justified. This specific process is designed to engage students in the pursuit of realistic problem where the process is thought more valuable than the solutions. In the problem-based learning, there is no obvious singular problem or solution. The first priority is identifying the problem. Students in this approach may be asked what they know. what do they need to know, how will they go about finding information, how will evidence be evaluated by those gathering it, how will it be presented, and how will their findings be evaluated by the class/teacher.

PBS are useful in advance than PBL for applying knowledge in demanding circumstances of challenges; responding spontaneously to changing circumstances; exploring issues and events at a deep level over a lengthy period of time; exploring ‘consensus’ and ‘difference’ as part of human dynamics; engaging students in processes of decision-making; and for constructing new knowledge as appropriate (Errington, 2010a). This implies that the journey is considered more important than the destination. Even simple decisions will have consequences, and often students report that choices often turn out to be more complicated than originally thought.

In PBS, perspective professionals are required to tolerate messy problems and appreciate the value of ambiguity and uncertainty, and present ideas to peers for evaluation, critique and reflection. This can be a big challenge for many aspiring professionals.

Problem-based scenarios appear in a variety of trainee professional contexts, including: helping students respond to global disasters as trainee disaster educators, (McKenzie, 2018); meeting the creative design demands of industry clients (Fleischmann & Daniel, 2010); engaging in a bridging strategy between 'top-down' theorising in pre-service teacher education (Adam, 2012) and the 'bottom-up realities of school-based teaching (OLA-ADAMS, 2023); and, in developing a professional identity in mental health nursing (Errington, 2011). Moreover, graduate attributes developed via PBS are likely to include decision making skills, teamwork, higher order reasoning, presentation skills, the ability to gather evidence to support hypotheses, CTS, tolerance of ambiguity, ability to evaluate and disseminate complex information, and self-awareness among others (Errington, 2010b). Therefore, this study has imposed to prefer PBS instructional method since it takes long time to investigate.

2.12. Indigenous knowledge

The meaning of the term IK differs depending on the particular case and on the specific aspects the writer wants to stress. For the people to whom IK is an integral part of daily life, it refers to ancient knowledge, or to particular local practices. Moreover, it varies in contexts. For example, it is defined as local knowledge, that is unique to a given culture or society. It is the basis for local-level decision-making in agriculture, health care, food preparation, education, natural resource management, and a host of other activities in rural communities. Another useful definition is that the information base for a society, which facilitates communication and decision-making. Local knowledge, refers to the large body of knowledge and skills that has been developed outside the formal educational system. IK is embedded in culture and locally bound, indigenous to a specific area, culture and context-specific, non-formal knowledge, orally transmitted, and generally not documented, dynamic, adaptive and holistic in nature (Boven & Morohashi, 2002).

This implies that IK is one source of prior knowledge according to Grogan *et al*. (2023), that may affect their learning of content in a compulsory indigenous studies subject. In line with this

Siregar and Novalinda (2020) has declared that initial knowledge is the knowledge and skills that students already have to be delivered in learning Thus, prior knowledge is the knowledge and skills that students already have which are used as provisions for learning. Moreover, high prior knowledge impacts CTS of students (Putri *et al*., 2023).

As cited in Wati *et al*. (2021) Hariri and Mulyani (2016) defined local cultural science-based as it is an innovative learning that can be applied in schools on biology, this learning combines the cultures that develop in the local community with the school curriculum to create contextual learning. For instance, local wisdom in the form of ecological aspects in the form of natural resources can be used as a source of formal and non-formal learning. This implies that local potential can be developed into local wisdom because one of the characteristics of local wisdom is teaching people to love nature (Puspasari & Attas, 2019). Moreover, science learning based on tourism in ecosystem teaching materials have improved CTS for high school students. However, it lacks attention to the socio-cultural environment of students. It tends to dead information, namely, the knowledge that is too book-centered (Wati *et al*., 2021).

Indigenous knowledge has also considered as background knowledge. Accordingly a study has concluded that there is positive connection between mathematical background knowledge and CTS in that mathematics (Kania *et al*., 2023) . Most CTS scholars find background knowledge important (Hitchcock, 2018) and essential for practicing CTS (Lai, 2011). Moreover, Ennis has asserted that background subject matter knowledge in an area calling for CTS is essential for doing high-quality CTS in that area (Ennis, 2016). Likewise, Halpern states that a critical thinker uses skills for learning new techniques and connects new knowledge with previously learned knowledge (Halpern, 2014). Based on this essentiality, educational programs have enacted IK systems in policy and practice that can reorient education, teaching and learning to become more holistic, relatable, resilient, and adaptive (Moore & Nesterova, 2020).

In science education it is recommended that better to provide education, motivation to local healers and documentation on the use of such medicinal plants and animals to preserve such knowledge (Panta, 2019). Likewise, IK incorporates animal and plant species which can used for treating different ailments including common cold, cuts, wounds, diarrhoea, dysentery, etc (Manisha & Singh, 2020). Moreover, studies have suggested that IK can be useful for promoting students' awareness of the importance of respecting the traditions and beliefs of indigenous communities (Archila *et al*., 2021); enhance the relevance of science education (Zidny *et al*., 2020); used to develop students CTS (Shizha, 2014) and offers ways to solve problems (Zidny & Eilks, 2020).

The most paramount importance it that transferring of knowledge is achieved when students are exposed to their IK, associate with local, environmental, scientific and contextual situations (Arsenault *et al*., 2019). For example in biology students who exposed to scientific process skills, such as developing hypotheses, interpreting data, crafting evidence-based arguments, and using and evaluating models of systems (Idris *et al*., 2022) learn skills that facilitate their development into competent problem solvers and exposes them to how scientists think about complex ideas in their disciplines (Rodzalan & Saat, 2015; Yadav *et al*., 2016).

Furthermore, Emeagwali and Dei (2014) have implied that the integration of IK into modern science education is positively impacts the provision of quality education which enable students to solve real problems (Assefa & Namaziandost, 2021; Govender & Mutendera, 2020). For instance, lessons can be learned from the lifestyles of indigenous communities connected with nature and people (Widianingsih *et al*., 2022; Zidny *et al*., 2020). Linking learning with the local environment is important. Because, IK is a source of potential means of enhancing involvement local people as guest lecturers, collaborative learning and local healthcare practices (Demssie *et al*., 2020b). Consequently, some scientists now believe that IK may help them to discover important new medicines for diseases such as AIDS and cancer (Anywar *et al*., 2020; Pal *et al*., 2015). In summary, although studies are limited, IK has a potential to enhance CTS, problem solving skills and AA of students (Ng'asike, 2019).

Even though CTS has suggested that trains students to think effectively based on the information they have, IK and critical thinkers need to be quick in decisions, students' CTS are still low due to direct learning that does not involve student participation and has never been trained to think from planning to evaluating answers (Wati *et al*., 2021). Classroom knowledge has to makes sense to students relevant for their lives, saving wisdom, stories and cultural practices (García Franco *et al*., 2022).

Therefore, bringing IK to the classroom is relevant to promote CTS because it is recognizing students' and community knowledge opens a door to develop CTS as a situated practice and as part of an intercultural dialogue. CTS as situated practice requires recognizing how thinking, doing, and living together can be incorporated in the classroom. IK emphasizes how CTS acquires relevance when topics in school are important for students and when knowledge is related to their own life projects and to their possibilities to construct a stance within the community as well as taking decisions that have relevant consequences for life. In short, CTS is useful to craft students' and communities' 'good living' (García Franco *et al*., 2022). Accordingly, some studies have reported that IK is effective to improve CTS of the students in physics (Damayanti & Kuswanto, 2021); can develop students' CTS and making decisions about their health in science education in biology (Puig & Jiménez-Aleixandre, 2022) and in science learning (Hikmawati *et al*., 2021).

A study has reported that the application of the PBL learning model integrated with local wisdom in the conservation biology course has a real effect and improves students' PSS. Moreover, it can raise students' awareness to be sensitive to the problems around them so that they can find solutions to overcome these problems to protect natural resources through conservation activities (Iwan *et al*., 2024). Some studies have also suggested that science teaching using IK improve problem solving skills of pre-service teacher (Winarto *et al*., 2022) and increase students and community problem solving skill in social work (Mabeyo & Kiwelu, 2019).

2.13. Theoretical framework

Teaching and learning are the two key elements of education that their quality can be improved or judged by activities of the teachers. Learning is an acquisition of knowledge (Mayer, 2019), (Irvine, 2017). It is not only acquiring knowledge but also being able to use knowledge to achieve all the goals of the educational process (Marra *et al*., 2014). Hence, science is aimed to produce reliable knowledge that enables students to understand the world they live in and to apply scientific concepts to real-life problems. Such relating of theories to real-world problems, enables their learning more meaningful (Vogelzang *et al*., 2019), (Hasanah, 2020b) and helps them to develop informed decision-making, CTS, and PSS (Coppola & Krajcik, 2014).

According to existing literature, CT can be used as benchmarks for developing students' skills in carrying out an activity to find a concept for decision making and PSS. Biology is one of the subjects that require concepts to be understood, decided and problems to be solved. Although CT has such classroom to real-life PSS paramount importance, inadequate emphasis has given for its learning practice. The reason may be its high argumentative skill in that researchers debate about its definition, amenability to assessment and degree of generality or specificity. Despite disagreement, educators and policy makers have included it with high emphasis as one of the core learning outcomes of students in education. In the diverse definitions of CT, some sources of the frameworks value the reasoning process of CT, while others emphasize the outcomes, such as whether it can be used for decision making or PSS.

The multivariate nature of the definitions has also tended to capture multiple themes such as reasoning, analysis, argumentation, and evaluation. They also differ along a few dimensions, such as whether CTS should include decision making and PSS. The dispositions are an integral part of CT that can help in predicting the skills include analyticity, truth seeking, self-confidence, maturity, open-mindedness, systematicity, and inquisitiveness (Facione, 1990). Whereas the CT skills are basic clarification, bases for a decision, inference, advanced clarification and tactic and strategies (Ennis, 2016). In addition to diverse definitions, the majority of existing CT literature have inclined to general CT skills, do not consider specific subject-matter skills. Therefore, interest on embedding CT within specific subject matter instructions has been increasing (Abrami & Waddington, 2015). In particular, (Ennis, 1990) suggested that having adequate knowledge and understanding in one domain urges the performance of CT skills rather than knowledge of general CT. Moreover, (Davies, 2013) claimed that the ability to think critically is highly dependent on in-depth and specific content knowledge that is required for competent performance in various thinking tasks.

A variety of studies on CTS have suggested that the design of CTS instruction must be developed based on CTS definitions and indicators (Purwaningsih *et al*., 2020), (Hidayat & Fadillah, 2019). Thus, the present study was attempted to develop a CTS learning tool based on CT theories reviewed above and taking Ennis *et al*. (1985)'s aspects of CTS and their indicators as a theoretical frame work. In this critical-thinking learning process, students at all may expect to clarify information more than its presence, infer and design the decisions to take action. In addition to indicators, to nurture students in such provocative learning (Saputro, 2021), students must be exposed to contexts or problems that are effective for examining skills (Fajari, 2021b) analyzing, interpreting, inferring and explaining information (Rusnayati *et al*., 2019). The information given are either in the form of scenario, concrete examples, authentical tasks, tables, graphics, and maps (Sugiarti *et al*., 2017).

In addition to CTS, PSS are theorized as leaning outcomes which can be taught through PBL. Indeed, Çeliker (2021) has found that PBS method increase CTS while this study has enforced to investigate its impact that may intensifies as well on PSS. Scenarios are categorized into skills-based, problem-based, speculative-based, issues-based, and scientific scenarios. Studies suggest that PBS are particularly suitable for learning biology at all levels (Çelike, 2021) because they present problems that simulate real-world contexts, requiring the application of knowledge in challenging situations. The learning method involves students working through a storyline based on an ill-structured problem-solving skill in a real-world context. Scenarios develop competencies such as understanding complex situations, questioning, and seeing multiple perspectives (ŞAŞMAZÖREN *et al*., 2022). They are essential for catching students' attention. In this approach, students are at the center of the learning process engaging in the problem-based activities, formulate problem statements, collecting data and practice skills of analysis, integration and application, through practical case-based scenarios (Nguyen *et al*., 2020b). PBS improve various skills, activating imagination and making the learning and teaching process enjoyable for teachers and students. Additionally, they help students specialize in their lives and others (Çeliker, 2021).

In PBS, scenarios are primary instructional materials or the main tools for PBL, encouraging students to apply what they have learned (Çeliker, 2021). These scenarios facilitate learning through realistic experiences and provide meaningful solutions. Scenarios intrinsically motivate students to learn and solve problems. The stories, characters, and events of scenarios increase curiosity and provoke deeper thinking. They inspire students to solve problems and authenticate problems to construct solutions and offer authentic contexts for constructing solutions (Çeliker, 2021). Scenarios also challenge students to display and reflect on their work, as well as to test and evaluate their values (Ribchester & Healey, 2019). Overall, they encourage students to determine methods for obtaining information to solve problems.

Learning is more effective when it is based on real-world problems (Simanjuntak *et al*., 2021). These problems serve as critical learning which triggers for students who may encounter similar circumstance in their future lives. Thus, when learning is based on problems situated in real-life contexts, students connect scientific concepts with real-life situations (Karakoç & ALACACI, 2015). More importantly, this approach enables students to link prior and acquired knowledge with new information, guiding them towards PSS goals. Therefore, real-world problems are preferable for meaningful learning in biology education through PBS. Biology is best learned by associating biological information with day-to-day life. Studies have shown that students learn biology more effectively through PBL by solving realistic, complex, and open-ended problems (Clark & Mahboobin, 2017).

Presenting scenarios with daily life problems helps to stimulate students on how to find information and choose the appropriate solution. Problem-based learning supported by scenarios helps students to develop flexible knowledge that motivating them to learn in real-life contexts. It also increases engagement, metacognitive growth, and long-term retention of knowledge, enabling learners to relate topics with real-life situations. Overall, it can serves as a potential strategy to develop students' character for the 21st-century learning emphasizing active learning, teamwork, and authentic assessment techniques (Bahri *et al*., 2021).

According to Sobocan *et al*. (2022), learning tools must rely on fundamental and powerful concepts that must not encompass a narrower and more restricted application Based on the suggestions above, the current study has developed critical-thinking and problem solving skills learning tool that were designed to reflect thinking and solving ability in human body system concepts. The reason for selecting this topic is physiological needs are high in humans' health whereby high school students may have adequate information about them formally in lower education and informally through their life experiences but not think critically to solve problems faced. Likewise, the learning tool considers the fundamental and powerful concept, including the digestive, breathing, circulatory, excretory, and immune systems.

Apart from problem-based scenario, most CTS scholars find background knowledge is important (Hitchcock, 2018) and essential for practicing CTS (Lai, 2011). For instance, tourism in ecosystem teaching can be considered as background knowledge that have improved CTS for high school students in science learning (Wati *et al*., 2021). A study has also reported that existence of positive connection between mathematical background knowledge and CTS (Kania *et al*., 2023) . Moreover, Ennis has asserted that background subject matter knowledge in an area calling for CTS is essential for doing high-quality CTS in that area (Ennis, 2016). Likewise, Halpern states that a critical thinker uses skills for learning new techniques and connects new knowledge with previously learned knowledge (Halpern, 2014). Overall, background knowledge enhance the relevance of science education (Zidny *et al*., 2020); used to develop students CTS (Shizha, 2014) and offers ways to solve problems (Zidny & Eilks, 2020).

Emeagwali and Dei (2014) have implied that the integration of IK into modern science education is positively impacts the provision of quality education which enable students to solve real problems (Assefa & Namaziandost, 2021; Govender & Mutendera, 2020). For instance, lessons can be learned from the lifestyles of indigenous communities connected with nature and people (Widianingsih *et al*., 2022; Zidny *et al*., 2020). Although studies are limited, IK has a potential to enhance CTS, problem solving skills and AA of students (Ng’asike, 2019).

A study has reported that the application of the PBL learning model integrated with local wisdom in biology has a real effect and improves students' PSS. Moreover, it can raise students' awareness to be sensitive to the problems around them so that they can find solutions to overcome these problems to protect natural resources through conservation activities (Iwan *et al*., 2024). Some studies have also suggested that science teaching using IK improve problem solving skills of pre-service teacher (Winarto *et al*., 2022) and increase students and community PSS in social work (Mabeyo & Kiwelu, 2019).

2.14. Conceptual framework

Based on literature review and theoretical framework, the guiding view for this study is progressivism. Under this view learning theories such as Ennis's CTS definition and indicators, general model of PSS and background knowledge were taking as conceptual framework for the study. Moreover, the framework shows the theoretical perspectives of the study and the relationship between independent and dependent variables while students learn about the human body system and health. As shown in figure 1, the independent variables of this study are PBS tool (PBSLT), IK, and conventional instruction (CI). The dependent variables are academic achievement, CTS, and problem-solving skills of the students on the human body system and health concepts. Therefore, the frame demonstrates the factors and the results.

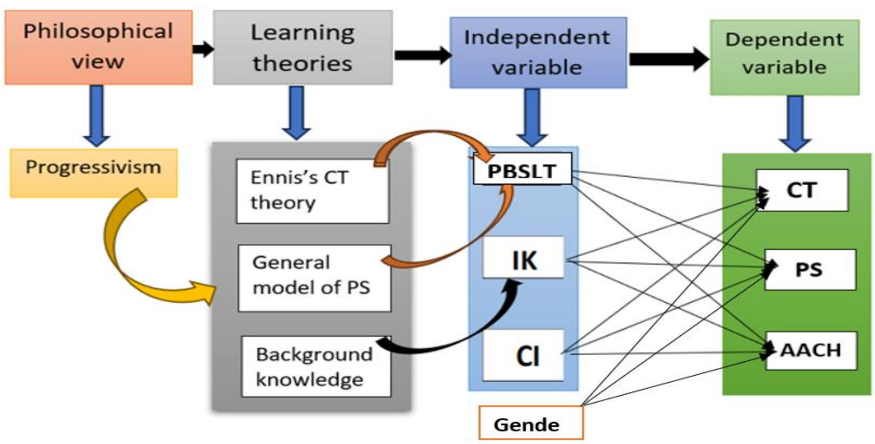

Figure 1. Conceptual frame work

CHAPTER THREE: RESEARCH METHODOLOGY

3.1. Research Method

This chapter presents the methodology employed in the study, outlining the philosophical and practical considerations that guided the research process. It begins with a description of the research paradigm and design, providing the underlying framework that shaped the study. The chapter then details the study setting, sample selection procedures, and characteristics of the participants. Following this, the instruments used for data collection are described, along with the processes of development and validation of the intervention. Attention is also given to the data collection procedures that ensured systematic gathering of information, and the data analysis techniques employed to answer the research questions. Together, these components provide a comprehensive account of how the study was designed and executed, ensuring rigor, validity, and reliability in addressing the objectives of the research.

3.2. Research paradigm

A paradigm is a philosophical worldview that reflects the assumptions and beliefs guiding a researcher's actions (Shah *et al*., 2019). This study is underpinned by the pragmatist paradigm, which holds that knowledge is grounded in experience and shaped by both individual and shared contexts (Morgan, 2014). Ontologically, pragmatism accepts the coexistence of single and multiple realities, open to empirical inquiry (Creswell & Clark, 2017).

Methodologically, pragmatism emphasizes the most useful means of understanding the world. Unlike positivism, which stresses objective knowledge through hypothesis testing, or constructivism, which views knowledge as relative, pragmatism positions knowledge acquisition as a continuum between objectivity and subjectivity (Goles & Hirschheim, 2000). It thus occupies a middle ground, favoring flexible inquiry that adapts to research needs.

While post-positivism aligns with quantitative methods and deductive reasoning, and constructivism with qualitative approaches and induction, pragmatism embraces both. It often employs abductive reasoning, moving between deduction and induction, with the researcher actively shaping both data and theory (Goldkuhl, 2012). Pragmatist philosophy also links thought to action, emphasizing that human actions are shaped by past experiences and beliefs, and that knowledge evolves through the consequences of those actions. Reality is therefore dynamic, constantly shaped by human activity (Morgan, 2014).

3.3. Research approach

3.3.1. Design-based research

Design-based research (DBR) is a methodological framework in the learning sciences that integrates theory-driven design with empirical investigation to address complex educational challenges (Peffer & Renken, 2016). This approach involves a cyclical process of identifying a specific learning problem, designing instructional tools such as reasoning strategies or worksheets, testing these tools in authentic settings like classrooms, evaluating their effectiveness, and refining them based on emerging evidence (Phillips *et al*., 2012; Scott *et al*., 2020). DBR is grounded in learning theories, such as progressivism and Ennis's critical thinking framework, and aims to produce measurable improvements in student learning, generate generalizable design principles, and conduct extended iterative experiments to observe long-term impacts (Armstrong *et al*., 2020; Reimann, 2011; Reinking, 2021).

Unlike traditional experimental methods, DBR fosters collaboration between researchers and educators throughout all stages, framing the hypothesis as a design solution and allowing flexible, in-situ modifications to tools (Kaliisa, 2022). This collaborative and adaptive process creates a dynamic learning ecology that enhances student outcomes around the identified problem (Aksela, 2019). By examining how student thinking evolves in response to interventions, DBR uncovers mechanisms of learning, contributing to both educational practice and theoretical advancements (Scott *et al*., 2020). Given its alignment with the research questions and the need to address a specific learning challenge through iterative design and evaluation, this dissertation adopts a DBR approach to develop and refine instructional tools, offering practical solutions and theoretical insights in the learning sciences.

3.3.2. Research design

Design-based research encourages the use of mixed methods to analyze data, integrating both qualitative and quantitative approaches to provide a comprehensive understanding of complex phenomena (Scott *et al*., 2020). Given that the research questions in this study required collecting both quantitative and qualitative data with equal emphasis, a convergent parallel mixed methods design was employed. This approach treats both data types as equally important sources of information, analyzing them separately before comparing the results in a side-by-side comparison to triangulate findings and determine whether they confirm or disconfirm each other (Creswell & Clark, 2017). The research process can be represented as a simultaneous collection and analysis of qualitative and quantitative data, QUAL+QUAN (Morse, 1991), ensuring a robust synthesis of insights.

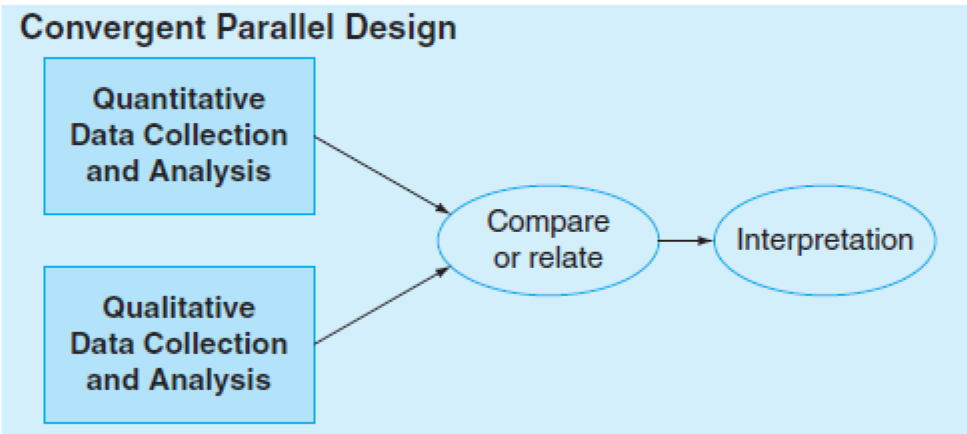

Figure 2 Convergent parallel mixed methods design adapted from Creswell (2012)

For the quantitative component, this study employed a quasi-experimental design due to the inability to fully randomize participants, which may result in unequal distribution of characteristics between control and intervention groups (Shadish *et al*., 2002). To account for potential differences in participant experiences, a nonequivalent control group quasi-experimental design was selected. The experiment was involving intact classes. The three intact grade 10 classes from Wagseyoum Admasu Wosen secondary school were randomly selected and assigned as follows: intervention group one (Ig1) and intervention group two (Ig2) and control group (Cg). As outlined in Table 1, during the first cycle, Ig1 received intervention 1 (X1), Ig2 received intervention 2 (X2), and Cg received no intervention. Schools and classes were assigned to intervention and control groups using simple random sampling to minimize selection bias (Trochim & Donnelly, 2001).

Following group assignment, a pretest was administered to all groups to establish baseline performance and inform posttest analysis (Creswell & Clark, 2017). The intervention groups engaged in PBS and IK, while the control groups received conventional instruction (CI). Ongoing posttests served as formative assessments after each subtopic, and a final posttest was administered as a summative assessment to evaluate the impact on CTS and PSS (Shadish *et al.*, 2002).

For the qualitative component, in-depth interviews and observations were conducted to explore IK, CTS, and PSS, enabling triangulation with quantitative findings (Creswell & Clark, 2017). This mixed methods approach facilitated a comprehensive comparison of data, enhancing the validity and depth of the study's conclusions.

Table 1 Quasi experimental design

Group	Pretest score	Intervention	Posttest score
Ig1	O_1	X_1	O2
Ig2	O1	X_2	O_2
Cg	O1		O2

The study employed qualitative data collection methods, including students' reflections, observation checklists for formative assessment, and interviews for summative assessment. Data patterns were analyzed using Braun and Clarke's six-phase thematic analysis, with themes identified deductively. The triangulation of systemic, procedural, and contextual data informed the design and implementation of effective interventions. Interviews captured students' self-assessments of their PSS and CTS activities in the classroom, as well as factors influencing these processes. Open-ended interviews were conducted with 15 participants, allowing for detailed and comprehensive responses. This instrument was selected to enable the researcher to align interview data with findings from other data collection methods.

3.3.3. Sample selection

In this design-based research study examining the impact of problem scenarios on CTS and PSS, three intact grade 10 classes from a government school in Sekota town were selected as the sample. The three classes were conveniently selected and then randomly assigned to Intervention

1, Intervention 2 (PBS + IK), or Control using lottery method. While randomization minimized allocation bias, the use of convenience sampling may limit the generalizability of findings. Pretest data confirmed baseline equivalence, allowing evaluation of the PBS+IK tool's impact on students' CTS, PSS, and AA.

3.3.4. Study setting

The research focused on tenth-grade students because adolescents at this stage display emerging skills in rational, complex thinking, and PSS, making them an ideal cohort for the study. The selection of Sekota town as the study area was informed by evidence indicating that formative assessments and classroom examinations in local schools rarely emphasize CTS and PSS. Additionally, the student-centered learning approach adopted by teachers in the area relies heavily on textbooks that do not prioritize learning objectives or outcomes related to these skills. Furthermore, quarterly and annual education review meetings, along with public education conference recommendations in Sekota, have consistently highlighted deficiencies in fostering PSS and CTS across all grade levels.

3.3. 5. Participants of the Study

The study involved 131 grade 10 students from the selected secondary school in Sekota town, Northwest Ethiopia.

3.3. 6. Instruments:

1. Critical Thinking Skills Test (CTST) and PSS Test (PSST): These instruments were employed to collect quantitative data. Additionally, the Critical Thinking Embedded Essay Test (CTEET) developed by Zubaidah (2019) and the PSS Test (PSST) rubric from ("https://www.scribd.com/document/597725023/K-12-CREATIVITY-INNOVATION-2018,") utilized to assess students' PSS and CTS (see Appendix C).
2. Students' reflections, Observations and Interviews: These methods were used to gather qualitative data, providing deeper insights into the research context.

3.3.6.1. Validity of instruments

The qualitative data collected varied across different phases, incorporating a diverse range of interventions and contexts, supported by multiple audio indicators to enhance validity, reliability, and applicability. Concurrently, the quantitative data collection instruments were rigorously evaluated for content and face validity through expert reviews from professionals in biology education, psychology, and curriculum and instruction. Biology experts specifically assessed the data collection tools, while a Ph.D. candidate in biology education and secondary school biology teachers reviewed the test items to ensure alignment with textbook objectives and concepts, as well as clarity and accuracy in the answer key. Feedback and recommendations from these experts were carefully considered. Following these validations, a pilot study was conducted to perform item analysis on the instruments.

3.3.6.2. Pilot study

The pilot test for biology exams confirmed the feasibility of the assessment models, evaluated the difficulty and discrimination levels of test items, verified the reliability of the instruments, and ensured comparable student abilities in CTS, PSS, and AA across selected schools in Sekota town.

3.3.6.3. Piloting the model

Initially, the researcher provided an orientation to teachers and students on the foundational principles of the instructional model and the student guide for PBS. Subsequently, these PBS, aligned with the first principle of instruction, were implemented in grade 10 classrooms over one week while covering topics on the human body system and health. Data were then collected through observation notes and discussions with participating teachers. Feedback from these activities informed the timing for implementing the five phases within a 40-minute period.

3.3.6.4. Piloting the instruments

The data collection instruments, including the CTST, PSS Test (PSST), and AA tests, were pilot-tested to ensure validity and reliability. These instruments were administered to grade 10 students following a one-week implementation of the instructional tool. Subsequently, the test items were analyzed for their difficulty and discrimination indices. The internal consistency reliability of the instruments was then evaluated, using Cronbach's coefficient alpha for the CTST and PSST and the Kuder-Richardson coefficient alpha for the AA tests.

3.3.6.5. Content validity of the CTST test instrument

The expert validation results for the instrument, as presented in Table 2, confirmed its validity in terms of purpose, content, clarity of wording, phrasing, grammar, relevance of information, alignment with learners' developmental levels, test evaluation requirements, indicators of CTS, and the accompanying diagram. These findings indicate that the instrument is valid in content, readability, and alignment between CTS indicators and test items, as well as the accuracy of concepts and the clarity of simplified terms provided by the diagram. Consequently, the content validity results demonstrate that the test items effectively measure the appropriateness of information in students' responses.

Table 2 Expert validity of CTST

No	Description of instrument with	Validator					%	Category	Comment
		1	2	3	4	5			
1	Clarity of words, phrases and the diagram	4	4	-	3	4	93.7%	Very valid	Minor revision
2	The grammar	4	4	-	4	4	100%	Very valid	Minor revision
3	Accuracy of information	3	4	-	4	4	93.7%	Very valid	Minor revision
4	Learner's level of development	4	4	-	3	4	93.7%	Very valid	Minor revision
5	Evaluation requirements	-	-	4	4	3	91.6%	Very valid	Minor revision
6	Consideration of CT skills indicators	-	-	4	4	4	100%	Very valid	Minor revision
Mean		3.75	4	4	3.5	3.8	73%	Valid	Revision

The interview findings indicated that secondary school teachers have not prioritized developing test items to assess CTS in biology. Similarly, students faced challenges expressing their thoughts in English, preferring to use their native language, Amharic. Of the 35 items in the CTST, 20 were deemed valid, clear, and easily comprehensible. Following revisions to the remaining 15 items, the CTST was refined to include 30 open-ended essay items. Additionally, feedback from a small-scale paper-and-pencil pilot test highlighted the need for further clarification and adjustments to five items, resulting in a final set of 25 Amharic-version items, with a recommended completion time of 40 to 50 minutes.

3.3.6.6.Construct validity of CTST

After dissemination, approximately 80% of the students were able to finish the test within 50 min, and the remaining students completed the test within 60 min. Based on the information in Table 3, each *r*-count (Pearson correlation) was greater than the *r*-table (0.279) in the table of product-moment values with 53 students, and all 25 critical-thinking skills test items were significant.

Table 3 Construct validity of CTST

Item	Validation				
	***r*-count (Pearson Correlation)**	***r*-table**	**N (Sample size)**	**Sig. (2-tailed)**	**Information**
1	0.671**	0.279	53	0.000	Valid
2	0.693**	0.279	53	0.000	Valid
3	0.594**	0.279	53	0.000	Valid
4	0.713**	0.279	53	0.000	Valid
5	0.677**	0.279	53	0.000	Valid
6	0.431**	0.279	53	0.001	Valid
7	0.585**	0.279	53	0.000	Valid
8	0.536**	0.279	53	0.000	Valid
9	0.640**	0.279	53	0.000	Valid
10	0.499**	0.279	53	0.000	Valid
11	0.639**	0.279	53	0.000	Valid
12	0.512**	0.279	53	0.000	Valid
13	0.551**	0.279	53	0.000	Valid
14	0.593**	0.279	53	0.000	Valid
15	0.638**	0.279	53	0.000	Valid
16	0.563**	0.279	53	0.000	Valid
17	0.597**	0.279	53	0.000	Valid
18	0.564**	0.279	53	0.000	Valid
19	0.742**	0.279	53	0.000	Valid
20	0.673**	0.279	53	0.000	Valid
21	0.650**	0.279	53	0.000	Valid
22	0.621**	0.279	53	0.000	Valid
23	0.566**	0.279	53	0.000	Valid
24	0.580**	0.279	53	0.000	Valid
25	0.375**	0.279	53	0.006	Valid

3.3.6.7. Reliability of CTST

The internal consistency of the CTST test was assessed using the Cronbach's alpha coefficient, with a threshold of $\alpha \geq 0.7$ deemed acceptable. As shown in Table 4, the Cronbach's alpha for the 25 items was 0.93, indicating strong reliability. Likewise, the Cronbach's alpha values for the five variables were 0.821 (variable one), 0.856 (variable two), 0.806 (variable three), 0.816

(variable four), and 0.846 (variable five). These results confirm that both the overall test and the individual CTS indicators demonstrate acceptable internal consistency for evaluating CTS.

Table 4 Cronbach’s alpha values of variables

Variables	Cronbatch’s alpha	No. of items
Basic clarification	0.821	5
Credible sources	0.856	5
Inference	0.806	5
Advanced clarification	0.816	5
Strategies and tactics	0.846	5
All items	0.93	25

3.3.6.8. **Item difficulty and discrimination**

According to Table 4, all 25 questions in the CTST test were classified as moderately difficult, exemplified by Question 1 (Q1), which had an average score of 174 out of a maximum of 5, yielding a difficulty index of 0.66. The discrimination index for most questions, including Q1 with an upper limit (UL) of 62, a lower limit (LL) of 4, and N equal to 25% (13.25) with a maximum score of 5, reached an excellent rating of 0.88. While 24 questions achieved excellent discrimination, Question 6 (Q6) was rated as good, suggesting minor refinements are needed. This indicates the test effectively avoids overly easy or difficult questions and excels in differentiating student performance, making it a robust tool for assessing CTS in the human body system. The instrument evaluates students’ skills in basic clarification (focusing on questions, analyzing arguments, and clarifying information), bases for decision (judging source credibility using prior knowledge), inference (making deductive and inductive conclusions), advanced clarification (defining terms, evaluating definitions, monitoring thinking quality, and organizing information), and tactics and strategies (decision-making, problem definition, criteria selection, formulating alternatives, and determining actions). The content and construct validity of these results confirm that the CTST is a valid and reliable instrument for measuring critical thinking skills in biology education.

Table 5 Difficulty and discrimination index of CTST

Items	$\sum \mathbf{UL}$	$\sum \boldsymbol{LL}$	Mark ranges				No. students	Dif. I	Dis. I
			*3.5 – 5	2 – 3	0.5 - 1.5	0			
1	62	4	27	18	1	7	53	0.66	0.88
2	57	0	29	18	0	6	53	0.66	0.86

3	57	4	31	16	2	4	53	0.71	0.8
4	69	12	36	9	3	5	53	0.75	0.86
5	58	4	32	15	2	4	53	0.73	0.82
6	27	5	17	24	3	9	53	0.54	0.33
7	47	0	21	19	2	11	53	0.54	0.71
8	64	21	38	7	2	6	53	0.76	0.65
9	69	17	24	12	3	4	53	0.73	0.78
10	65	19	33	13	2	5	53	0.75	0.69
11	67	14	33	15	1	4	53	0.72	0.8
12	54	9	21	22	2	8	53	0.58	0.68
13	47	9	25	19	3	6	53	0.63	0.57
14	54	9	27	20	6	0	53	0.68	0.68
15	69	30	37	12	2	2	53	0.79	0.59
16	50	4	22	13	2	16	53	0.5	0.69
17	42	0	16	22	3	12	53	0.5	0.63
18	52	4	25	16	1	11	53	0.59	0.72
19	68	0	32	17	2	2	53	0.74	1.03
20	60	0	23	22	1	7	53	0.6	0.91
21	53	4	19	13	2	19	53	0.44	0.74
22	41	0	12	14	5	22	53	0.37	0.62
23	49	5	16	12	5	19	53	0.42	0.66
24	40	0	13	13	5	22	53	0.37	0.6
25	60	26	32	8	3	10	53	0.65	0.51

*The correct answer score ranges from 3.5–5

3.3.6.9. Construct validity of PSST

Following the test's administration, about 80% of students completed it within 50 minutes, with the remaining students finishing within 60 minutes. As indicated in Table 5, each r-count exceeded the r-table value of 0.279, based on the product-moment table for 40 students, confirming that all 20 problem solving skills test items were statistically significant.

Table 6 Reliability and validity analysis of PSST pretest and posttest pilot data

Validation				
Question number	Pearson Correlation	r-table	Sample size	Sig. (2-tailed)
1	0.607	0.279	40	0.000
2	0.791	0.279	40	0.000
3	0.665	0.279	40	0.000
4	0.523	0.279	40	0.000
5	0.678	0.279	40	0.000
6	0.715	0.279	40	0.000
7	0.739	0.279	40	0.000
8	0.737	0.279	40	0.000
9	0.662	0.279	40	0.000
10	0.599	0.279	40	0.000
11	0.754	0.279	40	0.000

12	0.760	0.279	40	0.000
13	0.633	0.279	40	0.000
14	0.718	0.279	40	0.000
15	0.795	0.279	40	0.000
16	0.649	0.279	40	0.000
17	0.668	0.279	40	0.000
18	0.689	0.279	40	0.000
19	0.755	0.279	40	0.000
20	0.702	0.279	40	0.000

3.3.6.10. Reliability of PSST

The internal consistency of the PSST test was indicated by the Cronbach's alpha coefficient, which must be acceptable at $\alpha \geq 0.7$. According to Table 6, the Cronbach's alpha of the 20 items was 0.94. Similarly, the Cronbach's alpha values of the four variables were 0.822 for variable one, 0.831 for variable two, 0.875 for variable three and 0.889 for variable four. Therefore, the internal consistency of the overall items and the items concerning each PS indicator were acceptable for measuring problem solving skills.

Table 7 Reliability analysis of PSST

Variables	Cronbatch's alpha	No. of items
Define the problem	0.822	5
Plan the solution	0.831	5
Implement the plan	0.875	5
Evaluate the solution	0.889	5
All items	0.941	20

3.3.6.11. Item discrimination and difficulty of PSST

According to Table 7, all 20 questions of the PSST test were classified as moderately difficult. For example, Question 1 (Q1) had a difficulty index of 0.66, with an upper limit (UL) of 10, a lower limit (LL) of 5, and N equal to 27% (11) with a maximum score of 5, resulting in a discrimination index of 0.45. Each of the 20 questions achieved a discrimination index in the very good category, indicating that the test avoids overly easy or challenging items and effectively distinguishes student performance. This makes the instrument well-suited for assessing problem-solving skills in the context of the human body system. Students demonstrated the ability to identify problems from scenarios, devise solutions, implement them, and evaluate their effectiveness. The content and construct validity of these results confirm that the PSST test items are reliable and valid for measuring PSS in biology education.

Table 8 Item discrimination and difficulty analysis of PSST

Items	$\sum UL$	$\sum LL$	Mark ranges				No. students	Dif. I	Dis. I
			*3.5 – 5	2 – 3	0.5 - 1.5	0			
1	10	5	21	14	1	5	40	0.68	0.45
2	10	4	20	14	0	6	40	0.64	0.55
3	10	5	19	16	1	4	40	0.68	0.45
4	10	5	21	12	3	4	40	0.68	0.45
5	10	5	22	13	2	3	40	0.68	0.45
6	10	5	20	14	3	3	40	0.68	0.45
7	10	3	18	12	2	8	40	0.59	0.64
8	10	5	23	7	2	5	40	0.68	0.45
9	10	4	24	12	0	4	40	0.64	0.55
10	10	3	17	13	5	5	40	0.59	0.64
11	10	5	23	11	2	4	40	0.68	0.45
12	10	5	21	15	2	1	40	0.68	0.45
13	10	3	15	19	3	3	40	0.59	0.64
14	10	3	17	10	3	10	40	0.59	0.64
15	10	5	27	5	2	6	40	0.68	0.45
16	10	4	22	13	2	5	40	0.64	0.55
17	10	5	26	6	1	7	40	0.68	0.45
18	9	3	15	16	1	8	40	0.55	0.55
19	9	2	12	17	3	8	40	0.50	0.64
20	9	3	13	19	1	7	40	0.55	0.55

3.3.6.12. CT and PS achievement test validity

In addition to the assessment of CTS and PSS, an initial set of 47 multiple-choice items was developed for the Human Body System Achievement Test (HBSAT). These items underwent review by two experienced biology teachers, each with 15 years of teaching expertise, to verify face and content validity. Following their input, 5 items were eliminated, yielding a final instrument of 42 multiple-choice questions, each featuring four options (one correct answer and three distractors). This test was then administered to a pilot group to evaluate students' comprehension of human body system concepts both before and after the intervention. Given the dichotomous nature of multiple-choice questions, reliability was calculated using the Kuder-Richardson Formula 20 (KR-20). The formula is expressed as: KR-20 = $\frac{K}{K-1}$ [1 - $\frac{\sum pq}{s^2}$], where (K) represents the number of questions, (p) is the proportion of correct responses for each item, (q) is the proportion of incorrect responses ((q = 1 - p)), and (s^2) denotes the variance of the total scores. As detailed in Table 8, the KR-20 coefficient was 0.89 for the pre-HBSAT and 0.96 for the post-HBSAT. Both values surpass the established reliability threshold of 0.7, signifying excellent internal consistency (Ursachi *et al*., 2015). Consequently, the researcher-designed achievement test demonstrates high reliability and is well-suited for accurately gauging students' academic performance in this domain.

Table 9 Reliability test of the HBSAT

	Values			
Test	K	$\sum pq$	Var (S^2)	RK-20
Pre-HBSAT	42	9.59	74	0.89
Post-HBSAT	42	5.3	83	0.96

3.4. Development of intervention

3.5.1. Presenting the intervention

Initially, a dedicated research team was formed to oversee the intervention. The team comprised the researcher, two principals, one supervisor, and two biology teachers. The researcher's primary responsibilities included presenting a practical problem to the team, providing support, and observing and analyzing key aspects of the process: how principals and supervisors monitored the teaching-learning activities, how teachers facilitated student learning, and how students actively participated in the actions. Furthermore, the researcher oversaw the entire implementation of the intervention, which spanned eight weeks.

3.5.2. Design-based learning Cycle 1

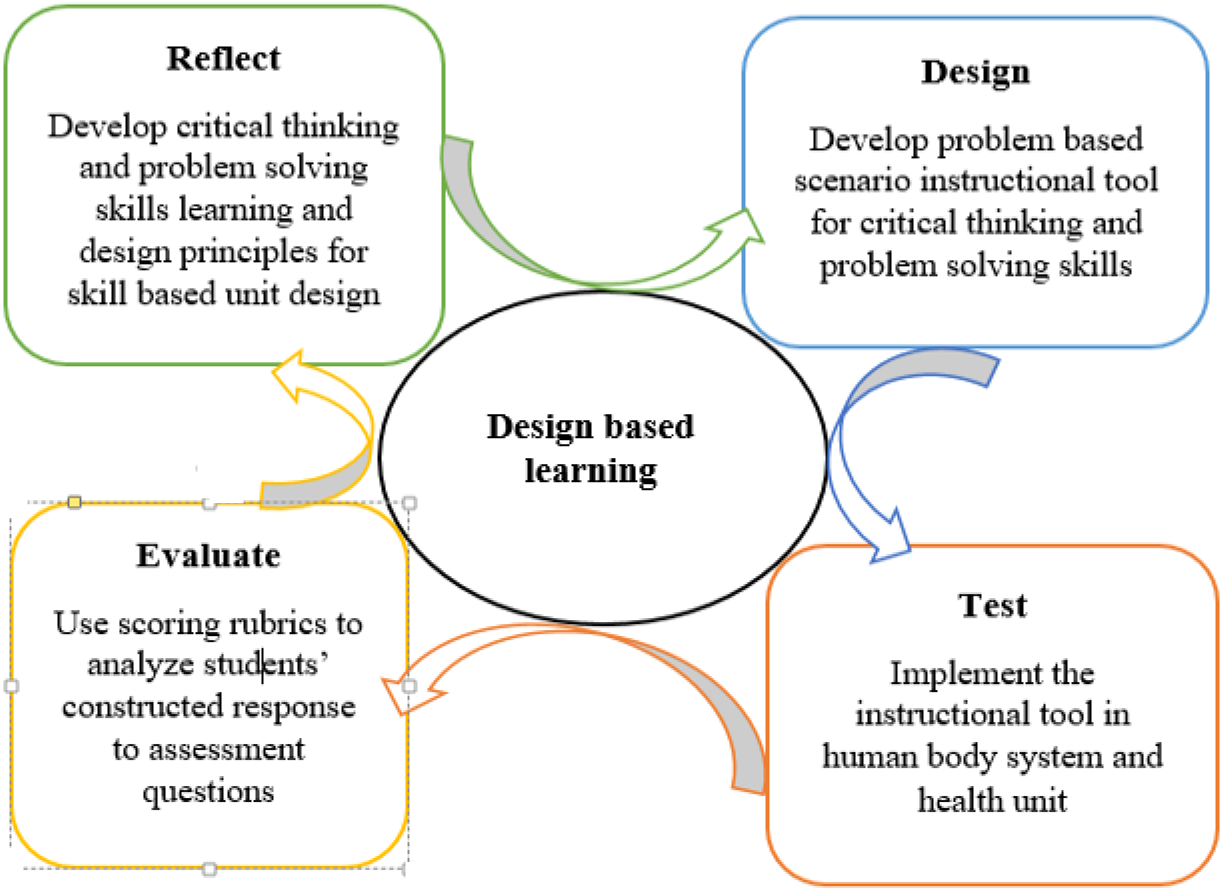

Figure 3 The 4 phases of design-based learning iterative cycle modified from Scott *et al*. (2020).

3.5.2.1. Design-based research cycle 1, phase 1: designing instructional tools

A problem-based instructional tool was developed for by incorporating realistic scenarios related to human body systems that reflect challenges students may encounter in daily life. These scenarios were carefully designed to promote CTS and PSS by requiring students to analyze, evaluate, and apply knowledge to solve practical problems. Indigenous Knowledge was integrated into the tool—drawing on traditional practices, local health remedies, and culturally relevant examples—to provide context-rich, meaningful learning experiences. The combined PBS+IK approach was applied to ensure that students engaged in authentic PSS tasks while critically evaluating both scientific and traditional perspectives, directly supporting to enhances CTS, PSS, and AA. In the classroom, students engaged with this tool through activities that addressed various human body system challenges, while also completing formative assessment questions crafted to promote PSS and CTS abilities. The problem-based learning tool serves as a guide for students, facilitating PSS and CTS activities. It presents human physiology scenarios followed by targeted questions, enabling students to identify problems or root causes, clarify and analyze information within the scenarios, support it with evidence, design devise solutions, implement plans, and evaluate their outcomes. Through this process, the tool effectively fosters the development of students' PSS and CTS competencies.

3.5.2.2. Phase 2: testing the instructional tools

In the second phase of the design-based research, the PBS tool was implemented in classroom settings to evaluate its effectiveness. The researcher analyzed iterative formative assessment results to gauge learning outcomes. Additionally, comparisons between pretest and posttest responses from the treatment and control groups were conducted to measure the tool's impact on enhancing students' CTS and PSS. The research team, including teachers, tested the tool's performance in real-world classroom environments, making design adjustments as needed to address unforeseen challenges. The implementation occurred during the 2023-2024 academic year, with students using the tool to explore human body systems and health topics through classroom activities. Five 40-minute lessons were delivered weekly, with classes divided into six groups of up to seven students, each assigned distinct roles to foster discussion during the intervention. In contrast, the control group followed a teacher-designed curriculum on human body systems, with the same lesson duration. To ensure accountability, students completed homework assignments prior to class and engaged with textbooks and local health professionals for deeper topic exploration. Throughout the intervention, students responded to CTS and PSS questions to refine and improve the scenario-based learning experience.

3.5.2.3. Phase 3: evaluating the instructional tools

In the third phase of the design-based research cycle, the effectiveness of the instructional tool was assessed by examining evidence of student learning through interviews, formative assessments, and exam data. The quality of students' responses on exams and formative assessment questions served as key indicators of improvements in CT and PS skills within the context of the PBS tool. Pretest responses were analyzed to identify overarching patterns in students' CT and PS abilities, which were then categorized into varying levels of sophistication to establish evaluation rubrics. By examining shifts in the frequency distributions of students' responses across these rubric levels at different stages of the intervention, the research team identified the number of students who developed more sophisticated CT and PS skills, qualifying them as having made significant progress.

3.5.2.4. Phase 4: reflecting on the learning tools and the implementation

In the concluding phase, a retrospective analysis was conducted to evaluate the methodology's reliability through targeted analytical questions, including: How did the research effort advance the underlying theory? Did the learning tool effectively facilitate student learning? What key design elements of the tool contributed to supporting student learning outcomes? This analysis aimed to assess the robustness and impact of the instructional approach.

3.5.3. Design-based learning Cycle 2

3.5.3.1. Phase 1: redesign and refine the experiment

To refine and redesign the experiment assessing the impact of the PBS tool on tenth-grade students' CTS and problem-solving skills in human body systems education, several improvements were implemented to enhance reliability, validity, and generalizability. The tool's scenarios were updated to ensure cultural relevance, age-appropriateness, and alignment with biology curricula, incorporating diverse, real-world health-related contexts to boost student engagement. Questions were refined to maintain moderate difficulty (difficulty index of 0.4–0.7) and strong discrimination (≥ 0.4), with underperforming items, such as Q6, revised based on pilot feedback.

Interactive digital components, like simulations, were integrated to enrich student interaction. The intervention was extended to an 8-week period with weekly 40-minute sessions, and classes were structured into groups of 5–7 students with rotating roles to promote collaborative learning. Teachers received professional development to ensure uniform implementation, while the control group followed a standardized traditional curriculum. The assessment approach combined quantitative methods (pre- and posttests) with qualitative methods (interviews, student reflections, and observations), utilizing detailed rubrics to classify CT and PS responses by sophistication level, with a focus on epistemic commitments such as evaluating source credibility. Reliability was confirmed using the Kuder-Richardson formula-20 (KR-20) and Cronbach's alpha (target $\geq$ 0.7), supported by expert reviews to ensure validity. Data analysis incorporated statistical tests (t-tests, ANOVA) and thematic coding of qualitative responses, with iterative refinements driven by formative feedback to optimize the tool's effectiveness.

3.6. Data collection techniques

Qualitative and quantitative data was collected simultaneously in 8 weeks in the first cycle to reduce time consumption.

3.6.1. Questionnaire

The instrument consisted of twenty-five open-ended essay items assessing CTS and twenty items evaluating PSS, designed to capture both the depth and application of students' reasoning. This questionnaire was administered as a pretest and posttest to measure baseline competencies and the impact of the PBS+IK instructional tool. Open-ended essays were chosen because they allow students to articulate their thinking, justify solutions, and demonstrate reasoning processes, providing rich data on how students analyze, evaluate, and apply knowledge in realistic biological scenarios.

3.6.2. Interview

The researcher used the semi-structured interview form to ask additional probe questions to analyze the issue in depth and to understand the reasons behind participants' answers. The interview form was composed of five main questions and seven probe questions. For example, some of the questions asked for students on CT were: do you clarify your information and concepts when learning with PBS? how do you infer your thought? and how do you provide tactics and strategies for the problem? explain it with concrete examples? The steps for qualitative data collection tool development were followed one by one when developing the interview form. The item pool was created, expert views were taken, and the tool was piloted. The item pool was created based on studies in the literature. Nine main questions and 14 probes were presented for to an expert for review. An expert with a PhD stated that two questions were repeat, one question was irrelevant, and two probes did not serve the study's purpose of the study. The questions were revised as that the expert and researcher agreed were selected and problematic were omitted.

3.6.3. Student reflection

Student reflections provide qualitative insights into students' learning experiences and cognitive development. To gather this data, the research team typically employs a reflective method tailored to capture students' thoughts, challenges, and progress. Students were engaged in written reflections, such as diaries, where they respond to guided prompts like "How did solving the digestive system case help you understand nutrient absorption?" or "What challenges did you face in diagnosing the respiratory condition?" These entries, collected regularly, allow students to articulate their PSS processes and CTS development. Moreover, verbal reflections were also common, with class discussions providing a platform for students to share insights about cases involving immune system disorders or excretory system imbalances, often recorded for later transcription and thematic analysis.

3.6.4. Observation

The researcher was made appropriate notes about students' CTS and PSS as quickly as possible after observation. To evaluate the activity process in its different dimensions activity observation form (AOF) was filled out in detail during the activity by note-taking technique. At the same time, the entire unit of the activity was recorded on a camera and presented to the research team, principals, and supervisors for evaluation purpose of the effectiveness of the intervention. The observation tool was used to triangulate the data and to see if the views students and teachers had stated in the interviews complied with their classroom practices. The observation form was designed according to the aims of the study and the data collected from the interviews. Later on, an expert with PhD was asked to assess the observation form by considering the study's aims. Accordingly, it was filled.

3.6.5. Data collection plan

- Pre-test was administered for all 5 systems in **Week 1**

- **Ongoing tests were conducted to improve the problem scenario learning tool in Weeks 2–7.** Formative data was collected from:
    - Digestive system scenario with student reflection and observation checklist **in Week 2–3**:
    - Circulatory and respiratory systems (e.g., analyze heart rate data or asthma case). Adjust scenarios based on student feedback **in Week 4–5**.
    - Immune and excretory systems (e.g., immune response to flu, kidney filtration issues). Refine scenarios iteratively in **Week 6–7**
- Post-test was administered for all 5 systems **in Week 8**.

3.7. Data analysis

The iterative and dynamic nature of DBR was integrated quantitative and qualitative methods to evaluate assessments and contextualize findings effectively. Iterative analysis was occurred after each DBR cycle (every two weeks), where interim data from formative assessments were examined to identify patterns and guide refinements to PBS. Data collection involved gathering qualitative insights from student reflections and teacher feedback to enhance scenario design and provide context for test outcomes. During summative assessments, quantitative and qualitative datasets were analyzed independently, followed by a comparative interpretation to determine whether the findings align or diverge, ensuring a robust evaluation of the learning process.

3.7.1. Quantitative method

The questionnaire data concerning PSS and CTS learning outcomes was analyzed quantitatively by extracting the mean values, standard deviations, and percentages of the students' ratings with SPSS statistical analysis software. Moreover, binary logistic regressions were performed to test the relationship between the predictor variables in the research questions.

3.7.2. Qualitative method

The interviews were face-to-face and recorded using an audio recorder. Voice recording was done in all observed classes and field notes were kept frequently. Afterwards, the voice recordings were transcribed. A qualitative codebook and corresponding rubrics were used to student response scoring. Besides this, data was analyzed in preliminary analysis, continuously (iterative cycle of analysis), and retrospectively. Primarily data analysis was taken place during the implementation of the intervention. The second level of data analysis was done after the implementation of the intervention whereby the remaining data was reduced again into manageable portions by highlighting relevant text. This text and the text reduced in the first level of analysis was then examined independently for repeating ideas until no repeating ideas were left to examine. Then these ideas were grouped according to common themes relevant to the learning tool and be examined through the lens of the problem-based learning scenario to make sense of what had emerged and to generate new design constructs. In the final level of analysis, the design constructs derived from the data was then be drawn upon to re-examine the data for the process.

3.8. Ethical issue

To ensure ethical compliance, approval was secured from the Ethical Committee of Bahir Dar University, with additional communication established with the Amhara Region Education Bureau and the Sekota Administrative Town Education Office regarding the study. Participants were informed about the study's purpose and assured of their anonymity to obtain their consent. A formal consent letter was prepared and signed by all participants to confirm their voluntary participation. After completion, all data collected for this study, including pretest and posttest responses, questionnaires, and observational records, were securely stored in password-protected files on an encrypted drive accessible only to the research team. Physical documents, if any, were kept in a locked cabinet within a secure office. To ensure long-term confidentiality, all participants’ identifying information was anonymized using unique codes, and no personal identifiers were linked to responses in any reports or publications.

CHAPTER FOUR: RESULT

Introduction

This chapter presents the study's results and accompanying data analysis. It begins with an examination of the quantitative findings from the pretest, followed by a detailed analysis of the qualitative data gathered during the study. The chapter then moves to the presentation of the quantitative results from the posttest and concludes with the qualitative analysis of the retrospective data.

4.1. Pretest scores analysis

One week prior to the intervention, the intervention group (IG) received training. Measures of PSS, CTS, and AA in human biology were administered as pretests to all groups to enable baseline comparisons between the intervention and comparison groups. The pretest ANOVA results revealed no statistically significant differences among the groups in biological critical thinking skills (BCTST), $F(2,118) = 2.233$, $p = .112$; biological problem-solving skills (BPSST), $F(2,118) = 1.321$, $p = .271$; or academic concept test scores (ACT), $F(2,118) = 2.085$, $p = .129$, indicating that the groups were comparable at baseline prior to the intervention (Table 10).

Table 10 ANOVA result

		Sum of Squares	df	Mean Square	F	Sig.
CTS	Between Groups	120.977	2	60.488	2.233	.112
	Within Groups	3197.023	119	27.093		
	Total	3318.000	121			
PSS	Between Groups	159.891	2	79.945	1.321	.271
	Within Groups	7139.250	119	60.502		
	Total	7299.140	121			
AA	Between Groups	164.159	2	82.079	2.085	.129
	Within Groups	4645.263	119	39.367		
	Total	4809.421	121			

4.1.1. Assumptions

4.1.2. Sample size

Pallant (2005) recommends that, for multivariate analysis, each cell should contain more cases than the number of dependent variables. With three dependent variables (PSS, CTS, and AA), the minimum required sample size per cell was three. The MANOVA output confirms that each of the six cells (intervention and control groups across all three variables) exceeded this minimum, indicating that the sample size was sufficient for conducting MANOVA.

4.1.3. Normality

Normality for CTS, PSS, and AA (n = 121 each) was assessed using the Kolmogorov–Smirnov and Shapiro–Wilk tests. For CTS, K–S = 0.066 (p = 0.200) and S–W = 0.979 (p = 0.062); for PSS, K–S = 0.074 (p = 0.098) and S–W = 0.980 (p = 0.076); and for AA, K–S = 0.072 (p = 0.183) and S–W = 0.980 (p = 0.069). All p-values exceed .05, indicating no significant departure from normality and supporting the use of parametric analyses such as ANOVA and MANOVA, as shown in Table 11.

Table 11 Tests of Normality

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	Df	Sig.	Statistic	Df	Sig.
CTS	.066	121	.200*	.979	121	.062
PSS	.074	121	.098	.980	121	.076
AA	.072	121	.183	.980	121	.069

4.1.4. Outliers

Multivariate normality was assessed using Mahalanobis distance, with a critical value of 16.27 for three dependent variables. As shown in Table 12, the maximum Mahalanobis distance was 11.064—well below the threshold—indicating no multivariate outliers. Regression diagnostics for the 121 cases further supported this: predicted values ranged from 0.70 to 3.55 (M = 1.98, SD = 0.627), standardized predicted values from –2.048 to 2.496 (M = 0.000, SD = 1.000), and residuals from –1.228 to 1.643 (SD = 0.539). Standardized residuals (–2.251 to 3.011, SD = 0.987) remained mostly within ±3. Cook's distance values (0.000 to 0.157) and leverage values (0.001 to 0.092) were low. Overall, Table 10 confirms the absence of influential cases or multivariate outliers, supporting the multivariate normality assumption required for MANOVA.

Table 12 Residuals statistics

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.70	3.55	1.98	.627	121
Std. Predicted Value	-2.048	2.496	.000	1.000	121
Standard Error of Predicted Value	.053	.173	.096	.025	121
Adjusted Predicted Value	.68	3.58	1.98	.631	121
Residual	-1.228	1.643	.000	.539	121
Std. Residual	-2.251	3.011	.000	.987	121
Stud. Residual	-2.373	3.096	-.001	1.004	121
Deleted Residual	-1.366	1.738	-.001	.557	121
Stud. Deleted Residual	-2.422	3.218	.001	1.014	121
Mahal. Distance	.157	11.064	2.975	2.049	121
Cook's Distance	.000	.157	.008	.021	121
Centered Leverage Value	.001	.092	.025	.017	121

4.1.5. Linearity

Figure 4 shows a matrix of scatterplots for the MANOVA variables, with no signs of non-linearity or curvilinear patterns. The scatterplots form clear positive linear trends—generally rising from lower left to upper right—confirming that the linearity assumption is met. This aligns with earlier diagnostics: the maximum Mahalanobis distance was 11.064, below the critical value of 16.27, and standardized residuals remained mostly within ±3, with low Cook’s distance values. Together, these findings support the suitability of MANOVA for analyzing group differences in PSS, critical-thinking skills, and AA.

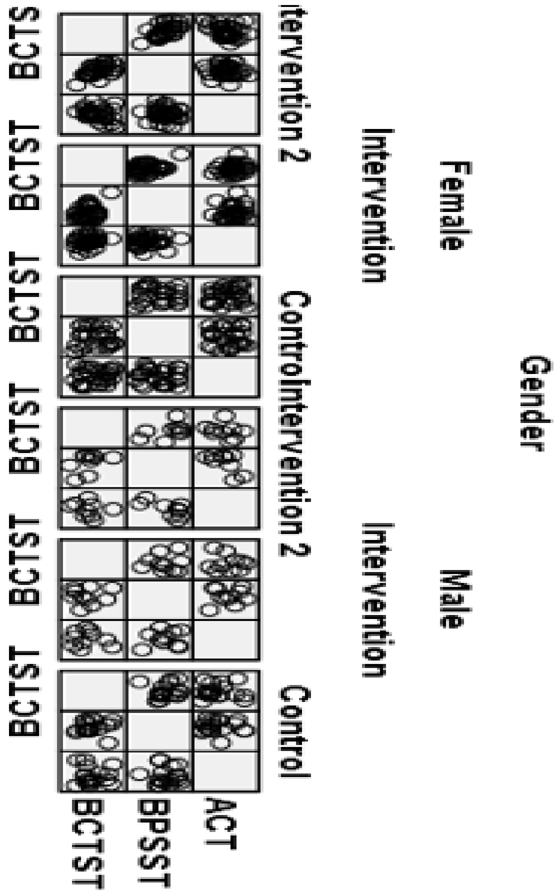

Figure 4 Linearity in pretest scores

4.1.6. Multicolinearity

Table 13 shows that the dependent variables meet the correlation requirements for MANOVA. PSS and CTS are moderately correlated, r = 0.505 (p = 0.000), while PSS and AA, r = 0.337 (p = 0.000), and CTS and AA, r = 0.361 (p = 0.000), show small to moderate correlations. All correlations are significant at $p < .01$. As Pallant (2016) notes, MANOVA performs best when dependent variables are moderately related but not highly correlated ($r < 0.80$), a condition satisfied here (Table 11). Combined with earlier evidence—Mahalanobis distance below 16.27, residuals mostly within ±3, and linearity confirmed in Figure 1—these correlations further support the appropriateness of MANOVA for this study.

Table 13 Pearson correlations of dependent variables

	PSS	CTS	AA	Sig (2-tailed)
PSS	1	.505	.337	.000
CTS	.505	1	.361	.000
AA	.337	.361	1	.000

4.1.7. Homogeneity of variance-covariance matrices

Table 14 shows no violation of the homogeneity of variance–covariance matrices assumption. Box’s M = 46.478, F = 1.408, df_1 = 30, df_2 = 7207.366, with $p = 0.069$. Because $p > 0.001$ following Pallant’s (2016) guideline, The covariance matrices for PSS, CTS, and AA can be considered equal across groups. This confirms that the homogeneity assumption for MANOVA is met (Table 13). Along with earlier evidence—Mahalanobis distance below 16.27, residuals mostly within ±3, linearity in Figure 1, and moderate correlations among variables—these results further support the suitability of MANOVA for the study.

Table 14 Box's test of equality of covariance matrices

Variables	Box's M	F	df1	df2	Sig.
Posttest	46.478	1.408	30	7207.366	.069

4.1.8. Levene‘s test

Table 15 shows that Levene’s test indicates no violation of the homogeneity of variance assumption for the posttest scores of PSS, CTS, and ACH. Specifically, PSS: F = 1.406, df_1 = 5, df_2 = 115, p = 0.227; CTS: F = 1.974, df_1 = 5, df_2 = 115, p = 0.088; ACH: F = 1.303, df_1 = 5, df_2 = 115, p = 0.268. All p-values exceed 0.05, supporting equal variances across groups. These results, combined with prior evidence—Mahalanobis distance < 16.27, standardized residuals mostly within ±3, low Cook’s distance, linearity in Figure 1, moderate correlations among variables (e.g., r = 0.505 for PSS-CTS), and Box’s M p = 0.069—confirm that the assumptions for MANOVA are satisfied, supporting its validity for analyzing group differences.

Table 15 Levene's test of equality of error variances

Variables	F	df1	df2	Sig.
PSS posttest	1.406	5	115	.227
CTS posttest	1.974	5	115	.088
AA posttest	1.303	5	115	.268

4.2. Ongoing data analysis

4.2.1. DBR data analysis on scenario 1 for CTS and PSS

Students showed a clear basic understanding that shifting from a high-fiber fasting diet to a meat-heavy diet caused Amare's constipation. Stronger students (S1, S2, S5) gave detailed examples, used stronger evidence, and explained mechanisms like gut motility; others (S3, S4, S6) gave simpler, fiber-only explanations (Table 16). Most students proposed practical, culturally relevant strategies (gomen, shiro, more water), though some recommendations lacked evidence or clear quantities. Tool feedback showed a preference for pictures, simpler diaries, and interactive charts, but raised privacy concerns. Overall, students demonstrated good foundational reasoning but need support in mechanistic explanations, evidence use, and precise documentation. Teachers should use visuals, structured discussions, and simple tracking tools to strengthen scientific reasoning.

Table 16 Students' reflection on CTS on scenario 1

Category	Summary of Student Responses
1. General Understanding	Strong shared understanding that Amare's shift from a high-fiber fasting diet to meat-heavy post-Easter diet caused constipation. Depth varied.
2. Elementary Clarification	All accurately summarized the diet shift. • Fasting diet: whole grains, fruits, vegetables (injera, lentils, cabbage). • Post-Easter diet: meats (doro wat, tibs, kitfo). • S1, S2, S5 gave detailed food lists; S3, S4, S6 used broad terms. • Missing: none mentioned "effective chewing."
3. Basic Support	All used scenario evidence (comfortable bowel movements, good movement of tract). • S1, S2: added personal anecdotes. • S4, S6: general experiences with weaker support.
4. Inference	All identified low fiber as main cause. • S2, S3, S5: added overeating/dehydration. • S4: vague, non-biological explanation.
5. Advanced Clarification	• S1, S2, S5: Expanded with motility, microbiome, enzyme adaptation ideas. • S3, S4, S6: Only fiber mentioned — limited depth.
6. Tactics / Strategies	Solutions recommended: • S1: Gomen, water. • S2: Small tibs, shiro. • S3: Injera, water, buna (weak evidence). • S4: Gomen, walking. • S5: Shiro, water. • S6: Less tibs, more injera. Strengths: practical considerations (water access, cost). Gaps: some lacked quantities or clear guidelines.
7. Students' Feedback on Tools	• S1, S6: Add pictures in food diaries. • S2, S6: Class tracking charts (fiber, water). • S3: Simpler food diary templates. • S4: Gamified lab tool (not detailed). • S5: Animated digestive diagrams. Issues: S3's bowel-movement tracking raises privacy concerns.

Category	Summary of Student Responses
8. Insights for DBR (Design-Based Research)	Students tested solutions (gomen, shiro) and refined them (papaya, mango, and banana). Collaboration strong in S2, S6. Needs: S3, S6 need more biological-mechanism support. All need better quantification, attention to non-dietary factors, precise documentation.
9. Implications for Teaching	Teachers can improve learning via multimedia tools, peer discussion, accurate documentation, and stronger scientific-reasoning support.

According to Table 17, Sstudents followed a clear PSS process: they identified low fiber, high meat intake, and low water as causes; planned realistic solutions with fiber-rich foods, water, and activity; and implemented these effectively. They noted improved bowel movements and proposed class-wide strategies. Students preferred simple, visual, interactive tools, and their iterative thinking shows strong potential for scalable, peer-supported health interventions.

Table 17 Students' reflection on PSS on scenario1

Phase / Category	Summary of Student Responses
1. Identification Phase	Consistently identified causes: low fiber (less injera/gomen/shiro), high meat intake (doro wat, tibs), low water intake after fasting.
2. Planning Phase	Proposed solutions: • Fiber-rich foods (injera, gomen, misir, lentils, fruits). • Increased water. • Physical activity. • Collaborative tools like water-tracking and "Injera Health" charts.
3. Implementation Phase	Encouraged Amare to: eat recommended foods, share fruits (mango/banana), drink more water (shakla), and engage in physical activities.
4. Evaluation Phase	Improvements: regular bowel movements (1–2x/day), reduced discomfort. Scaling: class fiber-tracking, add backup fruits like papaya.
5. Feedback on Tools	Liked food diaries, digestive diagrams, virtual labs. Requested: simpler layouts, more visuals, more interactive features.
6. DBR Alignment	Students used metaphors (constipation as "waste," diet as "budget"). Showed resource-efficient local solutions, collaboration, iterative refining.
7. Broader Implications	Suggests potential for scalable school-based interventions, improved tool designs (pictorial diaries), and strengthened peer-driven learning.

Students demonstrated strong CTS and PSS across Scenario 1 (Table 18-19). They accurately identified causes of constipation, proposed practical, culturally relevant solutions, implemented strategies effectively, and evaluated outcomes (improved bowel movements, scalable ideas). Tool feedback and DBR insights show engagement with iterative, collaborative approaches. The main gap is chewing, as no student linked chewing to digestion, and some students provided less detailed plans or evaluations. Visual aids, role-playing, and interactive tools could strengthen understanding of mechanical digestion and peer-oriented strategies.

Table 18 Observation checklist for CTS on scenario 1

Category	Indicator / Focus	Student Performance / Summary	Notes / Gaps
General Understanding	Recognize cause-effect in diet change	Strong CTS; most students link fiber reduction and meat increase to constipation	Missed chewing detail ("chewed well"); focus on diet composition over mechanical digestion
Elementary Clarification	Accurately list fasting and post-fasting foods	Fully met: fasting foods (injera, lentils, cabbage, teff, fruits); post-fasting foods (doro wat, tibs, kitfo)	Even less detailed responses adequate culturally; no student addressed effective chewing
Basic Support	Cite scenario evidence	Fully met: linked health benefits to fasting diet; constipation to meat's low fiber; some detailed (fiber), others sufficient	Some variation in detail; evidence mostly diet-based, non-dietary factors underexplored
Inference	Explain constipation causes logically	Fully met: low fiber, sudden meat intake, supported by scenario details or cultural experience; some added dehydration/overeating	Non-dietary factors like stress not explored
Advanced Clarification	Explain digestion impact	Fully met: fiber aids gut motility, 2-month meat absence effects (enzyme/microbiome); simpler explanations still meet criteria	Depth varies; some focus only on fiber
Tactics / Strategy	Suggest solutions	Fully met: culturally relevant and practical (injera, gomen, shiro, water, walking); consider barriers (costs)	Some solutions less evidence-based (coffee); missing precise guidelines/quantities
Tool Feedback	Evaluate and suggest improvements	Fully met: suggestions include pictures in diaries, class charts, animated diagrams	Some refinements lack detailed testing outcomes; S5, S6 need support or clearer feedback
Insights for DBR	Apply iterative, collaborative approach	Fully met: tested/refined solutions (papaya, mango), linked to DBR; metaphors used (constipation = waste, diet = budget)	S6 less detailed; reflective prompts could enhance articulation

Table 19 Observation checklist for PSS on scenario 1

Category	Indicator / Focus	Student Performance / Summary	Notes / Gaps
Identify	Recognize causes	All students identified constipation causes (low fiber, high meat, low water); S6 used simpler terms	Visual aids (digestive diagrams) could enhance clarity
Plan	Propose solutions	All students proposed feasible strategies; S2, S6 added collaborative tools	S5's plan less detailed; guided activities could strengthen peer strategies
Implement	Apply strategies	S2, S3, S5, S6 engaged Amare with foods/activities; S1 focused on personal actions	S6's peer tips vague; role-playing could enhance community involvement
Evaluate	Assess outcomes	All students noted improved digestion (1–2 bowel movements), suggested scalable strategies	S6 less detailed; case studies could deepen evaluation skills
Tools	Use and improve tools	Diaries and diagrams effectively used; S1 strong in fiber tracking	S5, S6 need teacher support or interactive demos for clarity
DBR Alignment	Link actions to DBR	Fully met: iterative testing, collaboration emphasized; metaphors applied	S6 less detailed; reflective prompts could improve articulation

4.2.2. DBR data analysis on scenario 2 for CTS and PSS

Students showed strong CTS, accurately identifying varicose veins and associated symptoms (Table 20), empathizing with the teacher, and proposing practical strategies like sitting, leg elevation, and compression socks. S3–S5 demonstrated deeper reasoning and linked symptoms to standing or lifestyle factors, while S1–S2 and S6 had more limited medical understanding and vague inferences. PSS were evident in their ability to identify the problem, plan feasible strategies, implement them in daily routines, and evaluate effectiveness, though S6's reflections lacked depth (Table 21). Engagement with tools varied, with some students benefiting from interactive formats or group discussions. Overall, students effectively applied identification and implementation skills, but gaps in inference, advanced clarification, tool use, and DBR articulation suggest a need for simplified terminology, collaborative activities, and visual aids to strengthen understanding and participation.

Table 20 Students' reflection on scenario 2 for CTS

Category	Indicator / Focus	Student Performance / Summary	Notes / Gaps
Clarification	Describe varicose veins, symptoms, causes	S1–S2: basic symptoms (heaviness, aching), limited grasp of medical terms. S3–S5: precise symptoms, link to standing. S6: inconsistent depth, sometimes misattribute causes.	Confusion between cause and symptom; inconsistent understanding of contributing factors.
Support	Empathize, suggest practical solutions	All students suggest leg elevation, sitting, compression socks; S1–S4 focus on immediate relief, S5–S6 recommends medical consultation.	Awareness of medical intervention varies.
Inference	Explain underlying mechanisms	S1–S3: connect standing to blood pooling; S3/S5: use personal experience or science sources. S4/S6: vague reasoning (tiredness, lack of movement).	Weaker inferences indicate need for clearer guidance.
Advanced Clarification	Ask deeper questions about condition	S1–S2: basic symptom/family history questions. S3–S5: lifestyle factors, diagnostic tests. S6: relevant but vague.	Engagement and specificity vary; S6 shows potential disengagement.
Tactics / Strategy	Propose preventive or alleviating actions	All: sitting, leg elevation; S2/S5: compression socks; S3/S6: hydration (less relevant).	Variable accuracy; some strategies less medically appropriate.
Tool Feedback	Evaluate scenario and tools	S1–S3, S5: relatable, engaging. S4/S6: boring/difficult writing tasks. Suggest drawing, discussions.	Engagement challenges; need alternative formats for comprehension.
Insights for DBR	Reflect on iterative learning	S2: group discussion. S4: creative tasks. S5: strong inferences but could enhance collaboration.	Gaps in engagement and articulation, especially for S4 and S6.

Table 21 Students' reflection on scenario 2 for PSS

Phase	Indicator / Focus	Student Performance / Summary	Notes / Gaps
Identify	Recognize problem/cause	All students identify varicose veins as cause of leg heaviness/tiredness; S1/S3 precise; S5 links veins to tiredness. S2/S6: simpler terms.	S6 struggles with terminology; visual aids could improve understanding.
Plan	Propose solutions	Practical strategies: sitting, leg elevation, walking, compression socks, drinking water. S1/S3/S6: rest-focused; S2/S5: movement-focused.	Some strategies less medically relevant; balance between rest/movement needed.
Implement	Apply strategies	All integrate strategies: S1/S3 sit during	Application strong,

Phase	Indicator / Focus	Student Performance / Summary	Notes / Gaps
		breaks; S2/S5 walk while teaching; S6 sits at lunch/after class.	practical, contextually appropriate.
Evaluate	Assess outcomes	All describe strategies as effective ("best, easy, free"); S6's evaluations less detailed.	Depth of reflection varies; S6 limited articulation.
Tools	Use and assess tools	S1/S3 appreciate tools; S2 wants group discussion; S6 struggles with medical terms.	Need simpler explanations and interactive formats.
DBR Insights	Reflect on iterative process	S1/S5: strong planning and reasoning. S2/S6: basic engagement; S6 struggles with medical terms.	Collaborative activities and guided reflection could improve DBR understanding.

Students showed strong PSS and CTS in the varicose veins scenario (Table 22-23). Most groups accurately identified symptoms and suggested practical strategies (sitting, leg elevation, compression socks), though some used simplistic terms or confused causes. Inference and advanced clarification were partial, with limited reasoning about blood flow and lifestyle factors. In PSS phases, identification, planning, and implementation were effective, but evaluation lacked depth. Engagement with tools was good, though some struggled with medical terminology. Overall, simplified terms, guided discussions, and role-playing could strengthen reasoning, strategy accuracy, and DBR alignment.

Table 22 Observation checklist on scenario 2 for CTS

Category	Indicator / Focus	Group Performance / Summary	Notes / Gaps / Recommendations
Clarification	Describe varicose veins, symptoms	G1–G5: solid understanding, symptoms like heaviness and aching ("Yes"). G6: sometimes confuses standing as cause.	Some use simplistic terms ("bumpy veins"); glossaries or simplified explanations recommended.
Support	Offer practical help and empathy	All groups "Yes"; suggested leg elevation, rest, compression socks. G5/G6 also suggested medical referrals.	G1–G4 focus on immediate relief; G4–G6 responses sometimes lack detail. Role-playing could enhance empathy.
Inference	Connect standing to poor blood flow	Rated "Partial"; G3/G5 accurately link standing to blood pooling; G1/G2 basic connections; G4–G6 vague reasoning.	Group discussions could strengthen reasoning and model connections.

Category	Indicator / Focus	Group Performance / Summary	Notes / Gaps / Recommendations
Advanced Clarification	Ask deeper or probing questions	Rated "Partial"; G3–G5 asked about lifestyle or priorities. G1/G2 simple questions; G6 lacked depth.	Guided prompts recommended to foster deeper inquiry.
Tactics / Strategy	Propose solutions and rationale	Rated "Yes"; all suggest sitting, leg elevation; G2–G5 include compression socks; G3–G6 suggest hydration (less relevant).	Targeted discussions to rank strategy effectiveness could clarify reasoning.

Table 23 Observation checklist on scenario 2 for PSS

Phase	Indicator / Focus	Group Performance / Summary	Notes / Gaps / Recommendations
Identify	Recognize problem and symptoms	G1/G5: clearly recognized varicose veins and leg heaviness. G6: relied on others' input; simpler descriptions.	Glossaries or simplified terms recommended to reinforce understanding for less confident groups.
Plan	Propose feasible strategies	All groups suggested sitting, walking, leg elevation; G6 followed lead of others.	Group discussions could encourage broader participation and idea-sharing.
Implement	Apply strategies practically	G5 detailed walking while teaching; other groups less applied.	Role-playing classroom movements could deepen understanding of practical application.
Evaluate	Assess effectiveness of strategies	All noted strategies were practical ("sitting is easy"), but reasoning limited; depth of evaluation varied.	Discussions to justify and rank strategies (e.g., why walking improves blood flow more than hydration) could strengthen analysis.
Tools / Engagement	Use and assess tools	T-charts effective for identifying problems/solutions; some groups struggled with medical terminology.	Collaborative creation of T-charts, simplified terms, and guided prompts recommended.
DBR Alignment	Reflect on iterative learning	Strong engagement overall; G5 modeled clarity; iterative adjustments noted.	Encourage collaborative reflection and peer modeling to enhance DBR understanding.

4.2.3. DBR data analysis on scenario 3 for CTS and PSS

Students showed strong CTS in identifying asthma symptoms and triggers, offering practical support, and suggesting strategies like inhalers, masks, and allergen charts (Table 24). Some students gave vague reasoning or misconceptions, especially on long-term management. In PSS, identification, planning, and implementation were generally effective, but evaluation and inference were limited for some (Table 25). Engagement varied, with tools like simulations, multilingual guides, and apps recommended to improve understanding, reasoning, and strategy effectiveness.

Table 24 Students' reflection on scenario 3 for CTS

Category	Indicator / Focus	Student Performance / Summary	Notes / Gaps / Recommendations
Clarification	Ask questions about symptoms/triggers	S1, S3, S5: targeted questions on symptoms, cold, allergens. S2, S4: narrow focus on breathlessness/management. S6: long-term care, lacks specificity.	Suggest adding basic health guidance, breathing exercises, relaxation techniques.
Support	Empathy and practical help	S1, S3, S6: direct assistance, translation, medical check suggestions. S2 (window) and S5 (water) less effective.	Include trigger data (allergens, prevalence) to correct misconceptions.
Inference	Identify triggers and causes	S1, S3, S5: accurate identification of asthma or triggers. S2/S4: focus on cold air/temperature. S6: chronic condition, underdeveloped.	Multilingual support can improve accessibility and inference accuracy.
Advanced Clarification	Explore long-term management and triggers	S1, S3, S5, S6: detailed insights. S2/S4: less comprehensive. S4: suggested emergency protocols.	Incorporate emergency response guidance to enhance practical knowledge.
Tactics / Strategy	Propose relevant interventions	S1–S6: varied approaches; S5 proposed allergen charts, S6 suggested health app links.	Strategies sometimes irrelevant; integrating allergen charts, health apps can improve relevance.
Tool Feedback / Engagement	Evaluate tool and participation	S1, S5: high engagement. S4: activity boring. S6: struggles with complexity.	Use interactive elements, health apps, multilingual resources to increase participation.

Table 25 Students' reflection on scenario 3 for PSS

Phase	Indicator / Focus	Student Performance / Summary	Notes / Gaps / Recommendations
Identify	Recognize asthma triggers/symptoms	S1, S3, S5: accurately identified triggers (dust, pollen, cold, breathlessness). S2, S4 limited; S6 struggled.	Use interactive allergen quizzes to reinforce identification.
Plan	Propose strategies	Practical options: inhalers, masks, scarves, closing windows. S2/S6: less effective strategies.	Peer mentoring can improve planning and reasoning.
Implement	Apply strategies in practice	S1, S5: detailed implementation (using inhaler). S2, S4, S6: simpler actions.	Hands-on simulations/role-playing can enhance practical application.
Evaluate	Assess effectiveness of strategies	S1, S5 recognized effective interventions. S2, S4, S6 prioritized ease over efficacy.	Real-world tasks like asthma action plans can deepen evaluation.
Tools / Engagement	Use and improve learning tools	Feedback: S1, S5 engaged; S4 bored; S6 struggled. Suggestions: interactive lung models, case studies.	Incorporate multimedia, simulations, and case studies for engagement and understanding.
DBR Alignment	Reflect on iterative learning	Students adapted strategies and reflected on effectiveness; S1, S5 showed strongest CTS.	Guided reflection prompts and collaborative activities could strengthen DBR application.

Students showed strong CTS in identifying asthma symptoms and triggers, offering empathy and practical support (Table 26). Clarification and support were generally effective, but inference and advanced clarification were partial, lacking depth on triggers and long-term management. In PSS, identification, planning, and implementation were mostly effective, while evaluation was limited (Table 27). Engagement could improve with interactive tools, simulations, and personalized management plans to strengthen reasoning and strategy effectiveness.

Table 26 Observation Checklist for Scenario 3 for CTS

Category	Indicator / Focus	Group Performance / Summary	Notes / Recommendations
Clarification	Understand asthma symptoms/triggers	Accurately identified symptoms triggered by allergens/cold; earned	Real-time symptom tracking could deepen recognition and categorization of triggers

Category	Indicator / Focus	Group Performance / Summary	Notes / Recommendations
		"Yes"	
Support	Empathy and practical help	Showed empathy and offered assistance even when refused; earned "Yes"	Peer-led workshops could expand collaborative support strategies
Inference	Identify condition and causes	Correctly inferred asthma based on symptoms; earned "Yes"	Interactive scenario builders could strengthen inference by testing "what-if" scenarios
Advanced Clarification	Explore triggers and management in depth	Partial: lacked detailed explanation of triggers or management strategies	Personalized action plan templates could enhance analysis and tailored management
Tactics / Strategy	Engage effectively with scenario	Proactive questioning and engagement; earned "Yes"	Community resource connections (clinics, support groups) could increase real-world relevance
Tool Feedback / Engagement	Use of learning tools and multimedia	High engagement with visual aids, multimedia, and role-play	Integrate apps, gamified quizzes, and interactive simulations for deeper engagement

Table 27 Observation checklist for scenario 3 for PSS

Phase	Indicator / Focus	Group Performance / Summary	Notes / Recommendations
Identify	Recognize asthma and key symptoms	G1 and G5 accurately identified asthma and breathlessness; others less precise	Real-time scenario simulations could improve symptom differentiation
Plan	Propose feasible strategies	Groups suggested inhaler use, scarves; G6 less independent	Peer-led reflection sessions could foster creativity and broader participation
Implement	Apply strategies in context	G5 detailed inhaler application; others less specific	Interactive trigger mapping can clarify actions and improve practical application
Evaluate	Assess effectiveness of strategies	Noted speed of inhaler action but limited analysis of effectiveness	Personalized asthma management plans could prompt critical evaluation of strategies
Tools / Engagement	Use and improve learning tools	Groups engaged with T-chart and multimedia	Gamified symptom quizzes and community health connections

Phase	Indicator / Focus	Group Performance / Summary	Notes / Recommendations
			could enhance understanding and relevance

4.2.4. DBR data analysis on scenario 3 for CTS and PSS

Most students showed a basic understanding of why alcohol increases urination, while S3 and S5 demonstrated the strongest CTS (Table 28) and PSS (Table 29) across the clarification, inference, planning, and evaluation phases. S1 and S2 offered simpler explanations, while S4 and S6 showed confusion and low engagement. Students were generally good at suggesting practical strategies like hydration, but deeper reasoning and advanced questioning were limited for the lower-performing group. Problem identification and implementation were strong across all students, but planning and evaluation were shallow for S2 and S6. Several students struggled with terminology and preferred more interactive or simplified tools. Overall, the data shows that while higher-achieving students benefit from reflective tasks, others need structured scaffolds—such as interactive worksheets and guided prompts—to strengthen understanding and engagement.

Table 28 Students' reflection on scenario 4 for CTS

Category	Indicator / Focus	Student Performance / Summary	Notes / Gaps / Recommendations
Clarification	Understanding alcohol's effect on urination	Most students (S1–S5) understood alcohol causes frequent urination via hormone inhibition; S1–S2 used simpler terms, S6 slightly confused	S1–S2 need clearer terminology; S6 needs guided clarification; use interactive worksheets to scaffold physiological concepts
Support	Suggesting practical solutions	All students suggested hydration; S5–S6 added advanced solutions like medical consultation; S1–S4 focused on immediate remedies	Encourage deeper medical insight for S1–S4; reinforce practical and advanced support strategies
Inference	Connecting causes and effects	S3 & S5 made strong connections between alcohol's diuretic effect and dehydration; S1–S2 made	Structured tools or guided prompts can clarify physiological processes and strengthen reasoning for S1–

Category	Indicator / Focus	Student Performance / Summary	Notes / Gaps / Recommendations
		basic comparisons; S4–S6 reasoning was vague	S2 and S4–S6
Advanced Clarification	Asking deeper questions	S3–S5 asked insightful questions about hormones, lifestyle, or family history; S1–S2 and S6 asked simpler or vague questions	Guided inquiry frameworks recommended for S1–S2 & S6 to improve specificity and engagement
Tactics / Strategy	Practical PSS measures	All students suggested hydration and limiting alcohol; S5 added avoiding salty foods; S3–S6 included diet or exercise (less relevant)	Strategies generally strong; refine irrelevant suggestions and clarify physiologically meaningful actions
Tool Feedback	Reflection on learning tools	S1–S3 & S5 found tools relatable but wanted more interactivity; S2 was confused and preferred collaboration; S4 bored, preferred creative tasks; S6 struggled with terminology	Introduce interactive, question-driven or case-based tools to enhance engagement and accessibility
DBR Insights / Iterative Reflection	Reflection and learning improvements	S1–S3 & S5–S6 showed strong reflective capacity; S4–S6 had lower engagement	Interactive worksheets and structured prompts can scaffold reflection, especially for S2, S4, S6

Table 29 Students' reflection on scenario 4 for PSS

Category	Indicator / Focus	Student Performance / Summary	Notes / Gaps / Recommendations
Identify	Recognize problem (beer → urination)	All students identified the problem; S1, S3, S5 (With Dialogue) noted hormone effects and kidney risk; S2 & S6 gave basic observations	S2 & S6 need structured guidance to deepen understanding of physiological effects
Plan	Propose solutions	S1, S3, S5 included advanced strategies (hydration, exercise, limit salt); S2 & S6 proposed basic solutions (water, food, stay near bathroom)	Encourage collaborative and advanced planning for S2 & S6 to improve strategy sophistication
Implement	Apply proposed solutions	Most students applied their plans effectively; S6's strategies were less proactive	Use engaging activities to increase proactivity, especially for S6
Evaluate	Assess effectiveness	S1, S3, S5 evaluated strategies effectively, linking to outcomes; S2	Provide structured reflection tools to guide deeper analysis

Category	**Indicator / Focus**	**Student Performance / Summary**	**Notes / Gaps / Recommendations**
		& S6 gave shallow evaluations	for S2 & S6
Tool Feedback	Usefulness of learning tools	S1 & S5 found tools engaging and interactive; S3 liked structure but wanted dynamic formats; S2 confused, preferred collaboration; S6 bored, struggled with terminology	Introduce case-based, interactive prompts with simplified terminology to scaffold understanding
DBR Insights	Iterative learning & reflection	S1, S3, S5 connected solutions to physiological and practical outcomes; S2 & S6 struggled with engagement and terms	Use structured, dialogue-like prompts to scaffold reflective PSS for S2 & S6
Category	Phase / Indicator	Observed Performance (S1–S6)	Notes / Gaps / Recommendations
Identify	Recognizing the problem	Dialogue versions resulted in clearer identification ("urination," "hormone effect"); no-dialogue versions gave vague labels ("beer"). All students recognized the core issue.	Guide students toward identifying causes, not just symptoms; use "What is happening?" prompts.
Plan	Proposing solutions	Plans from both contexts were similar (drink water, eat food, reduce alcohol). Some unclear choices (injera) appeared. S1, S3, S5 gave stronger plans.	Scaffold planning with step-by-step prompts ("Which action directly reduces dehydration?").
Implement	Carrying out the chosen strategy	Dialogue responses were more precise ("drink water between beers"); no-dialogue responses were general ("drink water").	Provide practice with specific, actionable implementation steps.
Evaluate	Judging the effectiveness of the strategy	Evaluations were shallow across students ("best," "cheap," "easy"). S1–S2 & S6 showed the weakest reasoning.	Introduce evaluation checklists ("What worked?" "Why?" "What could improve?").
Tool Feedback	Reflection on usefulness of tools	Students found dialogue engaging; S4–S6 struggled with terminology or attention.	Include simplified terms, visuals, and interactive prompts to support lower-performing students.
DBR Insights	Iterative reflection on learning	S3 & S5 connected strategies to physiology; S2 & S6 struggled to reflect meaningfully.	Add structured DBR-style reflective worksheets to strengthen analysis for S1–S2 & S6.

Students generally showed a basic understanding of how alcohol increases urination, with S3 and S5 demonstrating the strongest reasoning across clarification, inference, and planning phases (Table 30). Most students could suggest practical strategies like hydration, but deeper explanations and advanced questioning were limited, especially for S1–S2 and S6, who often used simple or vague reasoning. Dialogue-based tasks improved accuracy in identifying problems and implementing solutions, but planning and evaluation remained weak across several students (Table 31). Many struggled with scientific terms such as "hormone," and lower-engagement students (S4–S6) showed confusion or boredom. Overall, the data indicates solid foundational skills but clear gaps in deeper reasoning, evaluation, and scientific understanding—gaps that can be addressed through interactive, question-driven worksheets and structured prompts aligned with DBR principles.

Table 30 Observation checklist for scenario 4 for CTS

Category	Phase / Indicator	Observed Performance (S1–S6)	Notes / Gaps / Recommendations
Clarification	Understanding alcohol's effect on urination	Most students (S1–S5) connected alcohol to frequent urination and dehydration; S5 identified hormone inhibition; S1–S2 used simple terms; S6 confused or partially disengaged.	Simplify physiological terms; add visuals; include interactive explanation worksheets.
Inference	Connecting causes & effects	S3 & S5 formed strong links to dehydration and kidney function; S1–S2 used basic reasoning; S4–S6 vague or incomplete.	Use guided inference prompts ("Why does alcohol cause dehydration?") to deepen reasoning.
Advanced Clarification	Asking deeper questions	S3–S5 asked meaningful questions (hormone, lifestyle, family history); S1–S2 asked simple questions; S6 lacked specificity.	Introduce inquiry-based questioning tasks to help S1–S2 & S6 ask deeper questions.
Support / Empathy	Providing emotional/practical support	All students suggested hydration and limiting alcohol; strong empathy shown.	Strength area; can be expanded through scenario extensions.
Tactics / Strategy	Suggesting practical strategies	All students proposed hydration; S5 offered advanced strategies (avoid salt); some suggestions	Clarify which strategies directly affect the excretory system.

Category	Phase / Indicator	Observed Performance (S1–S6)	Notes / Gaps / Recommendations
		(exercise, injera) were less relevant.	
Tool Feedback	Reflection on learning tools	Dialogue increased engagement; several students (S2, S4, S6) struggled with terms like "hormone" or found tasks boring.	Add glossary, simplified explanations, interactive worksheets, creative options.
DBR Insights	Reflection for iterative improvement	Strong reflection from S3 & S5; moderate from S1–S2; low engagement from S4 & S6.	Use structured reflection prompts aligned with DBR (e.g., "What confused you and why?").

Table 31 Observation checklist for scenario 4 for PSS

Category	Phase / Indicator	Observed Performance (S1–S6)	Notes / Gaps / Recommendations
Identify	Recognizing the problem	Dialogue versions resulted in clearer identification ("urination," "hormone effect"); no-dialogue versions gave vague labels ("beer"). All students recognized the core issue.	Guide students toward identifying causes, not just symptoms; use "What is happening?" prompts.
Plan	Proposing solutions	Plans from both contexts were similar (drink water, eat food, reduce alcohol). Some unclear choices (injera) appeared. S1, S3, S5 gave stronger plans.	Scaffold planning with step-by-step prompts ("Which action directly reduces dehydration?").
Implement	Carrying out the chosen strategy	Dialogue responses were more precise ("drink water between beers"); no-dialogue responses were general ("drink water").	Provide practice with specific, actionable implementation steps.
Evaluate	Judging the effectiveness of the strategy	Evaluations were shallow across students ("best," "cheap," "easy"). S1–S2 & S6 showed the weakest reasoning.	Introduce evaluation checklists ("What worked?" "Why?" "What could improve?").
Tool Feedback	Reflection on usefulness of tools	Students found dialogue engaging; S4–S6 struggled with terminology or attention.	Include simplified terms, visuals, and interactive prompts to support lower-performing students.
DBR Insights	Iterative reflection on learning	S3 & S5 connected strategies to physiology; S2 & S6 struggled to reflect meaningfully.	Add structured DBR-style reflective worksheets to strengthen analysis for S1–S2

Category	Phase / Indicator	Observed Performance (S1–S6)	Notes / Gaps / Recommendations
			& S6.

4.2.5. DBR data analysis on scenario 3 for CTS and PSS

Students showed strong observation skills and empathy in Scenario 5, with all correctly identifying symptoms and recommending clinic visits, rest, and hydration. S3 and S5 consistently demonstrated the strongest PSS and CTS, offering detailed explanations, deeper inferences, and medically relevant questions (Table 32-33). In contrast, S1, S2, S4, and S6 relied on simpler reasoning and showed difficulty with scientific terms. While most students planned and implemented appropriate actions, evaluation skills were generally shallow, especially for S6. Overall, students have solid basics but need clearer language, guided inquiry, and interactive case-based simulations to deepen scientific reasoning and improve engagement.

Table 32 Students' reflection on scenario 5 for CTS

Category	Indicator / Focus	Student Performance / Summary (S1–S6)	Notes / Gaps / Recommendations
Clarification	Identifying symptoms (fatigue, appetite loss, weight loss, neck lump)	All students correctly identified symptoms; S3 & S5 gave the most precise descriptions.	Strong observation skills; reinforce detailed description using guided prompts.
Support	Empathy & basic suggestions	All students suggested rest, hydration, and medical care; responses were caring but basic.	Encourage deeper supportive reasoning; add scenarios showing severity of symptoms.
Inference	Connecting symptoms to possible causes	S3 & S5 linked symptoms to infections or thyroid issues; others gave simpler ideas (stress, injury).	Add structured tools for scientific reasoning; include cause–effect charts.
Advanced Clarification	Asking deeper questions	S3 & S5 asked targeted, medically relevant questions; others asked simple or unrelated questions.	Introduce guided inquiry worksheets to improve questioning skills.
Tactics / Strategy	Practical strategies	All recommended rest, hydration, and clinic visits; S3 & S5 added nutrient-rich food & activity limitation.	Strengthen planning relevance; clarify which strategies support medical conditions.
Tool	Reflections on	Many struggled with terms	Use simplified vocabulary,

Category	Indicator / Focus	Student Performance / Summary (S1–S6)	Notes / Gaps / Recommendations
Feedback	learning tools	like “lymph node”; S1, S4, S6 requested simpler language; S3 & S5 wanted interactive formats.	visuals, and interactive case-based simulations.
Insights for DBR	Reflection for improvement	S3 & S5 showed deeper understanding; others struggled with medical terminology and depth.	Include step-by-step reflection prompts and case simulations for S1, S2, S4, S6.

Table 33 Students’ reflection on scenario 5 for PSS

Category	Phase / Indicator	Student Performance / Summary (S1–S6)	Notes / Gaps / Recommendations
Identify	Recognizing the health problem	All students identified tiredness and neck lump; S3 & S5 added weight loss and seriousness.	Strong recognition; improve depth through symptom-mapping tools.
Plan	Developing a response	All proposed rest, food, hydration, clinic visit; S3 & S5 gave more refined dietary and medical plans.	Provide scaffolds to improve plan specificity for S2 & S6.
Implement	Acting on the plan	Most implemented clinic visits; S6 (one entry) only rested, missing key step.	Reinforce importance of appropriate medical actions using case simulations.
Evaluate	Judging strategy effectiveness	All judged clinic visits effective; S3 & S5 gave stronger reasoning; S6 remained vague.	Add evaluation checklists to strengthen justification skills.
Tool Feedback	Reflections on tool use	S1 & S5 engaged but wanted clarity; S3 requested more dynamic tools; S2 & S6 confused by terms.	Simplify medical terminology; use interactive simulations and visuals.
Insights for DBR	Reflection for refinement	S1, S3, S5 showed stronger insights; S2 & S6 had basic or limited reflection.	Guided reflection sheets needed, especially for S2 & S6.

Students showed strong observation and empathy, correctly identifying symptoms and suggesting rest, hydration, and clinic visits. S3 and S5 demonstrated higher PSS and CTS (Table 34-35), linking symptoms to medical causes, asking targeted questions, and proposing detailed strategies, while S1, S2, S4, and S6 gave simpler or vague responses and struggled with terminology. Implementation was mostly effective, but planning and evaluation lacked depth for lower-performing students. Overall, interactive case-based simulations and guided reflection tools are needed to deepen understanding, engagement, and scientific reasoning, aligning with DBR principles.

Table 34 Observation checklist for scenario 5 for CTS

Category	Indicator / Focus	Observed Student Performance (S1–S6)	Notes / Gaps / Recommendations
Clarification	Identifying key symptoms (fatigue, appetite loss, weight loss, neck lump)	All students identified symptoms; S3 & S5 gave detailed descriptions; others used simple terms like "lump."	Strength in observation; guide students to use precise medical terms.
Support	Empathy & initial response	All students showed empathy—suggested rest, hydration, and clinic visit.	Good foundation; enhance depth through scenario variations.
Inference	Connecting symptoms to possible causes	S3 & S5 linked to infections/thyroid issues; others gave vague ideas (stress, injury).	Use guided cause–effect tools to develop scientific reasoning.
Advanced Clarification	Asking deeper, relevant questions	S3 & S5 asked targeted medical questions; S1, S2, S4, S6 asked simple or unrelated ones.	Introduce question-prompt cards to support inquiry.
Tactics / Strategy	Planning appropriate actions	All students gave practical actions; S3 & S5 added nutrient-rich foods and limiting activity.	Reinforce relevance of strategies; avoid generic or culturally unrelated solutions.
Tool Feedback	Engagement with learning tools	Students struggled with terms like "lymph node"; S4 & S6 reported boredom; S3 & S5 requested more interactive tools.	Use simplified language, visuals, and interactive case-based simulations.
Insights for DBR	Reflection for iterative improvement	S3 & S5 showed strong reflective insights; others struggled with depth.	Add structured reflection templates for S1, S2, S4, S6.

Table 35 Observation checklist for scenario 5 for PSS

Category	Phase / Indicator	Observed Student Performance (S1–S6)	Notes / Gaps / Recommendations
Identify	Recognizing the problem	All recognized fatigue + neck lump; S3 & S5 added weight loss & severity; S2 & S6 gave simple recognition.	Dialogue helped deepen identification; strengthen detail through symptom-mapping.

Category	Phase / Indicator	Observed Student Performance (S1–S6)	Notes / Gaps / Recommendations
Plan	Creating a response plan	All planned rest, hydration, clinic visit; S3 & S5 added dietary strategies; others gave basic ideas (milk, injera).	Guide students to prioritize medically relevant strategies.
Implement	Acting on the plan	Most visited a clinic; S6 (one entry) relied only on rest.	Reinforce importance of medical intervention using simulations.
Evaluate	Judging strategy effectiveness	All evaluated "clinic visit" as effective; S3 & S5 gave reasoned evaluations; S6 weak and vague.	Add evaluation checklists to strengthen reasoning.
Tool Feedback	Reflections on tool use	S1 & S5 engaged but wanted clarity; S3 asked for dynamic tools; S2 & S6 confused by medical terms; S4 & S6 noted boredom.	Provide simpler language, visuals, and interactive simulation-based tasks.
Insights for DBR	Reflection for improvement	S3 & S5 showed strong connections between symptoms and strategies; S1, S2, S4, S6 showed shallow reflection.	Introduce step-by-step reflection guides and scenario-based questioning.

4.2.6. Phase 4 reflecting on instructional tool, for CTS and PSS: 1st, 2nd and 3rd cycles

Students demonstrated strong observation and empathy, accurately identifying symptoms and recommending rest, hydration, and clinic visits. S3 and S5 showed higher CTS and PSS (Table 36-37), linking symptoms to medical causes, asking targeted questions, and proposing detailed strategies, while S1, S2, S4, and S6 gave simpler or vague responses and struggled with terminology. Planning and evaluation were generally basic for lower-performing students, and some showed disengagement. Overall, interactive case-based simulations and guided reflection tools are recommended to improve scientific reasoning, engagement, and depth of understanding.

Table 36 reflecting on instructional tool for CTS

Category	Phase / Indicator	Observed Performance (S1–S6)	Notes / Gaps / Recommendations
Clarification	Identifying symptoms	All identified fatigue, neck lump, appetite/weight loss; S3 & S5 gave precise descriptions; others used simple terms.	Reinforce precise medical terminology and observation skills.

Category	Phase / Indicator	Observed Performance (S1–S6)	Notes / Gaps / Recommendations
Support	Empathy & response	All suggested rest, hydration, clinic visit; responses were basic.	Encourage deeper reasoning about severity and appropriate care.
Inference	Linking symptoms to causes	S3 & S5 linked to infections or thyroid issues; others offered vague causes (stress, minor injury).	Provide guided tools to develop scientific reasoning.
Advanced Clarification	Asking deeper questions	S3 & S5 asked medically relevant questions; others asked simple or unrelated questions.	Introduce structured inquiry prompts to enhance questioning skills.
Tactics / Strategy	Planning practical actions	All proposed rest, hydration, clinic visit; S3 & S5 added dietary guidance and activity limits.	Strengthen relevance of strategies for medical outcomes.
Tool Feedback	Engagement with learning tools	S1, S4, S6 struggled with terms like "lymph node" and reported boredom; S3 & S5 preferred interactive tools.	Use simplified language, visuals, and case-based simulations.
Insights for DBR	Reflection & improvement	S3 & S5 showed strong reflective skills; others had shallow reflection.	Provide structured reflection guides to enhance participation and CTS.

Table 37 reflecting on instructional tool for PSS

Category	Phase / Indicator	Observed Performance (S1–S6)	Notes / Gaps / Recommendations
Identify	Recognizing the problem	All identified fatigue & neck lump; S3 & S5 added weight loss and severity; S2 & S6 gave simple recognition.	Enhance depth via symptom-mapping activities.
Plan	Developing a response plan	All suggested rest, hydration, clinic visit; S3 & S5 included dietary strategies; others gave simpler plans.	Scaffold planning to improve specificity for S1, S2, S4, S6.
Implement	Acting on the plan	Most visited clinics; S6 partially implemented by resting only.	Reinforce importance of full implementation using scenario-based tasks.
Evaluate	Judging effectiveness	All evaluated actions as effective; S3 & S5 gave reasoned explanations; S6 remained vague.	Introduce evaluation checklists to deepen reasoning.
Tool	Reflection on	S1 & S5 engaged; S3 wanted	Use simplified terms, visuals,

Category	Phase / Indicator	Observed Performance (S1–S6)	Notes / Gaps / Recommendations
Feedback	tools	dynamic tools; S2 & S6 confused by terminology; S4 & S6 reported boredom.	and interactive simulations.
Insights for DBR	Iterative reflection	S3 & S5 showed strong connections between symptoms and strategies; others had limited reflection.	Structured reflection worksheets recommended for S1, S2, S4, S6.

4.3. Posttest scores analysis

The Table 38 provides a more granular breakdown, showing mean scores and standard deviations for each variable by gender (36 males, 85 females) and across three conditions: Intervention 1, Intervention 2, and Control. For PSS, males in Intervention 1 scored 57.60 (SD = 16.45), Intervention 2 scored 62.33 (SD = 20.1), and Control scored 52.59 (SD = 11.29), while females scored 55.72 (SD = 14.50), 77.55 (SD = 12.15), and 54.84 (SD = 9.36), respectively. For CTS, males scored 64.50 (SD = 7.26) in Intervention 1, 70.00 (SD = 13.26) in Intervention 2, and 54.71 (SD = 7.37) in Control, while females scored 69.79 (SD = 8.8), 73.87 (SD = 8.82), and 50.84 (SD = 5.51), respectively. For AA, males scored 31.00 (SD = 5.48) in Intervention 1, 21.89 (SD = 6.35) in Intervention 2, and 26.82 (SD = 6.05) in Control, while females scored 26.31 (SD = 7.13), 20.26 (SD = 4.35), and 30.64 (SD = 5.22), respectively.

The table reveals that both intervention conditions generally produced higher mean scores than the control for PSS and CTS, with females in Intervention 2 achieving the highest PSS score (77.55) and CTS score (73.87). However, for AA, the pattern is less consistent, with females in the Control group (30.64) outperforming those in Intervention 2 (20.26), and males in Intervention 1 (31.00) scoring higher than those in Intervention 2 (21.89). Overall, the table confirm the intervention’s effectiveness in improving PSS and CTS scores, with nuanced gender differences, particularly in AA, warranting further exploration.

Table 38 mean score of posttest results

Variable	N	Gender	Intervention 1		Intervention 2		Control	
			M	SD	M	SD	M	SD
PSS	36	Male	57.60	16.45	62.33	20.1	52.59	11.29
	85	Female	55.72	14.50	77.55	12.15	54.84	9.36
CTS	36	Male	64.50	7.26	70.00	13.26	54.71	7.37
	85	Female	69.79	8.8	73.87	8.82	50.84	5.51
AA	36	Male	31.00	5.48	21.89	6.35	26.82	6.05
	85	Female	26.31	7.13	20.26	4.35	30.64	5.22

The MANOVA results in Table 39 indicate that the independent variable Group has a highly significant and substantial effect on the dependent variables, with a Wilks' Lambda of .437, an F-value of 32.259, a p-value of .000, and a large effect size ($\eta^2 = .563$), suggesting that Group explains 56.3% of the variance in the outcomes. In contrast, Gender alone does not significantly influence the dependent variables, showing a Wilks' Lambda of .938, an F-value of 1.643, a non-significant p-value of .187, and a small effect size ($\eta^2 = .062$), indicating minimal practical impact. The interaction between Gender and Group is statistically significant (Wilks' Lambda = .899, F = 2.806, p = .045, $\eta^2 = .101$), implying that the effect of Group on the dependent variables varies by Gender, though the moderate effect size suggests a less pronounced impact compared to Group alone. These findings, based on 3 degrees of freedom and 75 error degrees of freedom, highlight Group as the primary driver of differences, with the interaction warranting further exploration to understand how group effects differ across genders.

Table 39 ANOVA results of posttest score

Independent variable	Wilks' Lambda	F	DF	Error DF	Sig.	η2
Gender	.938	1.643	3.000	75.000	.187	.062
Group	.437	32.259	3.000	75.000	.000	.563
Gender * Group	.899	2.806	3.000	75.000	.045	.101

The MANOVA results in Table 40 reveal that the Intercept has an extremely strong and significant effect on the dependent variables (Wilks’ Lambda = .014, F = 2699.673, p = .000 and $\eta^2 = .986$) indicating that 98.6% of the variance in the dependent variables is explained by the model’s intercept. This suggests a robust baseline effect across the dependent variables. For Gender, the results are non-significant across the test statistics (Wilks’ Lambda = .965, F =

1.368, p = .256 and η^2 = .035), indicating that Gender alone explains only 3.5% of the variance and does not significantly influence the dependent variables. In contrast, Intervention shows a highly significant effect, with (Wilks' Lambda = .410, F = 21.157, p = .000 and η^2 = .360).

The effect sizes suggest that Intervention explains 33.7% to 50.9% of the variance, indicating a substantial impact on the dependent variables. The Gender * Intervention interaction is also significant across the test statistics Wilks' Lambda = .824, with F-values ranging from 3.832 to 5.669, p-values of .001, and effect sizes ranging from .092 to .130, suggesting that the effect of Intervention varies by Gender, though the interaction explains a smaller portion (9.2% to 13.0%) of the variance compared to Intervention alone. Overall, Intervention is the primary driver of differences in the dependent variables, with a moderate interaction effect indicating that Gender modulates Intervention's impact to some extent, while Gender alone has minimal influence.

Table 40 MANOVA results of posttest score

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Intercept	Pillai's Trace	.986	2699.673	3.000	113.000	.000	.986
	Wilks' Lambda	.014	2699.673	3.000	113.000	.000	.986
	Hotelling's Trace	71.673	2699.673	3.000	113.000	.000	.986
	Roy's Largest Root	71.673	2699.673	3.000	113.000	.000	.986
Gender	Pillai's Trace	.035	1.368	3.000	113.000	.256	.035
	Wilks' Lambda	.965	1.368	3.000	113.000	.256	.035
	Hotelling's Trace	.036	1.368	3.000	113.000	.256	.035
	Roy's Largest Root	.036	1.368	3.000	113.000	.256	.035
Intervention	Pillai's Trace	.674	19.316	6.000	228.000	.000	.337
	Wilks' Lambda	.410	21.157	6.000	226.000	.000	.360
	Hotelling's Trace	1.234	23.034	6.000	224.000	.000	.382
	Roy's Largest Root	1.036	39.375	3.000	114.000	.000	.509
Gender * Intervention	Pillai's Trace	.183	3.832	6.000	228.000	.001	.092
	Wilks' Lambda	.824	3.835	6.000	226.000	.001	.092
	Hotelling's Trace	.206	3.837	6.000	224.000	.001	.093
	Roy's Largest Root	.149	5.669	3.000	114.000	.001	.130

Tests of between-subjects effects result Table 41 confirmed that the ANOVA results indicate that Gender has no significant main effect on any of the dependent variables. For PSS posttest, Gender yields a Type III Sum of Squares of 178.912, an F-value of 2.085, a p-value of .153, and a small effect size ($\eta^2 = .026$), suggesting it explains only 2.6% of the variance and is not statistically significant. Similarly, for CTS posttest, Gender shows a Sum of Squares of 281.020, an F-value of .889, a p-value of .349, and an η^2 of .011, indicating a negligible 1.1% variance explained. For AA posttest, Gender has a Sum of Squares of 81.538, an F-value of 1.517, a p-value of .222, and an η^2 of .019, accounting for 1.9% of the variance, also non-significant. In contrast, Group has a highly significant main effect across all dependent variables. For PSS posttest, Group produces a Sum of Squares of 1526.329, an F-value of 17.790, a p-value of .000, and an η^2 of .188, indicating a moderate effect explaining 18.8% of the variance. For CTS posttest, Group shows a Sum of Squares of 4709.032, an F-value of 14.894, a p-value of .000, and an η^2 of .162, explaining 16.2% of the variance. For AA posttest, Group has a Sum of Squares of 2559.053, an F-value of 47.617, a p-value of .000, and a large η^2 of .382, explaining 38.2% of the variance, demonstrating a particularly strong effect.

The Gender * Group interaction is significant only for AA posttest, with a Sum of Squares of 229.919, an F-value of 4.278, a p-value of .042, and an η^2 of .053, indicating a small effect explaining 5.3% of the variance. For PSS posttest, the interaction is non-significant (Sum of Squares = 144.242, $F = 1.681$, $p = .199$, $\eta^2 = .021$), as is the case for CTS posttest (Sum of Squares = 338.345, $F = 1.070$, $p = .304$, $\eta^2 = .014$). Overall, Group is the primary driver of differences across all three dependent variables, with the largest effect on AA posttest, while Gender alone has minimal impact, and the interaction effect is modest and only significant for AA posttest, suggesting that Group's effect on AA posttest varies slightly by Gender. These findings assume ANOVA assumptions (e.g., normality, homogeneity of variances) are met, and further post-hoc tests could clarify specific group differences.

Table 41 Results of tests of between-subjects effects in gender * group

Independent variable	Dependent Variable	Type III Sum of Squares	Df	F	Sig.	η2
Gender	PSS posttest	178.912	1	2.085	.153	.026
	CTS posttest	281.020	1	.889	.349	.011
	AA posttest	81.538	1	1.517	.222	.019
Group	PSS posttest	1526.329	1	17.790	.000	.188
	CTS posttest	4709.032	1	14.894	.000	.162

	AA posttest	2559.053	1	47.617	.000	.382
Gender * Group	PSS posttest	144.242	1	1.681	.199	.021
	CTS posttest	338.345	1	1.070	.304	.014
	AA posttest	229.919	1	4.278	.042	.053

The ANOVA results in Table 42 demonstrate that the Corrected Model, which includes all effects, significantly explains variance across all dependent variables, with CTS showing a Type III Sum of Squares of 10100.880 ($F = 29.114$, $p = .000$, $\eta^2 = .559$), PSS with 11565.759 ($F = 13.216$, $p = .000$, $\eta^2 = .365$), and ACT with 1971.151 ($F = 11.846$, $p = .000$, $\eta^2 = .340$), indicating large effect sizes and substantial model fit. The Intercept has an extremely strong effect, explaining 94.5% to 98.0% of the variance across the dependent variables CTS: $F = 5633.182$, $p = .000$, $\eta^2 = .980$; PSS: $F = 1972.775$, $p = .000$, $\eta^2 = .945$; ACT: $F = 1964.281$, $p = .000$, $\eta^2 = .945$), reflecting a robust baseline effect. Gender alone does not significantly affect any dependent variable, with non-significant results for CTS (Sum of Squares = 74.523, $F = 1.074$, $p = .302$, $\eta^2 = .009$), PSS (Sum of Squares = 645.325, $F = 3.687$, $p = .057$, $\eta^2 = .031$), and ACT (Sum of Squares = 16.646, $F = .500$, $p = .481$, $\eta^2 = .004$), with small effect sizes indicating minimal influence (0.4% to 3.1% of variance). Intervention, however, has a highly significant effect across all dependent variables, with CTS showing a Sum of Squares of 6955.140 ($F = 50.118$, $p = .000$, $\eta^2 = .466$), PSS with 4628.375 ($F = 13.222$, $p = .000$, $\eta^2 = .187$), and ACT with 1161.237 ($F = 17.446$, $p = .000$, $\eta^2 = .233$), indicating moderate to large effects, particularly for CTS (46.6% of variance).

The Gender * Intervention interaction is significant for all dependent variables, though with smaller effect sizes: CTS (Sum of Squares = 433.828, $F = 3.126$, $p = .048$, $\eta^2 = .052$), PSS (Sum of Squares = 1153.391, $F = 3.295$, $p = .041$, $\eta^2 = .054$), and ACT (Sum of Squares = 327.104, $F = 4.914$, $p = .009$, $\eta^2 = .079$), suggesting that Intervention's effect varies slightly by Gender, explaining 5.2% to 7.9% of the variance. The error terms and total sums of squares indicate a sample size of 121 participants with 115 error degrees of freedom. Overall, Intervention is the primary driver of differences across all dependent variables, with the largest impact on CTS, while Gender has negligible effects, and the interaction, though significant, has modest practical importance. These findings assume ANOVA assumptions (e.g., normality, homogeneity of variances) are met, and post-hoc analyses could further clarify specific group differences.

Table 42 results of tests of between-subjects effects in gender * intervention

Source	Dependent Variable	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected	CTS	10100.880	5	2020.176	29.114	.000	.559
Model	PSS	11565.759	5	2313.152	13.216	.000	.365
	AA	1971.151	5	394.230	11.846	.000	.340
Intercept	CTS	390875.814	1	390875.814	5633.182	.000	.980
	PSS	345275.873	1	345275.873	1972.775	.000	.945
	AA	65372.313	1	65372.313	1964.281	.000	.945
Gender	CTS	74.523	1	74.523	1.074	.302	.009
	PSS	645.325	1	645.325	3.687	.057	.031
	AA	16.646	1	16.646	.500	.481	.004
Intervention	CTS	6955.140	2	3477.570	50.118	.000	.466
	PSS	4628.375	2	2314.188	13.222	.000	.187
	AA	1161.237	2	580.618	17.446	.000	.233
Gender *	CTS	433.828	2	216.914	3.126	.048	.052
Intervention	PSS	1153.391	2	576.695	3.295	.041	.054
	AA	327.104	2	163.552	4.914	.009	.079
Error	CTS	7979.632	115	69.388			
	PSS	20127.348	115	175.020			
	AA	3827.262	115	33.281			
Total	CTS	519602.000	121				
	PSS	486950.000	121				
	AA	86248.000	121				
Corrected Total	CTS	18080.512	120				
	PSS	31693.107	120				
	AA	5798.413	120				

The post hoc comparisons in Table 43 reveal significant differences between intervention groups for all three dependent variables, particularly between the control group and intervention 2. For CTS, significant differences are observed across all pairwise comparisons. The Control group has a significantly lower mean than Intervention 1 (mean difference = -16.03, SE = 1.852, p = .000, 95% CI: -20.43 to -11.63) and Intervention 2 (mean difference = -20.60, SE = 1.840, p =

.000, 95% CI: -24.96 to -16.23), indicating that both interventions result in higher CTS scores compared to Control, with Intervention 2 showing a larger difference. Additionally, Intervention 2 has a significantly higher mean than Intervention 1 (mean difference = 4.56, SE = 1.875, p = .043, 95% CI: 0.11 to 9.02), suggesting a modest but significant advantage of Intervention 2 over Intervention 1.

For PSS, significant differences are found for most comparisons, except between Control and Intervention 1 (mean difference = -2.28, SE = 2.942, p = .720, 95% CI: -9.26 to 4.71), indicating no significant difference. However, Intervention 2 significantly outperforms Control (mean difference = -20.20, SE = 2.923, p = .000, 95% CI: -27.14 to -13.26) and Intervention 1 (mean difference = -17.92, SE = 2.977, p = .000, 95% CI: -24.99 to -10.85), suggesting that Intervention 2 substantially increases PSS scores compared to both other groups.

For AA, no significant difference is observed between Control and Intervention 1 (mean difference = 1.58, SE = 1.283, p = .436, 95% CI: -1.46 to 4.63). However, Intervention 2 significantly outperforms Control (mean difference = 8.47, SE = 1.275, p = .000, 95% CI: 5.44 to 11.50) and Intervention 1 (mean difference = 6.89, SE = 1.298, p = .000, 95% CI: 3.81 to 9.97), indicating that Intervention 2 leads to higher AA scores. Overall, Intervention 2 consistently shows the strongest effect across all dependent variables, significantly outperforming Control and Intervention 1 in most cases, while Intervention 1 only significantly differs from Control for CTS. These results suggest that Intervention 2 is the most effective, with the largest impact on CTS, followed by PSS and AA, assuming post-hoc test assumptions (e.g., homogeneity of variances) are met. Further analysis could explore the practical significance of these differences.

Table 43 Post Hoc Tests result of posttest

Dependent Variable	(I) Intervention	(J) Intervention	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
CTS	Control	intervention 1	-16.03*	1.852	.000	-20.43	-11.63
		intervention 2	-20.60*	1.840	.000	-24.96	-16.23
	intervention 1	Control	16.03*	1.852	.000	11.63	20.43
		intervention 2	-4.56*	1.875	.043	-9.02	-.11

	intervention 2	Control	20.60*	1.840	.000	16.23	24.96
		intervention 1	4.56*	1.875	.043	.11	9.02
PSS	Control	intervention 1	-2.28	2.942	.720	-9.26	4.71
		intervention 2	-20.20*	2.923	.000	-27.14	-13.26
	intervention 1	Control	2.28	2.942	.720	-4.71	9.26
		intervention 2	-17.92*	2.977	.000	-24.99	-10.85
	intervention 2	Control	20.20*	2.923	.000	13.26	27.14
		intervention 1	17.92*	2.977	.000	10.85	24.99
AA	Control	intervention 1	1.58	1.283	.436	-1.46	4.63
		intervention 2	8.47*	1.275	.000	5.44	11.50
	intervention 1	Control	-1.58	1.283	.436	-4.63	1.46
		intervention 2	6.89*	1.298	.000	3.81	9.97
	intervention 2	Control	-8.47*	1.275	.000	-11.50	-5.44
		intervention 1	-6.89*	1.298	.000	-9.97	-3.81

4.4. Retrospective analysis

4.4.1. Thematic analysis of seven participant responses to interview question

1. Can you describe your overall experience using PBS as a learning tool in your human biology?

Based on Braun and Clarke's thematic analysis (Appendix E), digital PBS engaged students through dynamic features like animations and 3D models (P1), while paper PBS promoted tactile interaction, such as highlighting and note-taking (P1). Both formats supported conceptual understanding and system integration, with digital PBS excelling at visualizing complex processes like antibody actions (P4) and paper PBS facilitating detailed, reflective analysis for circulatory cases (P5). Paper PBS were simple, universally accessible, and encouraged face-to-face collaboration (P3, P7), whereas digital PBS offered versatility but required technical skills and reliable devices, with virtual collaboration sometimes hindered by poor internet (P3, P6). Overall, paper PBS were perceived as less interactive but dependable (P6), while digital PBS were engaging yet occasionally disrupted by technical issues, including platform crashes (P1, P6).

2. In what ways have PBS helped you understand human biology concepts more deeply?

The thematic analysis (Appendix E) showed that PBS helped transform abstract concepts into tangible understanding. Paper-based scenarios enabled detailed explanations, with P1 noting, "Paper-based scenarios helped me understand digestion—how the esophagus and stomach interact," while digital scenarios provided dynamic visuals, such as "lung mechanics dynamically" (P5). Both formats supported system integration, with digital PBS illustrating interactions like gut inflammation in allergy cases (P6) and paper PBS aiding analysis of systemic effects like blood pressure (P4). PBS also fostered CTS: paper scenarios allowed step-by-step PSS, for example vessel resistance in hypertension (P5), while digital scenarios clarified respiratory issues like bronchial constriction despite occasional malfunctions (P2). Format-specific benefits included paper PBS supporting sequential analysis, such as mapping kidney filtration (P3), and digital PBS offering dynamic visualizations like T-cell animations (P4). Challenges included paper's static nature, described as "clear but static" (P6), and technical issues with digital platforms, such as slow performance or confusing interfaces, which disrupted focus (P1, P7).

3. How have PBS influenced your ability to think critically about human biology topics? Can you provide a specific example?

The responses revealed that PBS enhanced CTS across several dimensions aligned with Ennis's framework. Paper-based scenarios supported analytical PSS by enabling elementary clarification, as P1 noted, "paper scenarios clarified acid reflux by listing symptoms and causes," while digital scenarios facilitated inference, for example, identifying hypertension causes through heart strain visuals (P1). PBS also encouraged evaluating multiple perspectives, such as allergens versus exercise in asthma (P2) or diet versus genetics in hypertension (P4), and promoted system interconnectivity, with digital scenarios helping infer gut-immune interactions (P6) and paper scenarios clarifying systemic effects like airflow limitation (P7). Format-specific benefits included paper PBS supporting structured reasoning, such as strategic analysis of vessel resistance (P5), and digital PBS enabling dynamic inferences like lung mechanics in asthma (P5). Challenges included paper's static nature, limiting kidney analysis (P6), and technical issues in digital platforms that disrupted advanced clarification and strategy (P1, P7).

4. Can you share an instance where a problem-based scenario helped you solve a complex problem related to human biology? What made it effective?

The responses indicated that PBS supported complex PSS through structured identification, planning, implementation, and evaluation. Paper-based scenarios helped define problems systematically, as P1 noted, “Paper scenarios helped me identify acid reflux causes like diet,” while digital scenarios clarified triggers, such as asthma, through visuals (P2). PBS facilitated strategic planning, for example, dietary changes for hypertension (P4) or allergen avoidance for asthma (P2), with digital visuals aiding dynamic planning. Effective implementation was supported by paper scenarios, such as outlining hydration schedules for kidney failure (P3), and by digital simulations, despite occasional technical issues. PBS also encouraged solution evaluation, including blood pressure reduction after dietary changes (P5) or airflow improvement (P7). Overall, paper PBS were valued for simplicity and structure (P6), while digital PBS enhanced learning through vivid visualizations, though reliability issues occasionally limited effectiveness (P7).

5. How has the incorporation of IK in the lessons affected your understanding of human biology concepts?

Student responses indicated that incorporating IK enhanced understanding of human biology by making lessons culturally relevant and engaging. Practices like eating gomen for constipation or steaming with garlic helped students connect digestion and respiratory concepts to familiar Ethiopian traditions (P1, P2). Holistic understanding was supported through perspectives such as using selit for immunity or tikur azmude during fasting, highlighting system interconnections and deepening comprehension of digestion, immunity, and blood pressure regulation (P6, P5). Practical applications, including garlic hot drinks for airway clearance or damakassie teas for kidney filtration, provided tangible examples of biological processes (P3, P4), while real-world connections, like applying hot cloths to lymph nodes or consuming telba, reinforced immune responses and nutrient absorption (P7, P1). Challenges arose when unfamiliar practices or limited cultural context caused confusion (P5, P1). Overall, integrating Ethiopian IK fosters engagement, holistic understanding, and practical learning, though sufficient context is needed to maximize effectiveness.

6. In what ways has IK shaped your approach to CTS or PSS in this course? Can you give an example?

Student responses indicated that IK shaped PSS and CTS by clarifying concepts, providing practical applications, and supporting holistic reasoning. For example, gomen helped link fiber to peristalsis, allowing students to explore enzyme interactions (P1), while garlic steaming (P2) and hot cloth application (P5) guided identification, planning, and evaluation of solutions, such as reducing airway inflammation. Holistic system inference was fostered through selit (P3) and damakassie (P6), encouraging connections like gut-immunity or kidney-heart links, and strategic design was informed by tikur azmude, supporting culturally grounded interventions like fasting combined with exercise for hypertension (P4). Challenges arose when unfamiliar practices, such as damakassie, hindered analysis due to limited context (P7). Overall, Ethiopian IK enhanced CTS by offering relatable, practical, and holistic frameworks, though additional context is needed to fully support analytical skills.

7. Reflecting on your academic performance, how do you feel PBS and IK have impacted your achievement in human biology?

Based on student responses (Appendix E), PBS (PBS) and IK positively impacted AA in human biology. Paper-based scenarios, such as acid reflux cases, and digital scenarios with animations, like blood flow visuals, clarified complex concepts, improving test scores, while indigenous practices, such as bitter herbs for digestion, enhanced retention (P1). Engagement and motivation increased through interactive digital PBS, like enzyme animations, and culturally relevant knowledge, such as smoke-free practices for lung health, boosting study effort despite interface challenges (P7). PBS also developed CTS, with hypertension scenarios fostering analytical reasoning and herbal antivirals providing practical context for immunity, though stronger scientific links were desired (P4). Cultural relevance, including fermented foods for gut health, made concepts relatable and improved exam performance, while unfamiliar practices required additional background (P6). Challenges, such as technical issues or unfamiliar practices like fasting for heart health, occasionally disrupted focus and limited learning (P5). Overall, PBS and Ethiopian IK enhanced understanding, engagement, and CTS, though support is needed to address technical and cultural barriers.

CHAPTER FIVE: DISCUSSION

Introduction

This discussion synthesizes the results from the study on the impact of the PBS instructional model (Intervention 1) and the integration of IK (Intervention 2) on students' biological CTS, PSS, and AA in human biology, with a focus on gender differences. The analysis integrates quantitative data (pretest and posttest scores analyzed via ANOVA and MANOVA), qualitative data from student reflections and observation checklists across five scenarios, and thematic analysis of interview responses. To support these findings, recent research on PBS and IK integration in science education is cited, highlighting consistent positive effects on CTS, PSS, and achievement, alongside nuanced gender dynamics. The findings are organized by the specified topics, addressing the impact of PBS and IK on CTS, PSS, and AA, both overall and by gender.

5.1. Insights from DBR on PBS

The DBR provides valuable insights into how PBS, foster CTS, PSS, and AA among secondary school students. For instance, in scenario 1 (Constipation): students (S1–S6) demonstrated strong CTS in the clarification and basic support phases by accurately identifying the shift from a fiber-rich fasting diet (e.g., teff injera, lentils) to meat-heavy post-Easter foods (e.g., doro wat) as the cause of constipation. S1, S2, and S5 excelled in advanced clarification, linking fiber to gut motility and suggesting gut bacteria changes, while S3, S4, and S6 focused solely on fiber, lacking depth. The missed chewing indicator across all students highlights a gap in understanding mechanical digestion, suggesting a need for targeted prompts (e.g., “Why does chewing matter?”). Feedback for tool enhancements (e.g., pictorial diaries, class charts) reflects DBR’s iterative approach, aligning with research showing that culturally grounded PBL enhances CTS through relatable contexts (Iswari *et al*., 2020).

In the Identify-Plan-Implement-Evaluate framework, students consistently pinpointed low fiber, high meat, and low water as causes, proposing practical solutions like injera, gomen, and water. Implementation involved peer encouragement (e.g., sharing mangoes), and evaluation confirmed improved digestion (1–2 daily bowel movements). Collaborative tools like “Injera Health” charts suggested by S2 and S6 highlight community-oriented PSS, a strength in Ethiopian contexts where collective learning is valued (Yulianti, 2021). However, S6’s simpler plans and evaluations suggest that visual aids or role-playing could enhance engagement for less proactive students.

Across cycles, the instructional tool fostered PSS and CTS through relevant scenarios, with S3 and S5 consistently excelling due to their nuanced reasoning and detailed strategies. S2, S4, and S6’s struggles with terminology and engagement highlight the need for interactive simulations, peer-led workshops, and simplified glossaries, as suggested in student feedback. These align with DBR’s iterative design, ensuring inclusivity (Pallant, 2020; Tamrongkunanan & Tanitteerapan, 2020). Paper-based tools (e.g., T-charts) were accessible but less engaging for S4 and S6, while digital tools (e.g., asthma simulations) boosted engagement but confused some students, suggesting a hybrid approach (Suwono & Dewi, 2019).

Overall, DBR demonstrates that PBS, effectively foster PSS and CTS by grounding learning in relevant contexts. Strong performers (S3, S5) consistently showed advanced reasoning, while S2, S4, and S6’s challenges highlight the need for tailored tools like interactive simulations and simplified glossaries to enhance inclusivity. The iterative feedback (e.g., allergen charts, peer workshops) aligns with DBR principles, ensuring continuous refinement (Pallant, 2020). AA is supported by relatable scenarios, but gaps in terminology and non-dietary factor exploration suggest further tool enhancements. Gender dynamics, though underexplored, could be leveraged through mixed-gender collaboration to enhance outcomes, as supported by recent PBL research (Yulianti, 2021). Limitations include inconsistent engagement, terminology barriers, and missing gender-specific analyses, which could be addressed in future cycles with targeted prompts and demographic breakdowns.

5.2. The impact of PBS on biological CTS

The quantitative and qualitative findings from this study collectively demonstrate that PBS, significantly enhance biological CTS among students. The MANOVA results reveal a substantial effect of the intervention groups on CTS as measured by the CTS, with Wilks' Lambda = .410,

$F(6, 226) = 21.157$, $p < .001$, and a large effect size ($\eta^2 = .360$), accounting for 36% of the variance in outcomes. Complementing this, the ANOVA further underscores the intervention's impact, $F(2, 115) = 50.118$, $p < .001$, $\eta^2 = .466$, explaining 46.6% of the variance. Post hoc analyses highlight the differential effectiveness: Intervention 2 (incorporating IK) significantly outperformed both the Control group (mean difference = -20.60, $p < .001$) and Intervention 1 (mean difference = 4.56, $p = .043$), while Intervention 1 also surpassed the Control group (mean difference = -16.03, $p < .001$).

These statistical gains align with the qualitative evidence, where students across five health scenarios—constipation, varicose veins, asthma, alcohol-induced urination, and fatigue with a neck lump—demonstrated improved abilities in clarification, inference, and advanced clarification phases of the PBS framework. For instance, in the constipation scenario, students like S3 and S5 effectively linked low fiber intake to reduced gut motility, showcasing advanced inference skills. Similarly, in the fatigue and neck lump scenario, these students connected symptoms to potential thyroid dysfunction, reflecting deeper analytical reasoning. Thematic analysis of interviews reinforces this, illustrating how PBS fosters analytical PSS by enabling students to deconstruct complex cases (e.g., acid reflux in P1's response) and evaluate multifaceted perspectives (e.g., allergens versus exercise in asthma scenarios, as noted by P2). This structured framework encourages students to clarify symptoms, infer underlying causes, and propose evidence-based strategies, thereby promoting "learning by doing" as emphasized in progressive education (Tippett & Lee, 2019b).

Recent literature corroborates these findings, affirming PBL's efficacy in elevating CTS within biology-related domains. Studies have shown improvements in clinical skills (Alrahlah, 2016) and conservation biology (Suryanti & Festiyed, 2023), while a 2025 meta-analysis by Xu *et al.* (2023) confirms PBL's superiority over traditional methods in medical education, directly aligning with the observed CTS score enhancements in this study. The integration of digital elements in PBS, such as dynamic visuals depicting lung mechanics (P5), further amplified inference capabilities, whereas paper-based formats supported methodical reasoning, like analyzing vessel resistance in hypertension cases (P5). These modalities provide relatable, hands-on contexts that bridge abstract biological concepts to practical applications, enhancing overall CTS depth.

The marked superiority of Intervention 2 underscores the value of IK in CT. By incorporating culturally relevant elements, such as the use of ‘gomen’ (a local plant) for digestion-related issues, this intervention made abstract concepts more accessible and personally meaningful, thereby deepening CTS. This is evident in the qualitative data, where students engaging with culturally grounded scenarios (e.g., S3 and S5) exhibited stronger inference and advanced clarification skills, often reflecting Ennis's indicators—elementary clarification, inference, basic support, advanced clarification and design strategy and tactics—for robust CTS (Ennis, 2018b). Such outcomes resonate with constructivist theory, which posits that knowledge is actively built through personal experiences and culturally mediated interactions (Olugbenga, 2020). The quantitative edge of Intervention 2 over Intervention 1 and the control group suggests that cultural relevance acts as a catalyst, reducing cognitive barriers and fostering greater engagement with biological content. For example, students in Intervention 2 were better able to infer causal relationships in scenarios like varicose veins or alcohol-induced urination, drawing on familiar indigenous contexts to propose holistic strategies.

Despite these strengths, the study identifies notable challenges that occasionally hindered CTS development. Qualitative insights reveal that static paper formats (P6) and digital platform glitches (P1, P7) limited depth for some participants, particularly students like S4 and S6, who faced difficulties with biological terminology and engagement. These gaps manifested in weaker clarification and inference across scenarios, such as struggling to connect asthma symptoms to environmental triggers. To mitigate such issues, the findings advocate for clearer terminology and enhanced interactive tools, such as case-based simulations or mobile learning integrations, which align with research by Kohnke (2021) on boosting CTS in STEM through PBL-mobile hybrids. Furthermore, scaffolding instruction, as recommended by Abrami and Waddington (2015), could cultivate stronger CTS dispositions by providing graduated support, ensuring inclusivity for diverse learners.

In conclusion, this study's integration of quantitative metrics (e.g., significant MANOVA and ANOVA effects) and qualitative narratives (e.g., scenario-specific improvements and interview themes) provides compelling evidence for PBS as a transformative pedagogical tool in biological education. By leveraging IK and addressing implementation barriers through technological and scaffolding enhancements, educators can optimize PBS to cultivate advanced critical thinking skills. Future research should explore longitudinal effects and broader cultural adaptations to further validate and refine this approach, ultimately preparing students for real-world biological challenges.

5.3. Impact of PBS on biological PSS

The MANOVA results show a significant effect of Group on PSS, with a Wilks' Lambda of .410, $F(6, 226) = 21.157$, $p < .001$, $\eta^2 = .360$. Post hoc tests reveal that Intervention 2 significantly outperforms the Control group (mean difference = -20.20, $p < .001$) and Intervention 1 (mean difference = -17.92, $p < .001$), but no significant difference exists between Intervention 1 and Control (mean difference = -2.28, $p = .720$). The ANOVA results confirm Intervention's significant effect on PSS, $F(2, 115) = 13.222$, $p < .001$, $\eta^2 = .187$, explaining 18.7% of the variance.

The Identify-Plan-Implement-Evaluate framework of PBS effectively fostered PSS across scenarios. In scenario 1, all students identified low fiber as the cause of constipation and planned culturally relevant solutions like teff injera and water, with S1, S3, and S5 implementing detailed strategies (e.g., gomen and hydration schedules). In scenario 3 (asthma), S1, S3, and S5 accurately identified triggers like pollen and implemented inhaler use, while S2 and S6 offered simpler plans, indicating varying depths of PSS. The thematic analysis highlights structured problem identification (e.g., P1's acid reflux analysis) and strategic planning (e.g., P4's dietary changes for hypertension) as strengths, with digital scenarios aiding dynamic planning (P2) despite technical issues. Students like S4 and S6 struggled with less detailed evaluations, suggesting a need for structured reflection tools.

Problem based scenario enhances PSS by guiding students through systematic phases, with Intervention 2 showing a stronger impact due to its cultural relevance, which makes solutions like injera or garlic steaming more actionable. Studies support demonstrating that PBL in STEM significantly improves PSS, particularly when integrated with design thinking (Choi *et al*., 2024) or advanced mathematics (Sugiharto *et al*., 2019). The lack of significant difference between Intervention 1 and Control suggests that PBS alone may require additional scaffolding (e.g., interactive simulations) to consistently improve PSS, echoing findings that PBL develops these skills through interdisciplinary integration in STEM education (Yuniasih *et al*., 2025). Qualitative data underscores that students like S3 and S5 excel in applying structured solutions, but S2, S4, and S6 need enhanced tools to deepen evaluation and engagement.

The thematic emphasis on PBS enhancing CTS and PSS through visualizations, peer collaboration, and real-world application mirrors numerous studies demonstrating PBL's efficacy in biology and science contexts. For instance, a quasi-experimental study with 56 biology students found PBL significantly improved CTS (average score: 82.77 vs. 74.09 in conventional groups), accounting for 66.2% of variance in CTS gains, alongside boosts in scientific literacy (73% variance) and learning independence (31.5% variance) (Astina & Johnson, 2024). This quantitative effect size supports the participants' reports of superior conceptual integration and inference-making in PBS (e.g., animations aiding immune response analysis), though the thematic analysis adds qualitative depth on format-specific benefits (digital for dynamics, paper for structure) not always quantified in another research.

Similarly, meta-analyses and experimental studies confirm PBL's moderate to large effects on CTS in higher education biology, with posttest gains in CTS and creative thinking outperforming traditional methods (Liu & Pásztor, 2022). One review of PBL in science fields highlighted its greatest impact on CTS, aligning with participants' examples of evaluating multiple perspectives (e.g., asthma triggers) and solution evaluation (Lu *et al*., 2025). However, while the thematic analysis notes no superiority of pure PBS without IK, other findings show standalone PBL yielding significant CTS gains (e.g., normalized gain = 0.70 in ethnoscience-PBL, akin to IK-integrated PBS) (Gummah *et al*., 2023).

5.4. Impact of PBS on biology AA

The MANOVA results indicate a significant effect of Group on AA, with a Wilks' Lambda of .410, $F(6, 226) = 21.157$, $p < .001$, $\eta^2 = .360$. Post hoc tests show that Intervention 2 significantly outperforms Control (mean difference = 8.47, $p < .001$) and Intervention 1 (mean difference =

6.89, $p < .001$), but no significant difference exists between Intervention 1 and Control (mean difference = 1.58, $p = .436$). The ANOVA results confirm Intervention's significant effect on ACT, $F(2, 115) = 17.446$, $p < .001$, $\eta^2 = .233$, explaining 23.3% of the variance.

Students' reflections across scenarios show that PBS supports AA by clarifying biological concepts through practical applications. In scenario 4 (alcohol and urination), S3 and S5 linked diuretic effects to kidney function, likely contributing to higher test scores, as noted in the thematic analysis (P1: improved test scores from enzyme clarification). The interview responses highlight enhanced academic understanding through PBS, with paper scenarios aiding detailed analysis (e.g., P1's digestion) and digital scenarios visualizing complex systems (e.g., P5's lung mechanics). However, challenges like technical issues (P7) and unfamiliar terms (P6) occasionally hindered performance for S4 and S6.

Intervention 2 significantly boosts AA by integrating culturally relevant knowledge, making concepts like digestion and immunity more memorable. A meta-analysis aligns with this, showing PBL's high effect size on AA in science education compared to traditional methods (Liu & Pásztor, 2022). The non-significant difference between Intervention 1 and Control suggests that PBS alone may not sufficiently enhance achievement without cultural context, consistent with research indicating positive impacts on both cognitive and affective outcomes (Wulandari & Wulandari, 2025). Qualitative data supports this, showing that students who connected scenarios to cultural practices (e.g., S3 and S5) performed better academically, while engagement barriers for S4 and S6 indicate a need for simplified, interactive tools to maximize achievement.

In summary, for PSS and ACH, the analysis's reports of structured problem identification and improved test scores resonate with evidence from large-classroom PBL, where it enhanced PSS and learning outcomes, though with smaller effects in non-small-group settings (Klegeris & Hurren, 2011). Challenges like technical barriers in digital PBS echo broader critiques of PBL accessibility, suggesting the thematic findings' call for hybrids aligns with recommendations for refined implementation to sustain gains (Liu & Pásztor, 2022).

5.5. Impact of PBS on biological CTS by gender

The MANOVA results show no significant main effect of Gender on CTS, Wilks' Lambda = .965, $F(3, 113) = 1.368$, $p = .256$, $\eta^2 = .035$, but the Gender * Intervention interaction is significant, Wilks' Lambda = .824, $F(6, 226) = 3.835$, $p = .001$, $\eta^2 = .092$. The ANOVA results confirm this, with a significant interaction for CTS, $F(2, 115) = 3.126$, $p = .048$, $\eta^2 = .052$. Posttest scores show females in Intervention 2 scoring highest (M = 73.87, SD = 8.82) compared to males (M = 70.00, SD = 13.26), females in Intervention 1 (M = 69.79, SD = 8.8), and males in Intervention 1 (M = 64.50, SD = 7.26). Both genders in the Control group scored lower (females: M = 50.84, SD = 5.51; males: M = 54.71, SD = 7.37).

The qualitative data does not explicitly break down CTS by gender, but student reflections suggest that females like S3 and S5 often provided more detailed inferences and advanced clarifications (e.g., thyroid issues in scenario 5, hormonal effects in scenario 4), potentially contributing to higher CTS scores. Male students (e.g., S1, S2) sometimes used simpler terms or showed less engagement (e.g., S6 in scenario 4), aligning with slightly lower scores in Intervention 2.

The significant Gender * Intervention interaction suggests that females benefit more from Intervention 2, possibly due to greater engagement with culturally relevant scenarios, as seen in the nuanced responses of S3 and S5. Recent research on gender differences in PBL outcomes in STEM supports this, indicating that females may show greater gains in CTS when PBL addresses self-efficacy gaps (Fauzi, 2014). The lack of a main Gender effect indicates that PBS and IK are generally effective across genders, but females' higher scores in Intervention 2 suggest they may connect more readily with culturally grounded tasks. Enhanced tools like interactive simulations could further support males' engagement to reduce this gap, aligning with 2024 findings on gender disparities in STEM participation (Funk, 2018).

5.6. Impact of PBS on biology PSS by gender

The MANOVA results show no significant main effect of Gender on PSS, Wilks' Lambda = .965, $F(3, 113) = 1.368$, $p = .256$, $\eta^2 = .035$, but the Gender * Intervention interaction is significant, $F(2, 115) = 3.295$, $p = .041$, $\eta^2 = .054$. Posttest scores show females in Intervention 2 scoring highest ($M = 77.55$, $SD = 12.15$) compared to males ($M = 62.33$, $SD = 20.1$), females in Intervention 1 ($M = 55.72$, $SD = 14.50$), and males in Intervention 1 ($M = 57.60$, $SD = 16.45$). Control group scores were similar for both genders (females: $M = 54.84$, $SD = 9.36$; males: $M = 52.59$, $SD = 11.29$).

Reflections indicate that females like S3 and S5 often proposed detailed, culturally relevant solutions (e.g., teff injera for constipation, inhaler use for asthma), while males like S1 and S6 sometimes offered simpler plans (e.g., rest in scenario 5). The thematic analysis suggests that females may engage more with collaborative and culturally grounded tasks (e.g., P4's dietary planning), potentially explaining higher PSS scores in Intervention 2.

The significant interaction indicates that females benefit more from Intervention 2, likely due to stronger engagement with culturally relevant PSS tasks. A meta-analysis on STEM education supports this, showing positive effects on learning outcomes across genders but with nuanced differences in PSS gains (Liu & Pásztor, 2022). The lack of a main Gender effect suggests that PBS is broadly effective, but females' higher scores in Intervention 2 highlight the value of cultural context. Interactive tools could enhance males' PSS by providing more engaging, structured guidance, consistent with studies on gender differences in STEM interest and environmental factors (Funk, 2018).

5.7. Impact of PBS on AA by gender

The MANOVA results show no significant main effect of Gender on AA, Wilks' Lambda = .965, $F(3, 113) = 1.368$, $p = .256$, $\eta^2 = .035$, but the Gender * Intervention interaction is significant, $F(2, 115) = 4.914$, $p = .009$, $\eta^2 = .079$. Posttest scores show females in the Control group scoring highest ($M = 30.64$, $SD = 5.22$), followed by males in Intervention 1 ($M = 31.00$, $SD = 5.48$), females in Intervention 1 ($M = 26.31$, $SD = 7.13$), males in Intervention 2 ($M = 21.89$, $SD = 6.35$), and females in Intervention 2 ($M = 20.26$, $SD = 4.35$). The ANOVA confirms a significant interaction for AA, $F(2, 115) = 4.278$, $p = .042$, $\eta^2 = .053$.

The high female Control group scores are unexpected, possibly due to prior knowledge or test familiarity, as qualitative data does not explain this trend. Females like S3 and S5 showed strong academic connections in scenarios (e.g., thyroid knowledge in scenario 5), while males like S1 and S6 offered simpler responses, potentially impacting lower Intervention 2 scores.

The significant interaction suggests that Gender modulates the effect of Interventions on achievement, with females in the Control group outperforming others, possibly due to baseline advantages. Recent research on gender gaps in STEM education indicates persistent disparities in achievement, influenced by factors like self-efficacy, which PBL can help mitigate but may vary by intervention type (Fauzi, 2014). Intervention 2's lower scores for both genders may reflect challenges with unfamiliar indigenous practices (e.g., P5's confusion with damakassie). Enhanced scaffolding, such as simplified glossaries, could improve achievement across genders, aligning with 2025 findings on innovative pedagogies to reduce gender gaps (Francis *et al.*, 2022).

5.8. Impact of IK on biological CTS

Intervention 2 (IK) significantly outperforms both Control and Intervention 1 for CTS (post hoc: mean difference = -20.60 vs. Control, $p < .001$; mean difference = 4.56 vs. Intervention 1, $p = .043$), with a large effect size ($\eta^2 = .466$). IK, such as gomen for constipation (scenario 1) and garlic steaming for asthma (scenario 3), enhanced CTS by making concepts relatable. Students like S3 and S5 connected cultural practices to physiological processes (e.g., selit for immunity, P3), while P1 noted that gomen clarified digestion. Challenges included unfamiliar practices (e.g., damakassie, P7), which hindered S6's reasoning.

A study supports that integrating IK into science education improves comprehension and critical analysis in biology by fostering culturally responsive pedagogies that make abstract concepts tangible (Zidny *et al.*, 2020). This approach aligns with DBR's iterative process, which emphasizes cycles of design, enactment, analysis, and refinement in educational interventions to adapt to contextual nuances, such as iteratively incorporating feedback from IK holders to refine lesson plans on sustainable resource management (Wang & Hannafin, 2005).

For instance, for the digestive system indigenous communities have traditionally used oregano to treat indigestion, bloating, and gut infections, grounding abstract biology concepts in relatable practices; oregano essential oil (OEO) improves intestinal morphology, tight junction protein expression, and digestive enzyme activity (e.g., amylase) while modulating microbiota to reduce pathogenic E. coli populations, fostering critical analysis of how carvacrol and thymol disrupt bacterial membranes and alleviate inflammation, as seen in pig and sheep models where OEO enhanced nutrient absorption and barrier integrity (Jia *et al*., 2022).

5.9. Impact of IK on biology PSS

Intervention 2 significantly outperforms Control (mean difference = -20.20, $p < .001$) and Intervention 1 (mean difference = -17.92, $p < .001$) for PSS, with a moderate effect size ($\eta^2 = .187$). Culturally relevant solutions like teff injera (scenario 1) and garlic steaming (scenario 3) enabled practical PSS, with S3 and S5 proposing detailed plans. S2 and S6's simpler plans (e.g., rest) suggest a need for structured guidance. The thematic analysis highlights practical application (e.g., P2's garlic steaming) and strategic design (e.g., P4's tikur azmude for hypertension).

IK enhances PSS by providing relatable, actionable solutions, but its effectiveness depends on familiarity. A study on integrating IK in STEM emphasizes its role in fostering PSS through cultural responsiveness (Sumarni *et al*., 2021). Interactive tools could support students like S2 and S6 in deepening their planning and evaluation skills.

The findings are similar to those of a study that has claimed IK enhances PSS by providing relatable, actionable solutions, such as traditional herbal remedies that address health issues in various body systems, but its effectiveness depends on familiarity with cultural practices (Sumarni *et al*., 2021). For instance, in the digestive system, indigenous communities have long used aromatic plants like oregano for treating disorders such as indigestion, bloating, and microbial infections in the gut; oregano essential oil's antimicrobial properties, derived from compounds like carvacrol and thymol, help disrupt bacterial cell membranes and reduce inflammation, offering natural alternatives to synthetic drugs and enabling students to explore real-world applications in biology and chemistry (Nostro *et al*., 2004).

Similarly, for the respiratory system, traditional uses of oregano in ancient Greek and other indigenous traditions involve remedies for coughs, bronchitis, asthma, and respiratory infections, where its antiviral and antifungal activities support expectorant effects and improve airflow, fostering PSS by connecting cultural lore with scientific mechanisms like quorum sensing inhibition in pathogens (Ghosh *et al*., 2024). In the circulatory system, IK incorporates oregano oil to manage cholesterol levels, blood sugar, and lipid profiles, promoting cardiovascular health through antioxidant actions that prevent oxidative stress and inflammation in blood vessels, which can be integrated into STEM lessons on physiology to encourage hypothesis testing and data analysis (Soliman *et al*., 2016).

5.10. Impact of IK on AA

Intervention 2 outperforms Control (mean difference = 8.47, $p < .001$) and Intervention 1 (mean difference = 6.89, $p < .001$) for AA, with a moderate effect size ($\eta^2 = .233$). Practices like bitter herbs (P1) and fermented foods (P6) enhanced retention and exam performance by making concepts relatable. However, unfamiliar practices (e.g., fasting for heart health, P5) disrupted understanding for S4 and S6.

Indigenous knowledge boosts achievement by contextualizing biology, but unfamiliar practices require clearer explanations to maximize impact across all students. This is supported by research showing improved participation and learning outcomes through IK integration in life sciences (Sefoka & Chuene, 2025).

The thematic analysis's portrayal of IK as amplifying CTS, PSS, and AA through cultural clarification (e.g., gomen for digestion) and holistic inference (e.g., selit for gut-immunity links) is consistent with studies on IK integration in science education. An action research study with 52 Ghanaian high school students showed IK incorporation significantly boosted performance in integrated science (pre-mean: 5.85 to post-mean: 10.58, $p < 0.05$), with 80.77% passing post-intervention versus 17.31% pre, and fostered positive attitudes (e.g., 94% found science more interesting) (Aboagye, 2024; Yazidi & Rijal, 2024). This quantitative improvement parallels participants' reflections on enhanced retention and motivation leading to better AA, though the thematic emphasis on practical applications (e.g., garlic steaming for respiratory PSS) adds context-specific nuance not always captured in broader reviews.

Systematic reviews further affirm IK's benefits for equitable learning and sustainable development, enriching CTS and PSS by bridging traditional and scientific knowledge, as seen in improved self-concept and biology performance among secondary students exposed to indigenous practices (Afolabi, 2017; da Silva *et al*., 2024). However, mixed results emerge: American Indian students performed better on IK-related standardized science questions but lower overall, highlighting potential assessment biases similar to the thematic variability in AA (e.g., control groups occasionally outperforming) (Rampey *et al*., 2021). The analysis's noted challenges with unfamiliar IK (e.g., damakassie) align with calls for better contextual scaffolding to avoid hindering comprehension, as failure to integrate IK can threaten STEM performance and attitudes (Mkhwebane, 2024). Overall, the synergistic PBS-IK effects in the thematic findings extend evidence from chemistry and biology, where IK enhanced AA and skills like PSS through relatable, community-involved curricula (Günter & Alpat, 2017).

In summary, the thematic analysis converges with other findings on PBS and IK's positive impacts, with effect sizes ranging from 31.5–73% in quantitative studies, but adds unique insights on cultural and format nuances.

5.11. Impact of IK on biological CTS by gender

The Gender * Intervention interaction for CTS, $F(2, 115) = 3.126$, $p = .048$, $\eta^2 = .052$, shows females in Intervention 2 scoring highest ($M = 73.87$), suggesting greater benefit from IK. Females like S3 and S5 showed stronger CTS with culturally relevant practices (e.g., gomen, selit), while males like S1 and S6 used simpler terms, potentially explaining the score gap.

Females may engage more with culturally grounded tasks in biology education, enhancing CTS, as these approaches often incorporate relational and contextual elements that align with socio-cultural perspectives on learning. For instance, tasks rooted in indigenous practices can make abstract biological concepts—such as plant physiology, ethnobotany, and interactions with human body systems—more relatable and meaningful, encouraging deeper analysis and PSS. A study on gender-inclusive IK in biology supports this, examining the integration of indonesian medicinal plant knowledge—such as herbal remedies like "paitan" (made from Andrographis paniculata leaves, which contain alkaloids and exhibit anti-infection and anti-inflammatory properties to treat vaginal discharge by supporting immune responses in the reproductive system) and "jamu kunci suruh" (a blend including kunci rhizomes, betel leaves with tannins and essential oils for antimicrobial effects, and tamarind, aimed at eliminating body odor, shrinking the uterus, and regulating menstrual cycles through potential emmenagogue actions on the endocrine system)—into biology curricula (Sumarni *et al*., 2021).

This ethno-biology framework correlates community-based indigenous practices with scientific principles (e.g., chemical compositions like alkaloids, flavonoids, and phytoestrogens that influence hormonal balance and therapeutic effects on human physiology), highlighting improved critical analysis for underrepresented groups, including indigenous students who may feel more empowered when their cultural heritage is validated in educational settings.

By bridging traditional knowledge with modern biology disciplines a study demonstrates how such inclusive methods can foster higher-order thinking skills, such as evaluating evidence from natural remedies and redesigning experiments based on cultural contexts (Jessen *et al*., 2022). Similarly, a study has asserted that IK could further support males—who might prefer more hands-on or competitive elements to bridge this engagement gap and achieve similar enhancements in CTS within biology education (Wang *et al*., 2023).

In conclusion, these approaches are particularly relevant to biology education on the digestive, circulatory, respiratory, immune, and excretory systems, where traditional ethnobotanical knowledge highlights bioactive compounds from medicinal plants (e.g., chamomile for digestive cramps and gas expulsion, oregano for circulatory hypertension and respiratory infections, peppermint for immune-boosting antifungal effects, and lemongrass as a diuretic for excretory function) (S *et al*., 2022).

5.12. Impact of IK on biology PSS by gender

The Gender * Intervention interaction for PSS, $F(2, 115) = 3.295$, $p = .041$, $\eta^2 = .054$, shows females in Intervention 2 scoring highest ($M = 77.55$), indicating a stronger benefit. Females like S3 and S5 proposed detailed, culturally relevant solutions, while males like S2 and S6 offered simpler plans, aligning with the score difference.

Indigenous knowledge enhances PSS more for females, likely due to greater engagement with cultural contexts. This aligns with broader gender-racial effects in STEM, where IK can reduce disparities but may vary by cohort (Mangundayao, 2021).

The observed enhancement in PSS through IK integration appears more pronounced among female students, potentially stemming from their greater engagement with cultural contexts during learning activities. In the study, female participants frequently drew upon relational and narrative elements of indigenous epistemologies—such as interconnected views informed by traditional stories or community practices—which facilitated more holistic and creative approaches to biology problems. This aligns with socio-cultural learning theories, where females in indigenous often exhibit stronger affinities for contextualized, story-based pedagogies that emphasize relationships over abstract individualism. For instance, research indicates that girls from indigenous backgrounds may internalize cultural knowledge through everyday roles involving caregiving, environmental stewardship, or oral traditions, leading to heightened motivation and deeper cognitive processing when these elements are woven into STEM curricula. In contrast, males might prioritize procedural or mechanistic strategies, which could limit the immediate uptake of culturally infused methods unless explicitly scaffolded (Bang *et al*., 2013).

5.13. Impact of IK on AA by gender

The Gender * Intervention interaction for AA, $F(2, 115) = 4.914$, $p = .009$, $\eta^2 = .079$, shows females in the Control group scoring highest ($M = 30.64$), with lower scores in Intervention 2 for both genders. Females' high Control scores may reflect prior knowledge, while both genders struggled with unfamiliar indigenous practices in Intervention 2 (e.g., P5's damakassie confusion).

The finding in lines with a study that has asserted incorporation of IK into the teaching of human body systems—encompassing anatomy, physiology, and related life sciences—offers a culturally responsive approach that bridges traditional wisdom with Western scientific curricula, enhancing comprehension and engagement for indigenous and diverse students (Bilton *et al*., 2018). IK often emphasizes holistic views of the body in relation to traditional healing to make abstract concepts more relatable (Tremblay *et al*., 2023). For example, programs integrating IK have demonstrated improved student outcomes in anatomy and physiology by using indigenous pedagogies (IP) that ground lessons in cultural narratives, such as viewing the body as interconnected with the environment rather than isolated mechanisms In Australian tertiary education, IP frameworks like the 8 Aboriginal Ways of Learning have been applied to anatomy courses, promoting active, community-linked activities that foster deeper understanding of physiological processes (Bilton *et al*., 2018).

Gender-specific analyses reveal varied yet promising effects, with IK often empowering indigenous girls by aligning with traditional roles where women serve as knowledge keepers of healing and bodily wellness (Tremblay *et al*., 2023). Studies indicate that indigenous females may experience greater gains in body functionality appreciation and physiological understanding when IK highlights women's historical roles in herbal medicine and community health, countering Western emphases on aesthetics that can exacerbate gender-based body image issues (Stratton *et al*., 2015). A Kenyan study on biology achievement similarly found IK strategies effective for both male and female secondary students in understanding body systems, with gains in topics like digestion and circulation attributed to contextual relevance without gender biases (Dwi *et al*., 2025).

CHAPTER SIX: CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This study demonstrates that integrating problem-based scenarios with indigenous knowledge (PBS+IK) has a significant positive impact on students' problem-solving skills, critical thinking skills, and academic achievement in human biology. Students exposed to PBS showed measurable improvements across all three learning outcomes, with the strongest gains observed in the intervention that deliberately incorporated indigenous knowledge. These findings confirm that learning experiences grounded in authentic problems and local contexts promote deeper understanding and more effective application of biological concepts than conventional instruction.

The results further indicate that culturally relevant scenarios enhance student engagement and support meaningful knowledge construction. Qualitative evidence shows that linking biological content to familiar practices and community-based experiences helped students analyze situations more critically, apply concepts more confidently, and solve problems more systematically. The stronger effects observed among female students suggest that PBS+IK may be particularly effective in creating inclusive learning environments that support participation and achievement among groups traditionally less engaged in science classrooms.

Despite these positive outcomes, the study also identified implementation challenges, including unfamiliar terminology, technical and accessibility constraints, and difficulties experienced by some students when engaging with complex content. These issues highlight the importance of refining instructional materials to ensure clarity, accessibility, and sustained engagement. Strategies such as simplified glossaries, visual supports, interactive case-based activities, and peer-led learning structures are recommended to strengthen the effectiveness of PBS+IK across diverse learners.

Overall, the findings affirm the value of culturally grounded, student-centered instructional approaches in biology education. By combining problem-based scenarios with indigenous knowledge, biology learning becomes more relevant, inclusive, and transferable to real-life contexts. Guided by the principles of design-based research, this study contributes empirical evidence that iterative refinement of instructional design can enhance critical thinking, problem-solving, and academic achievement, and it provides a strong foundation for future research on scaling and sustaining such approaches in secondary school science education.

5.2. Recommendation

Based on study's findings the following recommendations are suggested:

Policy Makers should:

- Integrate IK into biology curriculum – include culturally relevant practices and local health remedies to enhance engagement and real-life application.
- Support digital PBS accessibility – ensure schools have reliable devices, internet, and offline-ready platforms for equitable learning.
- Encourage curriculum innovation – promote the adoption of design-based research approaches to iteratively refine PBS and IK integration.

Curriculum designers should:

- Implement PBS – use both digital and paper-based formats to balance visual engagement with hands-on analysis.
- Develop interactive learning tools – incorporate simulations, animations, diagrams, and practical exercises to support complex biological concepts.
- Simplify terminology and concepts – provide glossaries, annotated diagrams, and scaffolds to clarify both scientific and IK practices.

Teachers should:

- Promote collaborative learning – facilitate peer-led workshops, group discussions, and co-created solutions to strengthen PSS and CTS.
- Provide teacher training and support – build skills in digital literacy, culturally responsive teaching, and PBS facilitation.

Researchers and education planners should:

- Investigate gender and group differences – examine how different student demographics respond to PBS and IK interventions.
- Evaluate long-term impact – study how PBS and IK integration influence real-life application of biology knowledge in communities.

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Appendices

Appendix A. Problem based Scenarios

Problem scenario 1

Amare, a grade 10 student, abstained from meat for two months during the Ethiopian Orthodox Christian fasting season. During this period, he consumed whole grains, fruits, and vegetables, which his teeth chewed effectively, his digestive system processed well, and he had regular, comfortable bowel movements. However, after Easter, when he resumed eating meat, he experienced constipation and spent prolonged time in the bathroom.

Problem scenario 2

Kidu is my best friend, his hobby is extensive reading. Hence, one day he showed me the column of the medical newspaper that was written about Hemorrhoid. The newspaper defined it as a swollen blood vessel in and around the anus and lower rectum. This caused by several factors such as being overweight and pregnant; sitting for long periods and caught by constipation.

Problem scenario 3

Once up on a time I was traveled to Dessie town on a bus. But a man seat nearby a chair has started to sneeze continuously, latter on he signed with breathless, coughing and difficulty speaking as we approaching to the town. I have asked what to help him and he replied me that thank you! No matter! It is asthma case, which is caused by allergens or cold temperature. So, currently it might be due to the air condition of the town. Finally, we departed for bed.

Problem scenario 4

Bedilu and Mekuria are Biology and chemistry students respectively at Sekota College of teachers education. One day they were at a party to celebrate their completion of the program. In the celebration, they have been drinking beer over the evening with their friends. But Bedilu has been urinating now and then. Depending on this they take few conversations as follows:

Mekuria: Why you urinate in short intervals?

Bedilu: Alcohol inhibits a hormone that helps me retain water. This could also lead to body dehydration.

Mekuria: Is that disease?

Bedilu: No, since I drink occasionally this effect of alcohol is temporary. However, in people who drink excessive alcohol can have serious and long-term effects on the excretory system such as liver and kidney stones.

Mekuria: Oh! I see, I have never heard about the effect of alcohol on kidney stones, rather I have listen people faced with such a problem counseled as to drink water, to do moderate exercise, or to not eating food with too much salt or sugar.

Bedilu: That is right, this all can be factors of liver and kidney disease. So, let me read more on them latter.

Mekuria: Ok thank you.

Problem scenario 5

Today I am not feeling well. Despite I have gone to bed earlier, and napping in the meantime after meal, I have tired more than usual. In addition to this I have not much of an appetite and started losing weight. Suddenly when I pressed on the side of my neck, like the doctors do during diagnosis, I noticed an unusual lump which is painful and tender in finger touch.

Appendix B: test instruments

Human Biology critical thinking skill test
Bahir Dar University College of Science Department of Biology

Dear students, I am conducting PhD dissertation research. Thus, the questionnaire is aim to collect data from grade 10 students on how they think in biology. The information obtained from this questionnaire will serve as an input in enhancing students critical thinking. The questionnaire includes 25 essay questions from grade 10 human biology topics. Therefore, you are kindly requested to give genuine response to the questions. The responses to the questions will be kept confidential.

Thank You in Advance for Your Cooperation!
1. Do not write your name.the time given is 1 hour
Background Information
1.1. Name of school____
1.2. Student's code __________________
1.2. Sex: put a tick mark (√)Male F☐ale Age ☐________Grade _________

2. Read the following statements and write your response briefly to the questions accordingly.

Studies report that coffee reduces PH level and enhances hydrochloric acid in the stomach, wich increases digestion. However, some people believe that it causes gastritis.

1. Do you think that the study result and people opinion is correct? If yes, explain it.
____
____
____
_

A. How chemical and biological information supports you to clarify this issue?
____
____
____
_

B. Based on the information, what is your conclusion about digestion?
____
____
____
_

C. What is digestive system?
____
____
____
_

D. What action should increase digestion and prevent gastritis?
____
____
____

Common cold is a disease that has no medicine and affects breathing system, the passage of air through the nose. Despite this, people agree on taking hot drinks and steam bath can relive breathing system. Based on the information:

2. Do you think that taking hot drinks and steam bath can relive breathing? How?
____
____
____

A. What scientific or local information supports you to clarify this issue?

____

____

____

B. Based on the information, what is your conclusion about breathing system?

____

____

____

C. What is breathing system?

____

____

____

D. What should be done to increase breathing system?

____

____

____

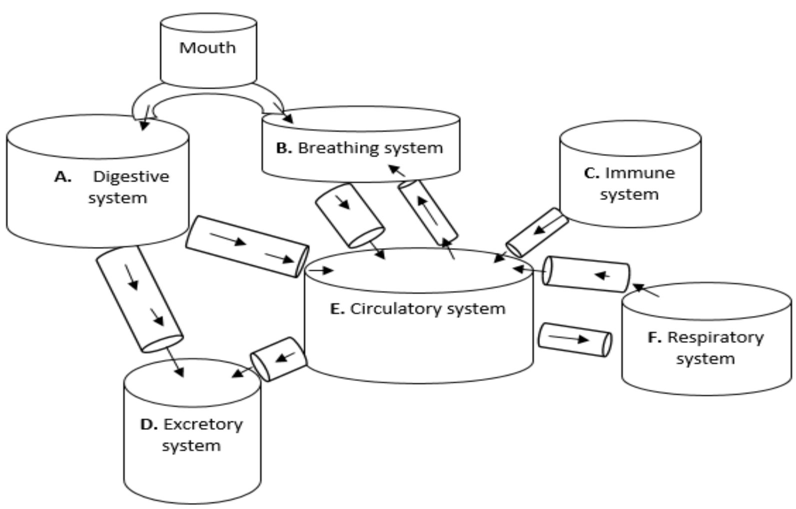

Figure 1. Body system

:

❖ , Give brief response for question number 3-5 based on figure 1.

3. How do you think that blood enriched by different substances?

____

____

____

A. In the figure, which information supports you to clarify this issue?

____

____

____

B. What is your conclusion about blood circulation and enrichment?

____

C. What is blood circulation?

____

D. What action can increase blood circulation?

____

4. Do you think that all these body systems can excrete? If yes, clarify.

____

A. In the figure, which information supports you to clarify this issue?

____

B. What is your conclusion about waste excretion?

____

C. What is excretory system?

____

D. How can you solve excretory problems?

____

5. Do you think that C to E transport is about immune system? If yes, how?

____

A. In the figure, which information supports you to clarify this issue?

____

B. What is your conclusion about immune system?

____

____

____

C. What is immune system?

____

____

____

D. What should increase immune system?

____

____

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Human biology problem solving skill test

Bahir Dar University College of Science Department of Biology

Dear students, I am conducting PhD dissertation research. Thus, the purpose of this questionnaire is to collect data from grade 10 students on problem solving skills in biology. The information obtained from this questionnaire will serve as an input in enhancing students' problem solving skills. The questionnaire consists of 20 essay questions from grade 10 human biology topics based on problem solving skill indicators. Therefore, you are kindly requested to give genuine response to the questions. The responses to the questions will be kept confidential.

Thank you in advance for your cooperation!

1. Do not write your name.

Background information

1.1. Name of school____

1.2. Student's code ____________________

1.2. Sex: Put a tick mark (√) Ma[ ] F[ ]e Age ____________Grade __________

2. Write your response briefly.

❖ People in Ethiopia practice eating meat, staying in bars for a long time, and taking too much alcohol like Tela and Teji. In addition, they have feeding habit in sweet or sugary foods for their children and strongly believe that is good feeding system. However, a lifestyle survey result of the country indicated that some of them fail in digestive problems. Based on this scenario:

1. What are people's digestive problems and their causes?

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A. If you are the concerned one, what is your plan to solve the problem?

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B. How do you implement your solution?

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C. What is the strength and weakness of your solution?

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In our village there was a farmer who works day and night tirelessly without taking enough rest. However, after long period of time he feels chest pain even when he walks up a stair. Hence, he has gone to hospital for diagnosis and comes up with 140/90mmgH blood pressure, 80/m heart beat and 230 mg/dl cholesterol level. Based on the scenario:

2. What is the disease of this farmer? What causes it?

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A. What plan do you design to treat this farmer?

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B. How do you implement your solution?

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C. What is the strength and weakness of your solution?

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A student in rural school was committed to learn seriously and help his parents after school. To achieve his desire, he has studied for long period of time sitting on one place. As the same time he has helped his parents by collecting straws of caws and cleaning their home. However, he has affected now and then with breathing problems. Based on the scenario:

3. What is the disease of this student? What causes it?

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A. If you were him, what plan do you design to study and help your parents?

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B. How do you implement your solution?

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C. What is the strength and weakness of your solution?

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In our school there was a cleaver student, who has always eaten dry meat mashed with salt, cookies and yogurt to get energy while she study. In same way, she likes taking juice and soft drinks. However, one day she feels a pain on her urinary organ and went to nearby clinic. As a result the Doctor detects kidney stone. Based on the story:

4. What is kidney stone? What causes it?

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A. What plan do you design to prevent kidney stone?

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B. How do you implement your solution?

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C. What is the strength and weakness of your solution?

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Even though I took enough sleep yesterday and good rest after meal today, I feel not good right now. I feel unusual tire, I have no appetite, when I measured my weight it is under the normal. As I am being in this situation, suddenly I touch the swelling with my finger under my neck. Based on my condition:

5. What looks my immunity? What is the cause?

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   A. If you were me, what plan would you design to maintain your immunity?

   ____
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   ____

   B. How do you implement your solution?

   ____
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   ____

   C. What is the strength and weakness of your solution?

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Human Biology Achievement Test

Dear students, I am conducting PhD dissertation research. Thus, the purpose of this questionnaire is to collect data from grade 10 students on how they achieve in biology. The information obtained from this questionnaire will serve as an input in enhancing students' academic achievement. The questionnaire consists of 42 multiple choice questions from grade 10 human biology topics based on objectives of the unit. Therefore, you are kindly requested to give genuine response to the questions. The responses to the questions will be kept confidential.

Thank You in Advance for Your Cooperation!

1. Do not write your name.

Background Information

1.1. Name of school____

1.2. Student's code ____________________

1.2. Sex: Put a tick mark (√) Ma[ ] F[ ]e Age ____________Grade __________

Choose the right answer for each questions and make a circle on the letter of answer.

1. How high altitudes affect our breathing system? At high altitude the:
   A. Number of red blood cells increase, as available oxygen increases
   B. Number of red blood cells decrease as available oxygen decreases.
   C. The amount of oxygen is low, as a result our breathing rate increases
   D. The amount of oxygen is high, as our breathing rate increases

2. How does body exercise affect the breathing rate? When the body:
   A. Begins exercise, the breathing rate increases
   B. Gets rest, breathing is totally lost
   C. Begins exercise, the breathing rate decreases
   D. Gets rest, breathing rate increases
3. What is the importance of mechanical digestion?
   A. Minimize the effect of microbes on the food we eat
   B. Initiate the release of digestive enzymes from their glands
   C. Increase the surface area of the food for enzyme action
   D. Change large and insoluble molecules to smaller and soluble one
4. What is the excretory function of kidney?
   A. Maintain homeostasis of the body C. Make urine
   B. Regulate plasma D. Influence other systems
5. What waste excretion is NOT filtered from blood?
   A. Urine C. Carbon dioxide
   B. Feces D. Debris of cells
6. Which of the following is inborn immune system?
   A. Lymphatic system C. Innate immune system
   B. Acquired immune system D. Endocrine system
7. ___________ is formed, in an increased response to future exposure to the same disease?
   A. Recognition C. Vaccination
   B. Neutralization D. Agglutination
8. Which one of the following is not the function of physical digestion?
   A. Chewed Food is and formed a bolus.
   B. Breaks food into smaller pieces.
   C. Breaks down starches into simpler molecules
   D. Increasing the surface area
9. ___________ is an elementary canal involved both in physical and chemical digestion?
   A. Esophagus C. Teeth
   B. Stomach D. Mouth
10. Which of the following accessory organ produces bile which helps to digest fats?
    A. Salivary glands C. Gall bladder
    B. Pancreas D. Liver
11. The process of digestion in which digested nutrients transport from the small intestine to the cells is ____________?
    A. Ingestion C. Egesting
    B. Absorption D. Digestion
12. A hydrochloric acid in the stomach is used to ___________?
    A. Kill microorganisms C. Break down food
    B. Activate enzymes D. Remove waste materials
13. __________ is a process of contraction of esophagus muscles to push food from esophagus into stomach?

A. Chewing
B. Peristalsis
C. Salivation
D. Hydrolysis

14. How food is break down by Trypsin enzyme?
    A. Starch $\rightarrow$ glucose
    B. Protein $\rightarrow$ amino acid
    C. Fat $\rightarrow$ glycerol
    D. Lipid $\rightarrow$ fatty acid
15. What reaction is produced by enzyme lipase in the small intestine?
    A. Protein +H_2O $\rightarrow$ amino acid
    B. Peptide + H_2O $\rightarrow$ amino acid
    C. Fat droplets + H_2O $\rightarrow$ glycerol + fatty acid
    D. Starch + H_2O $\rightarrow$ maltose
16. What does small intestine do in the digestive system?
    A. Stores waste materials
    B. Extracts water and mineral salts from undigested food
    C. Secrets digestive enzymes
    D. Houses bacteria
17. Which one of the following is the correct path of waste material in large intestine?
    A. Cecum ▶ rectum ▶ colon ▶ anus
    B. Cecum ▶ colon ▶ rectum ▶ anus
    C. Cecum ▶ anus ▶ rectum ▶ colon
    D. Cecum ▶ colon ▶ anus ▶ rectum
18. Why small intestine absorbs many substances?
    A. Because it secrets digestive enzymes
    B. Because it moves contents along peristalsis
    C. Because villi increases its surface area
    D. Because villi passes them through diffusion
19. How absorption of substances takes place in the small intestine?
    A. Through duodenum ▶ ileum ▶ jejunum
    B. Through Ileum ▶ jejunum ▶ duodenum
    C. Through jejunum ▶ ileum ▶ duodenum
    D. Through duodenum ▶ jejunum ▶ ileum
20. Which of the following statement is true about absorption of substances?
    A. Monosaccharide are absorbed into lacteals
    B. Amino acids are absorbed into lymph vessels
    C. Fats are absorbed into capillaries
    D. Fats are absorbed into lacteals
21. Which of the following statement is correct about blood and heart?
    A. Blood from the systemic system enters the left atrium
    B. Blood from the systemic system enters the left ventricle
    C. Blood from the pulmonary system enters the left atrium
    D. Blood from the pulmonary system enters the left ventricle
22. Which of the following valve separates the left atria from the left ventricle?
    A. Tri-cuspid valve
    B. Semi-lunar valve
    C. Bi-cuspid valve
    D. Septum

23. Which of the following statement is correct about pulmonary circulation?
    A. Blood move from heart to the body system for oxygenation
    B. Blood move from heart to lung for oxygenation
    C. Blood move from lung to heart for oxygenation
    D. Blood move from lung to body system for oxygenation
24. Which of the following statement is true about pulmonary artery?
    A. Carries oxygenated blood C. Carries deoxygenated blood
    B. Transports blood from lung to heart D. Transports blood from heart to body
25. What action is taken place correctly in the systemic circulation?
    A. Blood moves from lung to body to provide oxygen and nutrient
    B. Gases and nutrients exchange in the capillaries
    C. Metabolic wastes diffuse from blood into the cell
    D. Oxygen and glucose diffuse from cell to the blood
26. ____________ is the body's largest artery which supplies oxygenated blood to the body?
    A. Pulmonary artery C. Pulmonary vein
    B. Aorta D. Valve
27. What component makes up about half of the content of the blood?
    A. Protein C. Plasma
    B. Cells D. Oxygen
28. ______________ is a blood type contains hemoglobin to carry oxygen for the cells of the body?
    A. White blood cell C. Red blood cell
    B. Platelets D. Plasma
29. What type of cells are the first respondents of our immune system?
    A. Platelets C. Plasma cells
    B. White blood cells D. Red blood cells
30. What is the function of antigens?
    A. Transporting other molecules into and out of the cell,
    B. Maintaining the structure of white blood cells
    C. Detecting important cells that could cure illness
    D. Fighting microorganisms
31. What type of blood group has no antigen on the surface of red blood cell?
    A. Group A C. Group B
    B. Group AB D. Group O
32. Which blood group is universal recipient?
    A. Group AB C. Group O
    B. Group A D. Group B
33. What component of lymphatic system made up of lymphocytes and white blood cells?
    A. Lymph vessel C. Lymphoid tissue
    B. Lymph D. Macrophages

34. _______________ are lymphatic tissue located line the nose, mouth, and throat?

A. Spleen C. Tonsils

B. Thymus D. Lymph nodes

35. How tiny hairs of the nasal cavities keep foreign particles enter into breathing tract?

A. Through warming with mucus m C. Through moistens the incoming air

B. Through trap foreign particles D. Through filtering

36. What structure serves as both digestive and breathing organ?

A. Throat C. Larynx

B. Esophagus D. Trachea

37. Which of the following statement is false about breathing movements?

A. Pressure in the atmospheric remains constant while it vary in the chest cavity

B. In and out air of the lung is determined by atmospheric pressure

C. During inspiration the pressure inside the lungs is greater than the atmosphere

D. In expiration the pressure inside the lung is greater than the atmosphere

38. What action is under taken during inspiration?

A. Diaphram muscle contracts C. diaphragm pulling up

B. The chest volume decreases D. pressure in the lung increases

39. What happens in ribcage during inspiration?

A. Move downward C. Move inward

B. Move upwards D. Immovable

40. Which of the following breathing structure is responsible for gas exchange?

A. Trachea C. Bronchioles

B. Alveolus D. Larynx

41. Which of the following process and action is miss match in the formation of urine?

A. Glomerular filtration filters proteins

B. Tubular reabsorption reabsorbs water

C. Tubular secretion secrets extra solutes and wastes

D. Collecting ducts collect filtrate from the nephrons

42. What urologic organ differs significantly between males and girls?

A. Ureter C. Urethra

B. Uretary bladder D. Kidney

Appendix C: scoring rubrics

Rubrics for critical thinking skills test score

CTEE Test Rubric

Scores	Description

5	• Covers correct, clear, and specific concepts • Provides accurate, clear, and precise answers, and supports them by strong, right, and clear arguments • Shows a smooth flow of thinking, all of the concepts are interrelated • Presents perceptible aspects and provides fair and accurate evidence
4	• Most of the concepts covered are exact, clear, and specific • The descriptions of the answers are mostly correct and clear, but less specific • Shows a smooth flow of thinking, most of the concepts are interrelated and integrated • All of the aspects are perceptible, but the evidence is not yet fair
3	• Some of the concepts covered are correct, clear, and specific • Some of the descriptions of the answers are correct, but supporting arguments are sometimes irrelevant • The flow of thinking is quite smooth, only small parts of the concepts are interrelated • Most of the aspects are perceptible
2	• Covers unclear, sometimes exaggerated or confusing concepts • Provides irrelevant arguments to support answers • Shows the poor flow of thinking, unrelated concepts • Only small parts of aspects are correct
1	• Covers incorrect or insufficient concepts • Provides false arguments • Shows inferior flow of thinking • All of the elements are imperceptible
0	• No answer or incorrect answer

Rubrics for problem solving skills test score

Criteria	Excellent (4)	Good (3)	Fair (2)	Needs Improvement (1)
Understanding the Problem	Clear, full restatement with key details	Mostly clear	Partial understanding	Misunderstood or vague
Use of Evidence	Strong, relevant examples or data	Some support	Minimal support	Irrelevant or unsupported
Inference and Logic	Insightful and logical conclusions	Mostly logical	Somewhat logical	Illogical or flawed reasoning

Analysis of Assumptions	Clearly identifies and evaluates assumptions	Identifies some	Limited depth	None identified
Problem-Solving Strategy	Logical and detailed action plan	Clear but general steps	Vague or incomplete	No clear plan provided

Appendix D: ongoing data

Sample student reflection data for Amare's dietary scenario (S1–S6)

Student	Clarification	Basic Support	Inference	Advanced Clarification	Tactics/Strategy	Tool Feedback	Insights for DBR
S1	Amare ate whole grains, fruits, and vegetables like injera and cabbage during fasting, with no meat. After Easter, he ate meat like doro wat and got constipated, showing the diet change caused the issue.	The scenario says Amare's teeth chewed grains well and he had comfortable bowel movements during fasting, so vegetables and grains helped digestion. Constipation after meat suggests it was harder to digest.	I think Amare got constipated because he suddenly ate meat after two months without it. His stomach wasn't ready, and meat lacks fiber.	"Processed well" means fiber in injera and cabbage sped up digestion, keeping stools regular. Doro wat, being low-fiber and high-fat, likely slowed his gut, as his enzymes weren't ready for meat after fasting.	Amare should eat gomen with doro wat and drink 1.5L water daily to maintain fiber and hydration. Water is easy and free, but gomen might be costly post-fasting. This fits Easter traditions.	The food diary was useful for tracking injera and water, but adding pictures of gomen would make it engaging. Checkboxes for water would help kids track easier.	In DBR, I designed a solution (gomen, water), tested it on myself, and saw regular digestion. I'd refine it by adding papaya for fiber and share my diary in class for iterative feedback.
S2	Amare's fasting diet was teff injera, shiro, and fruits, with no meat. After Easter, he ate tibs and got constipated, indicating meat caused the digestive change.	The scenario says his tract moved well during fasting, so injera and fruits were easy to digest. Constipation after tibs shows meat disrupted digestion,	I infer Amare's constipation came from eating too much meat at once, as heavy meals can slow digestion. The lack of fiber in tibs was likely	"Tract moved well" means fiber in teff and shiro supported smooth gut motility. Tibs' high fat and low fiber likely slowed digestion, as his gut bacteria	Amare should eat small tibs portions with shiro to ease into meat and keep fiber high. Small portions are practical, as extra vegetables might be expensive for his family.	The "teff broom" diagram showed fiber's role clearly, but more food pictures would help. A class water chart poster would make	In DBR, I designed a solution (small tibs portions, shiro) and tested it, improving digestion. I'd refine it with a colorful water chart and test adding

		as the scenario highlights the diet shift.	the main issue.	weren't adapted to meat post-fasting.		tracking hydration fun for everyone.	mango for fiber in the next iteration.
S3	Amare ate whole grains, fruits, and vegetables during fasting, with no meat. After Easter, he ate meat and likely fewer vegetables, leading to constipation.	The scenario says he had good toilet experiences during fasting, so his diet was healthy. Constipation after meat shows it changed digestion, likely due to less fiber.	I think Amare got constipated because meat has no fiber, unlike vegetables. Less water or overeating at Easter might have also contributed.	"Good toilet experiences" means regular stools from fiber in grains and fruits. Meat lacks fiber, so his gut struggled to process it, possibly due to reduced enzyme activity after two months without meat.	Amare should eat injera with meat and drink water, as it's cheap and available. Buna (coffee) might help digestion, but it's not for everyone. This fits fasting traditions.	The food diary helped track injera but needs simpler boxes for kids. Adding a bowel movement column would clarify digestion patterns.	In DBR, I designed a solution (injera, water), tested it, and removed coffee after it failed. I'd test oranges next and simplify the diary with pictures for better classroom use.
S4	Amare ate lentils and injera during fasting, with no meat. After Easter, he ate kitfo and had toilet trouble, showing meat caused the issue.	The scenario says he was fine during fasting, so lentils and injera supported digestion. Toilet trouble after kitfo indicates meat disrupted his gut.	I infer Amare's body wasn't ready for kitfo after fasting, like when I overeat at holidays. Meat's lack of fiber likely caused constipation.	"Fine during fasting" means smooth digestion from fiber in lentils. Kitfo, being raw and high-fat, likely overwhelmed his gut, as enzymes weren't adjusted for meat after two months.	Amare should eat kitfo with gomen and walk after meals to aid digestion. Walking is free and fits fasting lifestyles, though vegetables might be hard to get post-fasting.	The virtual lab on injera's fiber was fun but could be a game with points for picking fibrous foods to make learning interactive.	In DBR, I designed a solution (gomen, walking), tested it, and saw better digestion. I'd refine it with papaya and create a gamified lab for iterative classroom learning.
S5	Amare ate teff, lentils, and fruits during fasting, with no meat. After Easter, he	The scenario says his digestion was good during fasting, so teff and	I infer Amare's constipation was due to meat's lack of fiber and possibly	"Good digestion" means fiber in teff and fruits supported gut motility. Doro wat's	Amare should eat shiro with doro wat and drink water to keep fiber and hydration high. Water is simple, but	The digestion diagram helped, but I needed teacher explanation for	In DBR, I tested a solution (shiro, water) and saw better digestion. I'd refine it

	ate doro wat and maybe bread, leading to constipation.	fruits helped. Constipation after doro wat shows meat was harder to digest.	less water after Easter feasts, slowing his digestion.	low fiber and potential dehydration likely slowed his intestines after fasting.	shiro might be more affordable than extra vegetables.	"intestines." Adding animations of digestion would make it clearer without extra help.	with papaya and improve the diagram with animations for clearer classroom learning.
S6	Amare ate injera and cabbage during fasting, with no meat. After Easter, he ate tibs and got constipated, showing meat caused the digestive issue.	The scenario says he felt good during fasting, so injera and cabbage helped digestion. Constipation after tibs indicates meat changed his gut function.	I infer Amare ate too much tibs at once, confusing his stomach after fasting. Meat's low fiber likely caused the constipation.	"Felt good" means regular digestion from fiber in cabbage and injera. Tibs' low fiber and high fat likely slowed his gut, as it wasn't ready for meat post-fasting.	Amare should eat less tibs with injera to maintain fiber. This is easy and fits post-fasting cravings, though he might want more meat.	The food diary was good for tracking injera; pictures of injera and cabbage would make it engaging. A class fiber chart would help us learn together.	In DBR, I designed a solution (less tibs, injera), tested it, and saw improvement. I'd refine it with bananas and create a class fiber chart for collaborative learning.

Sample observation checklist data for Amare's dietary scenario

Critical Thinking Skill	Indicator	Yes	Partial	No	Notes
Elementary Clarification	Accurately lists fasting foods (e.g., injera, lentils, vegetables) and post-fasting foods (e.g., doro wat, tibs, kitfo).	☑	☐	☐	All students list specific fasting foods (e.g., injera, lentils, cabbage, teff, fruits) and post-fasting foods (e.g., doro wat, tibs, kitfo). Some are less detailed (e.g., "injera and cabbage") but sufficient, fully addressing the simplified prompt: "How does the scenario show Amare's fasting diet was healthy for his digestion?"
	Explains why the scenario mentions "chewed effectively" and connects it to digestion.	☐	☐	☑	No student addresses "chewed effectively" or links chewing to digestion, missing the simplified prompt: "Why does the scenario say Amare's teeth 'chewed well' during fasting? How does good chewing help his digestion?" This indicates a gap in analyzing chewing's role.

Basic Support	Cites scenario details to show the fasting diet was healthy (e.g., “felt good on toilet,” “regular bowel movements”).	☑	☐	☐	All students cite scenario details (e.g., “felt good,” “tract moved well”) to support healthy digestion during fasting, fully addressing the simplified prompt: “How does the scenario show Amare’s fasting diet was healthy for his digestion?” Some are more specific (e.g., referencing fiber explicitly).
	Provides evidence that meat caused constipation (e.g., scenario’s mention of prolonged bathroom time).	☑	☐	☐	All students link constipation to meat, citing scenario evidence (e.g., “long toilet time,” “disrupted digestion”), fully addressing the simplified prompt: “What clues suggest meat caused his constipation?” Some explicitly mention fiber lack for stronger evidence.
Inference	Proposes a logical reason for constipation (e.g., low fiber, sudden meat intake).	☑	☐	☐	All students propose logical reasons (e.g., low fiber, sudden meat intake), fully addressing the simplified prompt: “Why do you think Amare got constipated after eating meat again?” Some add factors like overeating or dehydration, showing deeper reasoning.
	Supports inference with scenario details or personal/cultural experience (e.g., digestion diagram, family advice).	☑	☐	☐	All students support inferences with scenario details (e.g., toilet time, digestion diagram) or experiences (e.g., family advice), fully addressing the simplified prompt: “What might have gone wrong in his digestive system?” Some rely on peers for alignment but meet the criterion.
Advanced Clarification	Explains what “processed well” means biologically (e.g., fiber aiding gut motility).	☑	☐	☐	All students explain “processed well” as fiber in fasting foods (e.g., injera, lentils) aiding gut motility, fully addressing the simplified prompt: “What does ‘processed well’ mean for Amare’s digestion?” Some provide more detailed biological explanations.
	Explains how two-month meat absence affected digestion (e.g., enzyme or gut bacteria changes).	☑	☐	☐	All students address adaptation (e.g., enzymes or gut bacteria not ready for meat), fully addressing the simplified prompt: “How might not eating meat for two months have made it hard for his body to digest meat after Easter?” Some focus more on fiber but still meet the criterion.
Tactics and Strategy	Suggests at least two culturally relevant solutions (e.g., injera with meat, water, walking).	☑	☐	☐	All students suggest at least two culturally relevant solutions (e.g., injera, gomen, shiro, water, walking), fully addressing the simplified prompt: “What foods or habits could Amare try to avoid constipation?” Solutions fit Ethiopian traditions.
	Solutions are practical and easy for Amare’s context (e.g., affordable, accessible).	☑	☐	☐	All solutions are practical (e.g., water is free, injera is common), fully addressing the simplified prompt: “Why are your ideas easy and practical for him to follow?” Students note barriers like vegetable costs, showing

					context awareness.

Sample thematic analysis table aligned with IPIE model & Braun & Clarke's six phases for problem solving skills

Braun & Clarke Phase	IPIE Phase	Theme	Subthemes	Representative student responses	Related interview questions
Familiarization & Coding	Identify	Cognitive Structuring	- Sequential thinking - Decomposing problems - Structured mental processes	- "They assist me in structuring my thoughts..." (S1, S2, S3, S6) - "It helps me think step by step instead of jumping to conclusions." (S1, S2, S3, S5, S6)	Q1, Q3
Familiarization & Coding	Identify	Conceptual Understanding	- Applying prior knowledge - Systems thinking - Deep reflection	- "I think more deeply about the interactions between biological systems…" (S1, S4, S5, S6) - "The scenarios make me apply what I've learned instead of just memorizing." (S1, S2, S4, S5, S6)	Q1, Q3
Coding & Theme Generation	Identify	Information Management	- Locating key info - Filtering excess - Navigating text-based content	- "They teach me how to find important information..." (S2, S3, S4, S5) - "It can be disturbing when there's too much text or unnecessary information." (S1, S2, S4, S5, S6) - "Sometimes I struggle because there aren't any diagrams." (S2, S3, S5, S6)	Q1, Q2
Reviewing & Refining Themes	Plan	Strategic Planning	- Careful reading - Highlighting and outlining - Planning in stages	- "I start by reading the entire scenario carefully…" (S2, S3, S4, S5) - "I highlight or underline the key terms…" (S1, S2, S4, S5, S6) - "I plan out the steps in order…" (S2, S3, S4, S5)	Q4
Reviewing Themes	Implement	Stepwise Execution	- Follow-through - Step-by-step implementation - Using learned concepts	- "Once I have a plan, I go through each step…" (S2, S3, S5, S6) - "I compare my steps with the concepts we've learned…" (S1, S2, S3, S5, S6) - "I follow the sequence of steps... but make small changes." (S2, S3, S4, S5)	Q5

Braun & Clarke Phase	IPIE Phase	Theme	Subthemes	Representative student responses	Related interview questions
Reviewing Themes	Implement & Evaluate	Adaptability and Monitoring	- Revisiting the scenario - Revising plans - Using feedback from process	- "If I get stuck, I go back to the scenario…" (S1, S2, S3, S4, S5) - "I double-check my understanding as I go…" (S2, S3, S4, S5) - "Compare with similar problems we've done…" (S1, S2, S3, S4, S5)	Q5, Q6
Defining Themes	Evaluate	Metacognitive Evaluation	- Self-checking steps - Alternative perspectives - Reflective practice	- "I go through each step again to see if I followed my plan correctly." (S1, S2, S3, S4) - "If something feels off... I try to look at the problem from another angle." (S1, S2, S3, S5) - "Even though there's no feedback right away, I spend more time reflecting..." (S2, S3, S4, S5)	Q3, Q6
Defining Themes	Evaluate	Communication and Justification	- Clarity of reasoning - Justified answers - Audience awareness	- "I write my answers clearly, explaining how I got them..." (S2, S3, S4, S5, S6) - "I ask myself if my explanation makes logical sense…" (S1, S3, S4, S6) - "I think about whether my answer could be clearly understood by someone else." (S1, S2, S4, S5, S6)	Q5, Q6
Theme Finalization	Cross-cutting	Confidence and Autonomy	- Self-paced thinking - Ownership of reasoning - Using knowledge independently	- "I like that I can take my time and read through the problem carefully." (S2, S3, S4, S5) - "I'm becoming more utilizing my understanding of biology to strengthen my opinions." (S1, S3, S4, S6)	Q1, Q2

Appendix E: retrospective data

Table 1 for interview Q1

Braun & Clarke Phase	Theme	Description	Illustrative Quotes	Representative Student Responses	Interview Question (Q7)
Searching for Themes,	Engagement and	Digital PBS offered dynamic	- "Digital scenarios… were	"Paper-based scenarios were great for digestive system	Can you describe your

Braun & Clarke Phase	Theme	Description	Illustrative Quotes	Representative Student Responses	Interview Question (Q7)
Reviewing Themes, Defining and Naming Themes	Interactivity	simulations (e.g., animations, 3D models), enhancing engagement; paper PBS provided structured, tactile engagement via annotation.	engaging with animations of blood flow" (P1). - "Paper-based scenarios were great… I could highlight and write notes" (P1).	cases, like acid reflux, because I could highlight and write notes directly. Digital scenarios for the circulatory system were more engaging with animations of blood flow, but the platform sometimes froze, which was frustrating." (P1)	overall experience using PBS as a learning tool in your human biology?
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Conceptual Understanding and System Integration	Both formats clarified system functions; digital PBS excelled in visualizing interactions (e.g., immune responses), while paper supported detailed analysis.	- "Digital scenarios were best… animations of antibody action" (P4). - "Paper scenarios… helped me think through the problem" on circulatory system (P5).	"Digital scenarios were best for the immune system. A viral infection case had animations of antibody action, which paper couldn't match. Paper scenarios for circulation were clear but less exciting. Navigating digital platforms was sometimes confusing." (P4)	Can you describe your overall experience using PBS as a learning tool in your human biology?
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Usability and Accessibility	Paper PBS were simple and universally accessible; digital PBS were versatile but required technical skills and reliable technology.	- "Paper scenarios… we could spread them out for group discussions" (P3). - "Accessing [digital scenarios] was tough without a good laptop" (P3).	"I liked paper scenarios for excretory system cases, like kidney failure, because we could spread them out for group discussions. Digital scenarios for digestion had cool 3D models, but accessing them was tough without a good laptop or Wi-Fi." (P3)	Can you describe your overall experience using PBS as a learning tool in your human biology?
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Collaboration and Peer Interaction	Paper PBS encouraged face-to-face discussions; digital PBS enabled virtual collaboration but depended on technology.	- "Paper scenarios… were perfect for group work—we just shared the sheets" (P7). - "My group struggled with digital access due to poor internet" (P6).	"Paper scenarios for respiratory cases, like COPD, were perfect for group work—we just shared the sheets. Digital scenarios for digestion had awesome animations, but the interface was tricky. Both formats taught me a lot about the systems." (P7)	Can you describe your overall experience using PBS as a learning tool in your human biology?

Braun & Clarke Phase	Theme	Description	Illustrative Quotes	Representative Student Responses	Interview Question (Q7)
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Challenges and Limitations	Paper PBS lacked interactivity; digital PBS faced technical issues (e.g., crashes, navigation difficulties) and accessibility barriers.	- “The [digital] platform sometimes froze, which was frustrating” (P1). - “Paper scenarios… were straightforward but dull” (P6).	“Digital scenarios showed how digestive and immune systems interact, like in a food allergy case, with great visuals. Paper scenarios for the excretory system were straightforward but dull. My group struggled with digital access due to poor internet.” (P6)	Can you describe your overall experience using PBS as a learning tool in your human biology?

Table 2 Q2

Braun & Clarke Phase	Theme	Description	Illustrative Quotes	Representative Student Responses	Interview Question (Q8)
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Enhanced Conceptual Clarity	PBS made abstract concepts (e.g., kidney filtration, antibody action) concrete and understandable through practical scenarios.	- “Paper-based scenarios helped me understand digestion… how the esophagus and stomach interact” (P1). - “Digital scenarios… showed lung mechanics dynamically” (P5).	“Paper-based scenarios helped me understand digestion deeply by letting me annotate steps of acid reflux cases, like how the esophagus and stomach interact. Digital scenarios were better for the circulatory system—animations showed blood flow and heart function clearly. Sometimes, though, digital platforms were slow, which broke my focus.” (P1)	In what ways have PBS helped you understand human biology concepts more deeply?
Searching for Themes, Reviewing Themes, Defining and Naming Themes	System Integration and Interconnectivity	PBS highlighted interactions between systems (e.g., digestive and immune systems in allergies), deepening understanding of their interconnected roles.	- “Digital scenarios helped me see how the digestive and immune systems work together” (P6). - “Paper scenarios… helped me analyze blood pressure” and its systemic effects	“Digital scenarios helped me see how the digestive and immune systems work together, like in a food allergy case with visuals of gut inflammation. Paper scenarios for the excretory system were clear but static, so I didn’t get the full picture of dynamic processes.” (P6)	In what ways have PBS helped you understand human biology concepts more deeply?

Braun & Clarke Phase	Theme	Description	Illustrative Quotes	Representative Student Responses	Interview Question (Q8)
			(P4).		
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Critical Thinking and Application	PBS encouraged applying concepts to solve problems, fostering deeper analysis of system-specific issues (e.g., asthma triggers, hypertension causes).	- "Paper scenarios… let me break down concepts like vessel resistance" (P5). - "Digital scenarios made the respiratory system click… showed how bronchi constrict" (P2).	"Paper scenarios for circulatory system cases, like hypertension, let me break down concepts like vessel resistance by writing notes. Digital scenarios for respiration showed lung mechanics dynamically, which was awesome, but glitches sometimes made it hard to follow." (P5)	In what ways have PBS helped you understand human biology concepts more deeply?
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Format-Specific Learning Benefits	Paper PBS supported focused, step-by-step analysis; digital PBS enhanced understanding through dynamic visualizations (e.g., animations, 3D models).	- "Paper scenarios… helped me map out filtration processes step-by-step" (P3). - "Digital scenarios… had animations of T-cells attacking pathogens" (P4).	"Digital scenarios really deepened my understanding of the immune system. A viral infection case had animations of T-cells attacking pathogens, which was clearer than paper descriptions. Paper scenarios for circulation helped me analyze blood pressure, but they felt less vivid." (P4)	In what ways have PBS helped you understand human biology concepts more deeply?
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Challenges to Understanding	Complexity in paper PBS or technical issues in digital PBS (e.g., slow platforms, confusing interfaces) limited the depth of understanding.	- "Digital platforms were slow, which broke my focus" (P1). - "Paper scenarios… were clear but static" (P6).	"Paper scenarios for respiratory cases, like COPD, helped me understand airflow limitation by sketching diagrams. Digital scenarios for digestion showed enzyme breakdown in action, which was super clear, but the interface was sometimes confusing, slowing me down." (P7)	In what ways have PBS helped you understand human biology concepts more deeply?

Table3 Q3

Braun & Clarke Phase	Theme	Description	Illustrative Quotes	Representative Student Responses	Interview Question (Q3)

Braun & Clarke Phase	**Theme**	**Description**	**Illustrative Quotes**	**Representative Student Responses**	**Interview Question (Q3)**
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Analytical Problem-Solving	PBS promoted breaking down complex biological cases into clear components (elementary clarification) and making reasoned inferences about causes, aligning with Ennis's critical thinking framework.	- "Paper scenarios… clarified acid reflux by listing symptoms and causes" (P1). - "Digital scenarios… inferred hypertension causes from heart strain visuals" (P1).	"Paper-based scenarios sharpened my critical thinking by helping me clarify digestion issues, like acid reflux, by listing symptoms and causes (elementary clarification). For example, I analyzed heartburn and inferred diet as a primary cause, proposing lifestyle changes (inference). Digital scenarios for circulation, with animations of heart strain, helped me infer hypertension causes, but platform glitches disrupted my focus." (P1)	How have PBS influenced your ability to think critically (Ennis's framework) about human biology topics? Can you provide a specific example?
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Evaluating Multiple Perspectives	PBS encouraged weighing diverse causes and solutions (basic support) and judging their relevance (advanced clarification), fostering critical evaluation per Ennis's framework.	- "I weighed allergens versus exercise in asthma" (P2). - "I judged diet versus genetics for hypertension" (P4).	"Digital scenarios improved my critical thinking about the respiratory system by letting me weigh triggers like allergens versus exercise in an asthma case (basic support). I used diagrams to judge environmental factors as primary (advanced clarification). For example, I prioritized allergen avoidance. Paper scenarios for the immune system were less dynamic, limiting my ability to visualize T-cell responses." (P2)	How have PBS influenced your ability to think critically (Ennis's framework) about human biology topics? Can you provide a specific example?
Searching for Themes, Reviewing Themes, Defining and Naming Themes	System Interconnectivity	PBS fostered analysis of system interactions (e.g., digestive and immune systems), using inference and advanced clarification to understand causal relationships, per	- "Digital scenarios… inferred gut inflammation's role in immune responses" (P6). - "Paper scenarios… clarified airflow limitation's	"Digital scenarios helped me think critically about digestive and immune system interactions in a food allergy case. I inferred how gut inflammation triggers immune responses using visuals (inference) and clarified allergen roles (advanced clarification).	How have PBS influenced your ability to think critically (Ennis's framework) about human biology topics? Can you provide a

Braun & Clarke Phase	**Theme**	**Description**	**Illustrative Quotes**	**Representative Student Responses**	**Interview Question (Q3)**
		Ennis's framework.	systemic effects" (P7).	Paper scenarios for the excretory system were clear but static, limiting dynamic analysis of kidney issues." (P6)	specific example?
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Format-Specific Critical Thinking Benefits	Paper PBS supported structured reasoning (strategy and tactics); digital PBS enabled dynamic analysis (inference), enhancing Ennis's critical thinking aspects in distinct ways.	- "Paper scenarios… strategic breakdown of vessel resistance" (P5). - "Digital scenarios… inferred lung dynamics for asthma" (P5).	"Paper scenarios for circulatory cases, like hypertension, supported a strategic breakdown of vessel resistance (strategy and tactics), improving my analysis. For example, I clarified stress versus artery narrowing (elementary clarification). Digital scenarios for respiration inferred lung dynamics in asthma (inference), but app crashes disrupted my reasoning." (P5)	How have PBS influenced your ability to think critically (Ennis's framework) about human biology topics? Can you provide a specific example?
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Challenges to Critical Thinking	Paper's static nature limited dynamic inference; digital's technical issues (e.g., crashes) disrupted advanced clarification and strategy, hindering Ennis's critical thinking processes.	- "Glitches disrupted my reasoning" (P1). - "Paper scenarios… limited dynamic kidney analysis" (P6).	"Paper scenarios for respiratory cases, like COPD, clarified airflow limitation by sketching causes like smoking (elementary clarification), supporting strategic solutions (strategy and tactics). Digital scenarios for digestion inferred enzyme action in malabsorption (inference), but confusing interfaces slowed my reasoning. For example, I evaluated lactose intolerance triggers." (P7)	How have PBS influenced your ability to think critically (Ennis's framework) about human biology topics? Can you provide a specific example?

Table 4 Q4

Braun & Clarke Phase	**Theme**	**Description**	**Illustrative Quotes**	**Representative Student Responses**	**Interview Question (Q4)**

Braun & Clarke Phase	Theme	Description	Illustrative Quotes	Representative Student Responses	Interview Question (Q4)
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Structured Problem Identification	PBS enabled students to clearly define complex biological problems by analyzing symptoms and causes, grounding the problem-solving process.	- "Paper scenarios helped me identify acid reflux causes like diet" (P1). - "Digital scenarios pinpointed asthma triggers via visuals" (P2).	"In a paper-based scenario, I identified acid reflux as the problem by analyzing symptoms like heartburn and regurgitation. I listed potential causes, such as spicy foods or stress, which clarified the issue. The structured format of paper scenarios made it effective by letting me annotate and organize thoughts systematically. Digital scenarios for circulation were less effective due to platform lag." (P1)	Can you share an instance where a problem-based scenario helped you solve a complex problem (identify the problem, plan, implement, and evaluate the solution) related to human biology? What made it effective?
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Strategic Planning	PBS supported developing targeted plans by considering multiple factors and prioritizing solutions, fostering strategic thinking.	- "I planned dietary changes for hypertension" (P4). - "I planned allergen avoidance for asthma" (P2).	"In a digital scenario on asthma, I identified airway constriction and planned a solution by prioritizing allergen avoidance over exercise reduction, using interactive diagrams to visualize triggers. The dynamic visuals made planning effective, though navigation issues slowed me down. Paper scenarios for the immune system were less engaging but allowed clear planning of infection responses." (P2)	Can you share an instance where a problem-based scenario helped you solve a complex problem (identify the problem, plan, implement, and evaluate the solution) related to human biology? What made it effective?
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Effective Implementation	PBS facilitated applying solutions, with paper scenarios enabling detailed execution and digital scenarios offering dynamic simulations to test approaches.	- "I implemented lifestyle changes for kidney issues" (P3). - "Digital scenarios tested immune response strategies" (P4).	"In a paper scenario on kidney failure, I identified reduced filtration and planned increased hydration. I implemented this by outlining a fluid intake schedule, which was effective due to the scenario's clear structure for annotating steps. Digital scenarios for digestion showed enzyme action, but technical glitches hindered implementation." (P3)	Can you share an instance where a problem-based scenario helped you solve a complex problem (identify the problem, plan, implement, and evaluate the solution) related to human biology? What

Braun & Clarke Phase	Theme	Description	Illustrative Quotes	Representative Student Responses	Interview Question (Q4)
					made it effective?
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Solution Evaluation	PBS encouraged assessing outcomes by comparing expected versus actual results, refining critical thinking and PSS.	- "I evaluated blood pressure reduction after diet changes" (P5). - "I assessed airflow improvement in COPD" (P7).	"In a paper scenario on hypertension, I identified vessel resistance, planned dietary changes, and implemented a low-sodium diet. I evaluated the solution by comparing blood pressure readings, which was effective due to the scenario's clear framework for tracking outcomes. Digital scenarios for respiration were vivid but less reliable due to app crashes." (P5)	Can you share an instance where a problem-based scenario helped you solve a complex problem (identify the problem, plan, implement, and evaluate the solution) related to human biology? What made it effective?
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Factors Enhancing Effectiveness	Paper PBS were effective for their simplicity and structure; digital PBS excelled in visualization but were limited by technical issues, impacting problem-solving success.	- "Paper's structure made planning clear" (P6). - "Digital visuals were effective but crashed" (P7).	"In a digital scenario on food allergies, I identified gut inflammation, planned an elimination diet, implemented it via food logs, and evaluated reduced symptoms. The animations of immune responses made it effective by clarifying interactions, though slow interfaces disrupted progress. Paper scenarios for COPD were simpler but less dynamic for evaluating airflow solutions." (P6)	Can you share an instance where a problem-based scenario helped you solve a complex problem (identify the problem, plan, implement, and evaluate the solution) related to human biology? What made it effective?

Table 5 Q5

Braun & Clarke Phase	Theme	Description	Illustrative Quotes	Representative Student Responses	Interview Question (Q5)
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Cultural Relevance and Engagement	Ethiopian IK, such as using gomen for digestion or steaming for breathing, connected biology concepts to cultural practices, making	- "Gomen for constipation… felt relevant because it tied to cultural traditions" (P1). - "Steaming	"Learning about Ethiopian practices, like eating gomen to relieve constipation, helped me understand how fiber aids digestion in the intestines. It felt relevant because it	How has the incorporation of IK in the lessons affected your understanding of human biology concepts?

Braun & Clarke Phase	Theme	Description	Illustrative Quotes	Representative Student Responses	Interview Question (Q5)
		lessons more relatable and engaging.	with garlic… interesting to see how culture connects to biology" (P2).	tied to cultural traditions I recognized. For the circulatory system, learning how traditional dances promote heart health showed me the importance of physical activity, though I needed more background on practices like damakassie." (P1)	
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Holistic System Understanding	Ethiopian perspectives, such as using selit or tikur azmude, emphasized interconnectedness of body systems, enhancing comprehension of their interactions.	- "Selit in diets… boosts immune responses" (P6). - "Tikur azmude in fasting… helped me understand blood pressure regulation" (P5).	"Learning about Ethiopian fermented foods and selit in a lesson on digestion and immunity showed how gut bacteria boost immune responses, which was eye-opening and connected to my community's practices. For the circulatory system, using tikur azmude during fasting clarified blood pressure regulation, but I needed more context to fully grasp its cultural significance." (P6)	How has the incorporation of IK in the lessons affected your understanding of human biology concepts?
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Practical Application of IK	Applying Ethiopian practices (e.g., hot drinks with garlic for breathing, damakassie for kidneys) clarified biological processes through practical, culturally grounded examples.	- "Hot garlic drinks… clarified how airways function" (P3). - "Damakassie teas… made kidney filtration tangible" (P4).	"A lesson on the respiratory system discussed Ethiopian steaming with hot garlic drinks, which clarified how airways clear mucus. It was practical and relatable. For the excretory system, learning about damakassie teas helped me see kidney filtration, but I struggled to understand some cultural references like tikur azmude." (P3)	How has the incorporation of IK in the lessons affected your understanding of human biology concepts?
Searching for Themes, Reviewing Themes,	Cultural Connection to Real-World	Ethiopian IK, such as gomen or hot cloth for lymph nodes, grounded biology in community-	- "Hot cloth for lymph nodes… showed immune response" (P1).	"A lesson on the immune system used Ethiopian knowledge about applying hot cloth for lymph nodes,	How has the incorporation of IK in the lessons affected your

Braun & Clarke Phase	Theme	Description	Illustrative Quotes	Representative Student Responses	Interview Question (Q5)
Defining and Naming Themes	Biology	based contexts, linking concepts to real-world cultural practices.	- “Telba diets and their impact on nutrient absorption was relatable” (P7).	which made immune responses clearer. For digestion, learning about gomen and telba diets and their impact on nutrient absorption was relatable, but some practices like steaming felt too unfamiliar to fully connect with.” (P7)	understanding of human biology concepts?
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Challenges to Integration	Unfamiliarity with Ethiopian practices like damakassie or tikur azmude, or lack of sufficient cultural context, limited understanding of biological concepts.	- “Needed more background on damakassie” (P1). - “Tikur azmude terms unfamiliar” (P5).	“A lesson on circulation linked Ethiopian fasting practices with tikur azmude to heart health, helping me understand blood pressure regulation in a cultural context. For the respiratory system, learning how steaming with garlic aids breathing was fascinating, but I found terms like damakassie unfamiliar, which made it harder to follow.” (P5)	How has the incorporation of IK in the lessons affected your understanding of human biology concepts?

Table 6 Q2

Braun & Clarke Phase	Theme	Description	Illustrative Quotes	Representative Student Responses	Interview Question (Q6)
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Cultural Clarification of Concepts	Ethiopian practices clarify biological concepts, supporting elementary and advanced clarification by grounding problems in cultural contexts.	- “Gomen clarified digestion issues” (P1). - “Garlic steaming… made airways clear” (P2).	“Learning about gomen for constipation helped me clarify digestion problems by linking fiber to peristalsis. In a case study on slow digestion, I used gomen’s role to ask basic questions about diet and then explored advanced enzyme interactions, making critical thinking more relatable through Ethiopian practices.” (P1)	In what ways has IK shaped your approach to critical thinking or problem-solving in this course? Can you give an example?

Braun & Clarke Phase	Theme	Description	Illustrative Quotes	Representative Student Responses	Interview Question (Q6)
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Practical Application of Indigenous Solutions	Ethiopian remedies enable students to identify, plan, implement, and evaluate solutions to biological problems in a culturally relevant way.	- “Garlic drinks… planned airway solutions” (P2). - “Hot cloth… implemented immune fixes” (P5).	“Hot garlic drinks and steaming shaped my problem-solving for respiratory issues. In a discussion on asthma, I identified steam inhalation as a solution, planned its use based on cultural practices, implemented it in a hypothetical scenario, and evaluated how it reduces airway inflammation, making problem-solving practical.” (P2)	In what ways has IK shaped your approach to critical thinking or problem-solving in this course? Can you give an example?
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Holistic Inference of System Interactions	Ethiopian practices encourage inferring connections between biological systems, fostering holistic critical thinking.	- “Selit… inferred gut-immunity link” (P3). - “Damakassie… connected kidneys-heart” (P6).	“Selit in diets helped me infer how digestion supports immunity. In a case on immune weakness, I critically analyzed how selit’s nutrients strengthen gut health, which influences immune responses, encouraging me to think holistically about system interactions rather than isolating them.” (P3)	In what ways has IK shaped your approach to critical thinking or problem-solving in this course? Can you give an example?
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Strategic Design Using Cultural Knowledge	Ethiopian knowledge informs the design of culturally relevant strategies to address biological challenges, enhancing critical thinking.	- “Tikur azmude… strategic hypertension plan” (P4). - “Telba… designed nutrient solutions” (P7).	“Tikur azmude for blood pressure regulation shaped my strategic thinking for circulatory problems. In a hypertension task, I designed a strategy combining fasting with tikur azmude and exercise, critically comparing it to pharmaceuticals to create a culturally informed solution.” (P4)	In what ways has IK shaped your approach to critical thinking or problem-solving in this course? Can you give an example?
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Practical Application of Indigenous Solutions	Applying practices like hot cloth for lymph nodes supports practical problem-solving by identifying and implementing culturally grounded	- “Hot cloth… solved lymphatic issues” (P5). - “Garlic steaming… cleared airways” (P2).	“Using a hot cloth for lymph node swelling shaped my problem-solving for immune issues. In an infection case study, I identified heat as a solution, planned its application based on cultural practices, implemented it hypothetically, and evaluated	In what ways has IK shaped your approach to critical thinking or problem-solving in this course? Can you give an

Braun & Clarke Phase	Theme	Description	Illustrative Quotes	Representative Student Responses	Interview Question (Q6)
		solutions.		its effect on lymphatic flow, blending cultural and biological approaches." (P5)	example?
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Holistic Inference of System Interactions	Practices like damakassie promote inferences about interconnected systems (e.g., kidneys and circulation), enhancing holistic analysis.	- "Damakassie… inferred kidney-heart link" (P6). - "Selit… gut-immunity connection" (P3).	"Damakassie as a diuretic helped me infer connections between the excretory and circulatory systems. In a fluid retention problem, I analyzed how damakassie's kidney effects reduce heart strain, encouraging me to critically think about system interactions for a holistic solution." (P6)	In what ways has IK shaped your approach to critical thinking or problem-solving in this course? Can you give an example?
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Challenges in Critical Analysis and Solution Evaluation	Unfamiliar practices like damakassie or tikur azmude hinder critical thinking and solution evaluation due to lack of cultural context.	- "Damakassie… unclear for analysis" (P7). - "Tikur azmude… hard to evaluate" (P4).	"Telba diets clarified nutrient absorption, but unfamiliar terms like damakassie hindered my critical thinking. In a kidney function task, I struggled to analyze and evaluate damakassie's role in filtration due to limited cultural context, which made it harder to develop and assess solutions." (P7)	In what ways has IK shaped your approach to critical thinking or problem-solving in this course? Can you give an example?

Table 7 Q7

Braun & Clarke Phase	Theme	Description	Illustrative Quotes	Representative Student Responses	Interview Question (Q7)
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Enhanced Academic Understanding	Paper and digital PBS, along with IK, clarified complex concepts, leading to improved grades and performance.	- "Paper-based scenarios… improved my test scores by making enzyme functions clear" (P1). - "Digital scenarios… deepened my understanding…	"Paper-based scenarios on digestion, like acid reflux cases, helped me break down concepts and improved my test scores by making enzyme functions clear. Digital scenarios on circulation, with animations of blood flow, made learning engaging, boosting my quiz	Reflecting on your academic performance, how do you feel PBS and IK have impacted your achievement in human biology?

Braun & Clarke Phase	Theme	Description	Illustrative Quotes	Representative Student Responses	Interview Question (Q7)
			raised my exam grades" (P2).	performance, though platform lags were frustrating. IK about bitter herbs for digestion gave me a cultural perspective, making concepts stick, but some practices were unfamiliar." (P1)	
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Increased Engagement and Motivation	Interactive PBS and culturally relevant IK increased interest and study effort, positively impacting achievement.	- "Digital scenarios… made learning engaging, boosting my quiz performance" (P1). - "IK… made learning meaningful, improving retention" (P7).	"Paper scenarios on respiration, like COPD, helped me analyze airflow through sketches, boosting my project grades. Digital scenarios on digestion, with enzyme animations, were engaging, but the interface was tricky. IK about smoke-free environments for lung health made learning meaningful, improving retention, though some practices were hard to grasp." (P7)	Reflecting on your academic performance, how do you feel PBS and IK have impacted your achievement in human biology?
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Development of Critical Thinking Skills	PBS fostered analytical and PSS, enhancing academic performance in assessments.	- "Paper scenarios… helped me analyze details, improving my essays" (P4). - "Digital scenarios… clarified concepts and boosted my test performance" (P4).	"Digital scenarios on immunity, like viral infections with T-cell animations, clarified concepts and boosted my test performance. Paper scenarios on circulation, like hypertension, helped me analyze details, improving my essays. Indigenous herbal antivirals gave a practical angle, making immunity memorable, but I wanted more scientific links." (P4)	Reflecting on your academic performance, how do you feel PBS and IK have impacted your achievement in human biology?
Searching for Themes, Reviewing Themes, Defining and Naming	Cultural Relevance and Contextual Learning	IK provided cultural connections, making concepts more memorable and improving retention and	- "IK… gave me a cultural perspective, making concepts stick" (P1). - "Indigenous fermented foods…	"Digital scenarios on digestion and immunity, like food allergies with gut visuals, deepened my understanding, raising my exam scores. Paper scenarios on the excretory system, like	Reflecting on your academic performance, how do you feel PBS and IK have impacted your achievement in

Braun & Clarke Phase	Theme	Description	Illustrative Quotes	Representative Student Responses	Interview Question (Q7)
Themes		performance.	made concepts relatable” (P6).	kidney stones, were clear for analysis, improving assignments. Indigenous fermented foods for gut health made concepts relatable, but I needed more cultural background.” (P6)	human biology?
Searching for Themes, Reviewing Themes, Defining and Naming Themes	Challenges Impacting Performance	Technical issues in digital PBS or unfamiliarity with indigenous practices occasionally hindered academic achievement.	- “Platform lags were frustrating” (P1). - “Some practices were unfamiliar” (P1).	“Paper scenarios on circulation, like hypertension, improved my grades by letting me annotate causes like stress, which clarified concepts. Digital scenarios on respiration, with lung simulations, were motivating, but app crashes disrupted my focus. Indigenous fasting practices for heart health connected culturally, aiding my understanding, though some practices felt foreign.” (P5)	Reflecting on your academic performance, how do you feel PBS and IK have impacted your achievement in human biology?