The Effects of Inquiry-based Learning on the Development of High School Biology Students' Critical Thinking Skills in the UAE

آثار التعلم الاستقصائي على تطوير مهارات التفكير الناقد لدى طلاب مادة علم الأحياء في الإمارات العربية المتحدة

by

SURA "MOHD OSAMA" SABRI

A thesis submitted in fulfilment

of the requirements for the degree of

DOCTOR OF PHILOSOPHY IN EDUCATION

at

The British University in Dubai

October 2019

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Abstract

Background: Critical Thinking (CT) skills are believed to be essential skills that would enable people to improve the quality of their lives. Being a strong critical thinker is a major characteristic required for future job seekers. Educators agree that people can develop critical thinking skills through training and practicing core critical thinking skills. A suitable environment where CT skills can be implemented is in science education, as it is one of the strongest tools that can be utilized to train learners to use the core CT skills, which can be developed by the implementation of Inquiry Based Learning (IBL) strategies in science classrooms. Moreover, it has been established in educational research that learning through inquiry-based activities positively affects students' learning experiences and promotes their self-regulatory learning skills.

Purpose: The purpose of this study was to Investigate the implementation of inquiry-based learning in biology on the development of high school students' critical thinking skills by investigating the current practices of IBL instructions and relating them to the development of students' CT skills.

Methods: This research followed the constructivist and postpositivist philosophies of research; the case study was employed with a multiple method design. The case study research included both quantitative and qualitative methods. The quantitative tool utilized was a non-experimental questionnaire and the qualitative tools included lesson observations, teachers' interviews and document analysis of students' artefacts.

Results: The findings of this study revealed a lack of effective implantation of IBL instructions, as IBL application was limited to structured or guided inquiry and lacked appropriate assessment methodologies in the observed practices. Results also showed a variation in teachers' ability to develop students' CT skills within classroom instructions. The result of this study proposed a professional development program that targets science teachers' skills in utilizing IBL instructions effectively to support students to develop CT skills.

Implications Contributions: it was evident that science teachers were struggling to prepare IBL activities that would help deliver the required outcomes without compromising the quality of students' understanding and their readiness to sit for standardized assessments. They were avoiding the use of open IBL activities due to concerns related to time management, the fear of losing control on students' learning and the condensed curriculum that needs to be completed before standardized testing. The implementation of the suggested professional development programs will help the teachers to transform their teaching style with the confidence that their students will achieve the required learning outcomes.

Keywords: Critical Thinking, Inquiry-Based Learning Instructions, Biology Education, UAE Education.

الملخص

معلومات أساسية: يُعتقد أن مهارات التفكير الناقد هي مهارات أساسية تمكن الأشخاص من تحسين جودة حياتهم. كما أن التمكُن من التفكير الناقد هي سمة رئيسية مطلوبة للباحثين عن العمل في المستقبل. يتفق اختصاصيو التعليم أنه يمكن للأشخاص تطوير مهارات التفكير الناقد، من خلال التدريب وممارسة مهارات التفكير الناقد الأساسية. ويعتبر تعليم العلوم بيئة مناسبة يمكن من خلالها تنفيذ مهارات التفكير الناقد، حيث آن تعليم العلوم هو أحد أكثر الأدوات فاعلية التي يمكن استخدامها لتدريب المتعلمين على استخدام مهارات التفكير الناقد الأساسية، والتي يمكن تطويرها من خلال تطبيق استراتيجيات التعليم القائم على الاستقصاء في حصص العلوم. علاوة على ذلك، فقد ثبت في البحوث التعليمية أن التعلم من خلال الأنشطة القائمة على الاستقصاء يؤثر إيجابياً على خبرات تعلم الطلاب ويعزز مهارات التعلم الذاتي- التنظيم.

غرض الدراسة: كان الغرض من هذه الدراسة هو التحقيق في فاعلية التعلم القائم على الاستقصاء في مادة علم الأحياء في تطوير مهارات التفكير الناقد لدى طلاب المدارس الثانوية من خلال التحقيق في الممارسات الحالية لاستراتيجيات التعليم القائم على الاستقصاء وربطها بتطوير مهارات التفكير الناقد لدى الطلاب.

أساليب البحث: اتبعت هذه الدراسة الفلسفة البراغماتية للبحث؛ حيث تم استخدام أسلوب دراسة حالة، وتطبيق التصميم المتزامن لجمع البيانات الكمية والنوعية والتي كان لها وزن متساوٍ في تغذية النتائج. وشمل أسلوب دراسة الحالة كلاً من الأساليب الكمية والنوعية. وكانت الأداة الكمية المستخدمة عبارة عن استبيان غير تجريبي، بينما شملت الأدوات النوعية ملاحظات الحصص ومقابلات المدرسين وتحليل لأعمال الطلاب.

نتائج الدراسة: كشفت نتائج هذه الدراسة عدم وجود دمج فاعل لتعليمات التعلم القائم على الاستقصاء، حيث اقتصر تطبيق التعلم القائم على الاستقصاء المنظم أو الموجه وافتقر إلى منهجيات

التقييم المناسبة، في الممارسات المرصودة. أظهرت النتائج أيضاً تبايناً في قدرة المعلمين على تطوير مهارات التفكير الناقد لدى الطلاب ضمن تعليمات الحصة الدراسية. اقترحت نتائج هذه الدراسة برنامج تطوير مهني يستهدف مهارات معلمي العلوم في استخدام تعليمات التعلم القائم على الاستقصاء بفاعلية لدعم لتطوير مهارات التفكير الناقد لدى الطلاب.

الآثار/ الإسهامات: كان من الواضح أن معلمي العلوم يواجهون صعوبة لإعداد أنشطة التعلم القائم على الاستقصاء والتي من شأنها أن تساعد في تحقيق النتائج المطلوبة دون المساس بجودة فهم الطلاب واستعدادهم للتقدم لاختبارات تقييم موحدة. كان المعلمون يتجنبون استخدام أنشطة التعلم القائم على الاستقصاء المفتوحة بسبب المخاوف المتعلقة بإدارة الوقت، والخوف من فقدان السيطرة على تعلم الطلاب والمناهج المكثفة التي يجب إكمالها قبل الاختبار الموحد. سيساعد تنفيذ برامج التطوير المهني المقترحة المعلمين على تغيير أسلوب التدريس لديهم، وهم على ثقة في أن طلابهم سيحققون نتائج التعلم المطلوبة.

الكلمات المفتاحية: التفكير الناقد، تعليمات التعلم القائم على الاستقصاء، تعليم مادة علم الأحياء، التعليم في الإمارات العربية المتحدة.

DEDICATION

The goal of this research study is to enrich science instructional practices in the Arab region and further develop them, to better cater to the learning requirements of students in the region. I hereby dedicate this piece of work to all the students and teachers in the Arab region, in hopes that the results and recommendations of this study would have a real impact on the current educational practices, eventually benefiting the communities where these practices take place.

This achievement is also dedicated to my parents, husband and lovely children for their patience and support throughout the four years of hard work that have been devoted to the completion of this study.

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The completion of this research would not have been possible without the support of special people, who facilitated and directed my progress during the implementation.

I would like to express my sincerest thanks to my supervisor Prof. Sufian Forawi for his continuous support, valuable advice and constructive feedback that encouraged me to complete the work and produce this thesis.

Additionally, a great deal of appreciation is due to the management of the Applied Technology High Schools for their support and approval to house my research study. I am thankful to all of the teachers and students who volunteered to contribute to the research study through the questionnaire, lesson observations, interviews and by sharing their artefacts.

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List of Definitions

Abbreviation	Definition
ATHS	Applied Technology High Schools
CT	Critical Thinking
IBL	Inquiry-based learning
NBPTS	National board for Professional Teaching Standards
OECD	
PISA	Programmed for International Student Assessment
TIMSS	
UAE	United Arab Emirates
UNESCO	United Nations Educational, Scientific and Cultural Organization

1. Introduction

This is an introductory chapter to the thesis. In this thesis, the link between learning through inquiry-based activities and the development of students' critical thinking skills in High School Biology classrooms is studied. Within this chapter, three main concepts are explained based on their employment in this research study including inquiry-based learning, critical thinking skills and biology instructions. As a secondary school biology teacher, the researcher thinks that introducing biological concepts through inquiry-based learning activities is a suitable opportunity for students to develop their critical thinking skills, especially if they were guided through discussion questions that evoke their cognitive skills. In addition to giving them the opportunity to communicate their learning experiences and reflect upon their thinking processes. This chapter includes an overview of the research study, key definitions of the main constructs addressed within the study and the structure of the thesis.

1.1 Overview of the research study

This overview includes the historical and geographical background of the study including educational reform efforts in the Middle East and the role of teachers in the educational reform process, followed by the problem statement, rationale and significance of the current research study. Then, it will describe the gap in research related to critical thinking development through inquiry-based learning instruction in the UAE. The section concludes by mentioning the purpose of the study and the research questions.

1.1.1 Study background

The word bank group released alerting reports regarding the status of education and how students learn in different regions around the world. Despite available access to education the graduates are not able to reflect the foundation literacy and numeracy skills (The World Bank group annual report, 2018). In addition, most countries in the world don't have enough data about students' learning progress, especially the development of students' reading and mathematics skills at end of primary and at the end of the lower secondary school. According to the report, only 45% of the countries in the world have data about the results of the learning outcomes for students in the lower secondary schools and 60% of the Arab states have this type of data. Even when data is available it is not consistent and cannot be used to adjust the learning process in these countries (International Bank for Reconstruction and Development, 2018 page 17). The report also highlighted that graduates in general lack critical thinking and higher order thinking skills and emphasized on the importance of these skills to provide students with various career opportunities (International Bank for Reconstruction and Development, 2018 page 157) Recent research studies show a central focus on the effectiveness of education on the quality of workers' skills (OECD 2017). Since education is the steppingstone that enables competent participation in the workforce, students should be trained to develop the skills required to keep up with technological and scientific advances, prior to joining a specific career (Linn et al., 2016). To achieve this target, education must switch from content-based to skill-based. During "The Digital Future of Work" summit, McKinsey & Company (2017) published a discussion panel that involved several educational experts, regarding the skills needed in the future, where the presence of the technological and digital developments is prevalent. Speakers emphasized that students need to learn how to find information, become flexible and build new skills to adapt to the evolving market requirements.

In the Middle East, educational reform movements led to increased schooling by four times since 1960 and decreased illiteracy by half since 1980 (World Bank, 2014). In addition, large interest has been allocated to funding public education by governments in the region. This rapid transformation in education aimed to equip students with the skills necessary in the 21st century, including critical thinking skills (Aph.gov.au, 2019). However, educational reform efforts in the Middle East faced some challenges including the low quality of education, as students do not learn basic literacy and numeracy skills and the discrepancy between learned skills and skills required in the labor market (World Bank, 2014). This was evident in the Programmed for International Student Assessment (PISA) results in 2015 as 89% of the schools in the Middle East and North Africa performed poorly which shows a significant difference when compared with the percentage of schools performed poorly in other regions namely 14% in North America and 25% in Europe (OECD 2017). Educational reform efforts in the middle East must consider the increasing number of youth population by 2030 which urge the necessity of providing quality education. Such efforts are not only necessary for building high-achieving students, but also preparing them to become resilient members of the workforce. This requires thought development, as Paul and Elder (2014) related the quality of thoughts to the quality of life, whereby improved quality of life is achieved by applying critical thinking in all daily activities.

Therefore, to prepare capable candidates for the future labour market, educational systems must equip students with the skills needed to build mind habits that direct them to develop their critical thinking skills and improve the quality of their achievements (Paul and Elder 2014; OECD 2016; Linn et al.). Improving thoughts includes the ability to interpret, analyse and evaluate information to make responsible decisions and contribute to both local and global prosperity. To build those skills, a context whereby scientific disciplines are taught is ideal; The American Association for the Advancement of Science explained that the nature of science implies that knowledge is gained by questioning natural phenomena (Rutherford and Ahlgern, 1990; Abell and Lederman 2010; Linn et al., 2016). The study of scientific disciplines including physics, chemistry and biology commonly relies on the inquiry process, through designing, planning and carrying out investigations to provide scientific evidence and explain natural phenomena (Abell and Lederman 2010; Zohar & Dori 2012). Consequently, following the scientific way of thinking trains people to use reasoning, logic and other critical thinking skills that develop mind habits, through implementing a series of thinking processes to construct explanations to various observations, including those that would help them improve the quality of their judgments about their own beliefs and actions (Zohar & Dori 2012). Socially, learning science would make for an interactive activity that requires collaboration, with each participant playing a certain role in the process of knowledge development. This makes science also suitable for developing students' social skills (Rutherford and Ahlgern, 1990; Abell and Lederman 2010). Biology as one of the sciences can be utilized to build students' essential skills and reduce the focus on content knowledge, thereby keeping up with the continuously evolving scientific and technological fields (Abell and Lederman 2010). Thus, science education, including biology, can be considered a suitable context in which students can practice analysis, evaluation and decision making that leads them to develop their critical thinking skills. Accordingly, all educational reform efforts must focus on developing student' skills, such as critical thinking and problem solving, as opposed to the common focus on solely building content knowledge (National Research Council, 2012). Research studies identified various skills that are required for future jobs; Eberhard et al., (2017) proposed a skill portfolio that should be developed for all students and ranked the skills required for future jobs in their list according to their importance. Social skills such as negotiation and emotional intelligence were the most important, followed by cognitive skills, personal abilities and process skills including creativity, analytical skills, critical thinking and dealing with pressure persistence. It then listed system skills such as decision making, entrepreneurial skills, followed by technical and content skills, which were at the same level of importance. The least important in their list were intercultural skills and resource management skills. Next to skill development, educational reform efforts should consider the swift development of communication technologies. With easy access to endless content knowledge, students must learn to use the available content to design the best solutions for future problems. Various tools and educational strategies must be developed to support teachers and enable them to ensure the transfer of the required skills through their educational practices (Eberhard et al.,2017). Educational research studies focused on the factors that contribute to the development of students' skills, several studies concluded that utilizing instructional strategies like the Mind Map and Sharing model, Argument-Based Inquiry approach, Problem-Based Learning models and performance tasks with a common rubric all improved students' critical thinking (Muhlisin et al., 2016; Memiş, 2016; Cargas et al., 2017; Cowden & Santiago 2015; Boleng et al., 2017; Siew and Mapeala 2016; Duran 2016). Furthermore, Enger and Yager (2009) and Chappuis (2016) emphasized the importance of assessment for learning strategies to facilitate students' development of critical thinking skills, as it provides students with constructive feedback that will give them a chance to think about their work and reflect upon their learning experiences to adjust their thoughts and improve their learning outcomes. In addition, Cajiao and Burke (2016) stated that instructional strategies affect the development of students' social skills, meaning that developing instructional practices that encourage social behavior would positively affect students' social skill development.

Learning sciences would be one of the most effective ways to develop essential 21st century skills such as critical thinking and problem solving (Rutherford and Ahlgern, 1990; Enger and Yager 2009; Zohar & Dori 2012). During science instruction, teachers are able to create opportunities for students to work collaboratively with others and practice appropriate problem-solving strategies (Bruce, 2011). Therefore, adopting inquiry-oriented activities in science education would maximize learning opportunities and better prepare students to face future challenges as working members of society (Orlich et al., 2013). In addition, utilizing science assessment tools would inform educators about the progress of students and the level of their skill development (Enger and Yager 2009; Chappuis 2016). Science education aims to build students' scientific literacy, which involves their ability to develop inquiry skills, apply what they learned, gain conceptual judgment and understand the nature of science (Enger and Yager 2009; Bassham et al., 2010). Science teachers should focus on students' development in six domains identified by Enger and Yager (2009) when they assess their progress in gaining scientific literacy. The six domains include concepts, processes, application, attitudes, creativity and nature of science. Progress assessment of student development should include assessing the use of higher cognitive level questioning techniques, particularly in the third domain (Enger and Yager 2009). Teaching biology as one of the scientific disciples would support students' preparation and their skill development; Research studies indicated that there is a correlation between students' achievement in biology and their cognitive development (Lazarowitz and Penso, 1992). Research studies also found that students' critical thinking skills are affected by changing the instructional design and following specific models in learning (Nuryakin and Riandi, 2017; Mahanal et al., 2016). This study will specifically investigate the impact of inquiry-based learning instructions on the development of students' critical thinking skills.

The United Nations Educational, Scientific and Cultural Organization (UNESCO) presented a new vision of education in the Education 2030 Incheon Declaration and Framework for Action (2016), in which promoting life-long learning skills is the major priority. Educational reform efforts around the world are focusing on empowering students by helping them gain the skills required to use the information available and construct meaningful applications to solve expected future problems. An example of this effort is Ark, an inquiry development project in Europe, which was initiated by

UNESCO to increase students' interest in science and innovation (UNESCO, 2017). Additionally, OECD (2017), considered developing cognitive skills as a foundation required to succeed in the social and economic development of any country. OECD's report "Education at a Glance" (2018) confirmed that to improve the transition from education to work, education systems need to target improving students' skills to make them on par with the requirements of the labor market. According to literature, an essential cognitive skill that must be developed to meet the requirement of future jobs is CT (Eberhard et al.,2017; Paul & Elder 2013; Enger and Yager 2009). Likewise, Zohar & Dori (2012) explained Dewey's views about the importance of the implementation of scientific inquiry and critical reflection across all disciplines, and how this can enhance the development of individuals able to make well-established judgments, which leads to effective democratic citizenship.

Most educational research agrees that the essential role of the teacher is to develop students' learning. Drivers of Student Performance: Middle East and North Africa Insights' (2017) report emphasized that high performance systems usually have effective teachers; the report highlighted the rise in students' results in PISA when IBL was utilized in the classroom. In general, successful educational systems put extra effort in qualifying teachers before and during their service (OECD 2018). The National board for Professional Teaching Standards (NBPTS) (2013) described the new vision of teaching needed for today's learners that focus on application of knowledge and skills, how teaching practice is aligned to this new vision, how it develops over time, and what strategies teachers can employ to improve their practice both individually and collectively. Therefore, teachers are encouraged to review their instructional practices on a regular basis to ensure effectiveness of their methodologies. If teachers were able to identify strength and weakness points in their practices, they will then be able to improve their teaching strategies and create a better learning environment (Enger and Yager 2009). Educational research studies related to the effectiveness of specific instructional practices in improving students' skills would be an important source for teachers to adopt new practices and keep evaluating the effectiveness of each practice on students' learning.

1.1.2 Problem statement and rationale

The effectiveness of IBL was targeted in several recent studies that focused on IBL as a pedagogy that is in line with the constructivist theory, how guidance affects the results of IBL activities and the effect of IBL instruction on students' engagement in the learning process (Lazonder & Harmsen 2016; Serafín, Dostál & Havelka 2015; Zafra-Gómez, Román-Martínez & Gómez-Miranda 2014). The focus of these studies did not highlight the effectiveness of IBL in improving students' CT development. However, another study by Duran (2016) investigated the impact of IBL on the development of students' critical thinking in an elementary school science and technology course. The current study targets the effect of IBL on students' CT development in a high school biology course.

Locally, one of the main priorities of the government of the United Arab Emirates (UAE) is to cultivate well-educated citizens, equipped with the life skills needed to resolve anticipated problems and lead their society in the future. Therefore, excelling in education was naturally one of the top priorities in the UAE vision of 2071, which highlights developing the ability to innovate in sciences as one of its points of focus, as it is stated: “Certain areas of focus in education include advanced science and technology, space science, engineering, innovation and health sciences” (Mocaf.gov.ae, 2017). Developing the fields of focus depends on the advancement of science education throughout the K-16 educational system. Hence, one of the adopted strategies to advance science education is inquiry-based learning (IBL), as students develop their knowledge, skills and attitudes when they investigate natural phenomena (Llewellyn 2011). IBL activities would entail that students practice various cognitive skills throughout the inquiry cycles (Forawi 2016), which are related to core critical thinking skills. Facione (2015) identified five core critical thinking skills including interpretation, analysis, inference, evaluation, explanation and self-regulation. Evidence shows that these skills are developed through IBL instructions (Forawi 2016). Accordingly, the UAE school inspection framework incorporated the implementation of IBL as part of the assessment criteria used to evaluate science education across the country (United Arab Emirates School Inspection Framework, (2015). Hence, IBL must be adopted by schools if they seek to be categorized as acceptable on their performance evaluation. On the other hand, the 2016 results of the Programme for International Student Assessment (PISA) in the UAE, revealed that the average score for students in UAE is less than their peers in OECD countries (Oecd.org, 2018). This result highlights the need for developing students’ reasoning and problem-solving skills (Pennington, 2017). Similarly, during the recent AdvancED Global Conference 2018, Bohling, (2018) presented in her keynote speech some data collected after inspection activities done by the AdvancED team in the UAE, and one of the items they were looking at is an effective learning environment. The results of the survey reflected discrepancies between students' responses and teachers' responses regarding the kinds of activities done mostly in the classroom. 93000 teachers responded that their students mostly work with others, think, complete challenging work and normal classroom work, while 401000 high school students responded that most of their time they listen to the teacher, complete worksheets and take tests. These results reflect a poor learning environment that lacks active learning activities such as IBL. Accordingly, this necessitates further investigation regarding the effectiveness of existing science pedagogies in improving students' reasoning and problem-solving skills. A few studies were performed in the UAE to examine the effectiveness of educational strategies, one study at the level of higher education in the UAE proved the positive effect of a scenario-based simulation in radiology education on the development of students' CT skills (Abuzaid and Elshami, 2016). Another study by El Tanahy, (2015) investigated the effect of the IBL approach on students' achievement in the TIMSS assessments in chemistry. A study by Badri et al. (2016) investigated the effect of science instructions on students' decisions regarding their future careers, concluded that delivering science instructions in an interesting methodology is not enough to encourage students to seek STEM jobs in future. They emphasized the need to affect students' attitudes towards science and include career guidance at the school level. Their study did not discuss the effect of science instructions on students' skill development, which would consequently help them select careers related to science in the future. Recent studies by Eltanahy and Forawi, (2019) investigated teachers' perceptions regarding the implementation of IBL instructions in middle school science subjects. Their study did not discuss the impact of IBL instructions on the development of students' skills. The current study is the first research performed in the UAE to focus on the effectiveness of the implementation of IBL in developing students' critical thinking (CT) skills.

1.1.3 Purpose and questions of the study

The aim of this study was to investigate the implementation of inquiry-based learning instruction and critical thinking skills development in high school Biology course. Four major questions drive this study:

1. What are students' experiences with IBL implementation in a high school biology course in UAE?
2. To what extent do students develop critical thinking skills through the use of high school biology IBL activities in UAE?
3. What are the high school biology teacher's perceptions on the use of IBL and development of CT?
4. How do demographic factors affect the development of students' critical thinking skills when applying IBL biology activities?

Investigating the effectiveness of instructional strategies was done through three different research strategies. First, a quasi-experiment, where Bati & Kaptan (2015), Memiş (2016), Siew, and Mapeala, (2016) and Boleng et al., (2017) investigated the effect of learning strategies on the development of students' critical thinking (CT) skills, by performing both a pre- and post-test. Second, utilizing developed CT assessment tools to survey targeted participants. Demir, (2015) used "California CT Scale" and "The Reflective Thinking for Problem Solving Scale" (Facione & Facione 2013) to evaluate science teachers' reflective thinking and CT development. The third approach used was an action research approach, utilizing self and peer assessment tools, an observation checklist and a rating scale to assess students' interactions during the implementation of instructional strategies (Haridza and Irving, 2017). The current study followed a case study with a multiple-method approach described in the next section, to explore and further understand the implementation of IBL instruction and critical thinking skills in biology classroom.

1.1.4 Context of the study

The study is conducted in a series of high schools belonging to one system in the UAE, in which latest educational methodologies are adopted to prepare students to join top universities and lead in various career pathways (Appendix 1.1 outcomes of ATHS) the school system follows the Ministry of Education curriculum in all the core subjects and provide career related courses in four different career pathways including Health Science and Technology, Computer Science, Engineering Science and Applied Engineering. The researcher has been working in the field of education for 22 years, 15 of them as a full-time physical science and high school biology teacher. In addition to her role as a curriculum and instructional developer for middle school science and high school biology subjects for six years and recently her current role as an academic vice principal to one of the schools in system. The major role of a curriculum specialist is to develop curriculum documents, instructional guides and assessment tools for learned courses to ensure that the required benchmarks in each subject area are being met. As an academic vice principal, the researcher is responsible for the implementation of instructional strategies for all subjects, in addition to supporting teaching staff in the school to deliver the curricula in a safe learning environment. The researcher was granted approval by the management to access the schools and collect the required data in the capacity of an independent researcher. This research study is part of the efforts done to develop science pedagogies and utilize instructional time to maximize students' learning and skill development. The researcher believes in the effectiveness of the social cognitive theory developed by Vygotsky (1930). Through her teaching experience, students' learning through social groups was evident and her students reflected good understanding of the concepts they have discussed. Additionally, the researcher is confident that thinking skills can be learned and developed as per Dewey (1910), if students were exposed to the explicit meaning of critical thinking; given guidelines to develop their thinking and guided to practice thinking, students will gain relevant thinking skills and become critical thinkers (Paul and Elder 2014). As a biology teacher, the researcher focused in this study on the biology curriculum and perform this investigation to prove that IBL instructions which require social interaction and thinking skills to explore and interpret facts may help students develop critical thinking skills.

This study is framed within a mixed method approach that includes a quantitative tool which is the nonexperimental questionnaire for students, three qualitative tools including lesson observation protocol, a form for teachers' interviews and a document analysis checklist to explore the practices that take place during interactions in classrooms and in students' written assignments that would reflect the development of critical thinking skills. It is important to explore whether discussions that lead to critical thinking development exist in the typical biology classroom, as a first step for conducting a future research to develop a tool to determine the level of students' critical thinking application after IBL instructions.

IBL instructions can be adopted in different disciplines. However, biology was selected as one of the sciences that requires more focus on IBL implementation. Based on a previous study that was conducted in 2015 in the same series of schools, IBL instructions were strongly evident in physics and chemistry lessons but were less implemented in biology (Sabri and Forawi 2019). This result led to a change in the curriculum design to include IBL activities within the instructional guides. In this study, IBL is better implemented and can lead students to develop CT. In addition, the researcher's personal relationships with Biology teachers would encourage them to cooperate and participate in this study.

Results presented in this study are based on lesson observations to evaluate how interactions in the classroom can lead to CT skill development, a nonexperimental questionnaire addressed to students to explore the effect of IBL activities on their cognitive skills development, an analysis of students' artefacts and various assessment documents to understand how deeply students learn biological concepts and reflect upon their learning experiences. In addition to interviews with teachers to explore their background knowledge regarding IBL instructions and CT skills and explain their perceptions regarding the effectiveness of IBL instructions on developing students' critical thinking skills.

The result of this research is expected to identify IBL instructional practices in the biology high school curriculum that would positively affect students 'development of critical thinking skills. Thus, designing a series of professional development workshops to support science teachers in order to effectively utilize IBL instructions in their daily practices to promote the development of students' CT skills.

1.2 Key definitions

The key concepts tackled in this study are Inquiry-Based Learning (IBL), Critical Thinking (CT) and Biology instruction. IBL instructions are based on the constructivism theory, which is defined as an educational theory about cognitive psychology, in which students learn new concepts through sequenced learning experience, they draft their own understanding of new concepts based on prior knowledge and the interaction with external factors such as the information gained from teachers, parents and their peers (Long et al, 2011; Slavin 2013). The main constructivist concept utilized in this study is built on Vygotsky's Social Cognitive Development Theory and the Zone of Proximal Development Model that emphasizes the importance of the social context in students' learning process. During appropriate cognitive development, children can build their understanding of a concept by applying their knowledge when doing difficult tasks, given that they are provided with suitable scaffolding (Vygotsky 1930).

Inquiry-based learning: there are three main usages of the term "inquiry" in the national curriculum, including scientific inquiry, inquiry learning and inquiry teaching (Abell and Lederman 2010). Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry in classrooms refers to "the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (NSES, 2000, p 23). Inquiry as a constructivist learning method as per Abell and Lederman 2010 is identified by four main requirements in the learning process: first, the evident involvement of students in their own learning. Second, students' pervious knowledge must be employed in building new concepts. Third, the context in which new concepts are introduced must be considered to build an understanding of the new concepts. Fourth, learning should take place within social groups based on the cognitive and sociocultural view of knowledge. Inquiry teaching mandates that teachers diversify the methods they use to teach scientific concepts, and consequently, utilize inquiry as a process to lead all learning activities (Abell and Lederman 2010). The definition of inquiry-based learning (IBL) applied in this study is the use of the inquiry process as an instructional pedagogy to explain scientific concepts and the utilization of scientific methods and processes to learn scientific content (Llewellyn 2011).

Critical thinking is used in this study as a skill interrelated with reflective thinking, which was defined by Dewey (1910) as an "Active, persistent and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it, and the further conclusions to which it tends" (pp. 6). Ennis (1993) also confirmed that CT is one type of reflective thinking that concentrates on what a person believes and does. Although, Zohar & Dori (2012) did not describe critical thinking and reflection as interrelated concepts, yet they clarified that isolating the two thought constructs will not be beneficial for actual application in the educational field. They explained that in order to expand the actual applications of critical thinking and reflection, they must be understood in their integrated view to include variety of learning strategies and actions (Zohar & Dori 2012). Facione (2015) identified six core critical thinking skills that can be developed through instructional practices including interpretation, analysis, inference, evaluation, explanation and self-regulation. The development of the critical thinking skills would lead to critical thinking dispositions that are reflected on the critical thinker's behaviour and approach to life. Such dispositions include making informed decisions based on reasoned inquiry, being fair minded and avoiding prejudices, stereotyping and egocentric tendencies (Facione 2015). CT is used in this study based on the definition provided by Paul and Elder (2006; 2014) which is the art of thinking that involves analysing and evaluating thinking with a view of developing it. It is self-directed, monitored and corrected.

Biology Instructional Reform

Modern scientific advances have transformed life sciences to become more quantitative, yet biology is still taught in the traditional form in many educational systems, leaving a remarkable gap between teaching and research (Karsai and Kampis, 2010).To overcome that gap, it is necessary to introduce inquiry-based teaching in biology curricula and include mathematical concepts in them (Karsai and Kampis, 2010). This is because adopting inquiry instructions in Biology promotes active learning and encourages students to gain problem solving abilities and critical thinking skills (Gardner and Belland, 2017). Similarly, facilitating practical laboratory experiments provides better opportunities for students to develop critical thinking skills and become more proficient in science (Strimaitis et al., 2017). In the current study, Biology instructions investigated consist of inquiry-based learning activities integrated in a high school's biology curriculum, including three different levels of inquiry: structured, guided and open-ended. Guided and structured activities were applied within classroom instructions, while open-inquiry lessons investigated were associated with practical lab experiments.

1.3 Structure of the thesis

The current chapter is the first part in which a general introduction about the topic is presented. It includes a description of the study background, the problem statement and the rationale of the study. It also includes the main aim, the questions that guide the study and the context of the research. The second chapter presents the conceptual framework, including theories related to reflective thinking, critical thinking and inquiry-based learning models, followed by the literature review related to critical thinking, inquiry-based learning instructions and biology instructions. The third chapter provides a detailed description of the research design and methodology, including the approach, instruments, participants, analysis methods and study limitations. Chapter four presents the quantitative and qualitative results including the non-experimental questionnaire, lesson observations, interviews of the teachers and document analysis. Finally, chapter five presents the discussion of the results, main conclusion and recommendations for the educational field and future research studies.

2. Theoretical Framework and Literature review

This chapter consists of two main sections: the theoretical framework and the literature review. The theoretical framework includes the descriptions and discussions of the two main theories and two models used in this study. The theories and models that support this study are Vygotsky's Social Cognitive Development Theory (1978) and Dewey's Reflective Thinking (1910), Paul and Elder's model of Critical thinking (2006), and Branchi's model of Inquiry-Based Learning (IBL) (2008). Building a theoretical framework in educational research studies provides guidance and background justification for all the discussions, conclusions and results of the study, since instruments and data collection methods were based on the specific theories and models that support the study (Kilbourn 2006; Creswell 2006). Particularly, Dewey's Reflective Thinking (1910) and Paul and Elder's model of Critical thinking (2006) constitute the main background and the sources of justification in the discussion related to the implementation of CT core skills in the non-experimental questionnaire. The CT attributes were used in the lesson observation form, data analysis checklist and the interview questions. Vygotsky's Social Cognitive Development Theory (1978) and Branchi's model of Inquiry-Based Learning (IBL) (2008) provided the background and justification for the discussions of the IBL attributes used in the non-experimental questionnaire and the questions related to the interactions and discussions during the interviews with teachers, in addition to the attributes related to IBL instructions and class interactions in lesson observations.

The literature review illustrates and discusses previous empirical studies related to the main concepts tackled in this study. The literature part is focused around three main areas. First, critical thinking in science education. Second, the impact of inquiry-based learning strategies on students' learning and the third presents the research studies that are related to the development of biology instruction. Creswell (2006) emphasized the importance of including a comprehensive literature review in research studies, as it serves several roles. First, it summarizes relevant research studies, keeping the research up to date with current issues in the field. Second, it displays gaps in previous studies and identifies areas that requires more research. Third, the literature review strengthens the study's results and validates the research findings, by relating them with the findings of previous research studies.

2.1 Theoretical Framework

The theoretical framework of the current study is based on two theories and two models, all demonstrated in Figure 2.1 and further described below. The social

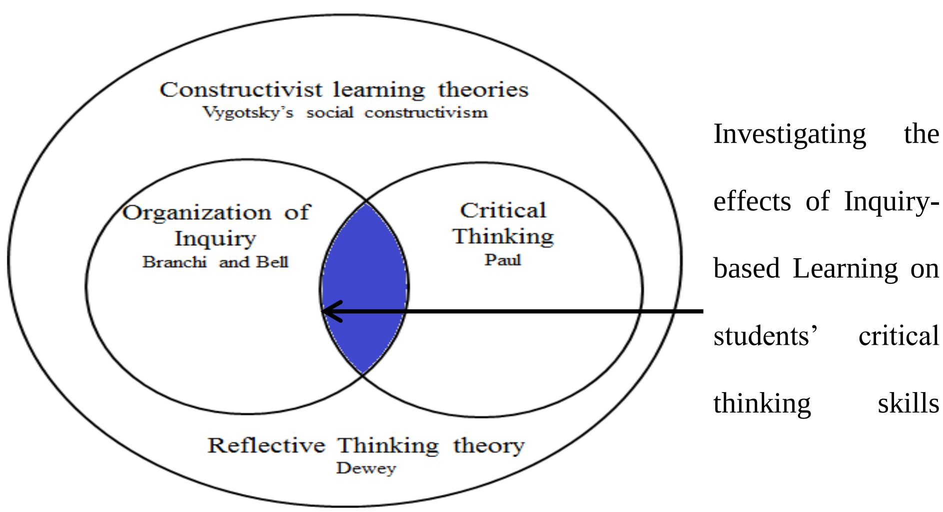


Figure2. 1Theoretical Framework of the current study

constructivism by Vygotsky and the reflective thinking theory by Dewey support the study as the wider framework. Within these theories, the implementation of two models is explored: the “Elements of Critical Thinking and the Scientific Literacy” model by Paul, and “The Organization of Inquiry” model by Banchi and Bell (2008). As a case study design with multiple methods, the quantitative method of the current study contains theories and models that are used deductively to investigate the implementation of IBL instructions and whether it leads to building CT skills (Creswell 2006). This is apparent in the constructs of the study, which include application of IBL instructions as a factor extracted from Vygotsky's Social Cognitive Development Theory (1978) and Branchi's model of Inquiry-Based Learning (IBL) (2008), in addition to the development of CT skills, which is derived from Dewey's Reflective Thinking (1910) and Paul and Elder's model of Critical thinking (2006). The qualitative methods utilized in this study are related to the same theories and models inductively to provide explanations for behaviors and attitudes related to IBL instructions and the development of CT and sharpen the results to come up with focused recommendations to improve Biology instructions (Creswell 2006).

2.1.1 Vygotsky’s. Social Cognitive Development Theory

The social cognitive development theory by Vygotsky is related to social constructivism, which entails that people generate knowledge through their interactions and the exchange of experiences and ideas. It also considers the role of the social factor in developing knowledge, implying that the way in which children are raised in certain social circumstance will influence their learning. This section explains the relation between the social cognitive development theory by Vygotsky and social constructivism. Main ideas discussed include constructivism as a theory of learning, the introduction of the zone of proximal development model, the importance of scaffolding to develop students' learning and the implications of the constructivism theory on the classroom environment.

Constructivism is defined as an educational theory about cognitive psychology, in which students build their own understanding of concepts based on prior knowledge and external factors such as interacting with well-informed adults in their surrounding (Long et al, 2011; Slavin 2014). Nola and Irzk (2010) identified four different forms of constructivism: cognitive which explains that knowledge and information are mentally constructed, semantical which means that concepts are learned by experience, epistemic which is originated form the idea that knowledge is gained based on observing or sensing the nature and ontological constructivism that relates reality to the experience of the mind. Considering how constructivism is a theory that applies to pedagogies as well as knowledge highlights its role in actual educational practices, where following it would direct changes in teaching and learning instructions that would allow students to build an understanding of new concepts. This has been shown in science education, where constructivism as a pedagogical approach is considered to be the most accepted learning theory, since it influenced a change in science instructions in the past 20 years guiding science education to include more IBL instructions (Nola and Irzk 2010). For a Teaching and Learning model to follow the constructivist learning theory, it must satisfy four main points in the classroom environment as per McComas (2013). First, it must provide learning opportunities that allow students to be active learners and construct their own knowledge. Second, it should identify students' previous knowledge about the concept and existing misconceptions related to the new knowledge. Third, the model must provide opportunities for students to work with others in a suitable social environment. Fourth, the model should outline learning activities that are reliable and relevant to the core of the new idea. The students are expected to have an active role in their own learning, seeing that this approach will enable them to apply the knowledge they gain in different contexts (McComas 2013). Simultaneously, the role of teachers is focused on identifying students' areas of improvement and guiding them to understand the concepts required and reflect upon their understanding (Orlich, 2013).

Vygotsky's theory of social constructivism and the zone of proximal development model emphasize the importance of the social context during appropriate cognitive development; children can build their understanding of a concept by applying their knowledge when doing difficult tasks, if they were provided with suitable scaffolding (Slavin, 2011; Long et al, 2011).

In his book "Mind and Society", Vygotski et al. (1978) identified three main existing theories related to learning and development. The first theory states that development comes first, then learning happens based on the existing developmental cycles. The second theory defined learning as development and both processes are completely merged and occur concurrently. The third theory combined the first and the second theories; it stated that learning and development are two different processes that are related to each other. The learning process promotes maturation that prepares for a special type of learning to occur. Accordingly, Vygotski et al. (1978) introduced the concept that a child's development is reflected in two types of development: the actual development cycles that are measured based on the child' ability to solve problems independently, and the zone of proximal development that is decided based on the child's ability to solve problems with guidance of adults or other capable peers. The understanding of the zone of proximal development as per Vygotski et al. (1978) implies that some internal development processes will not occur unless the child was exposed to a social environment that allows interaction. For children to develop higher mental abilities such as internal speech, reflective thoughts and self-regulation, they must be interacting within a specific social environment.

In their book, "Psychology for the classroom" Pritchard and Woollard (2010) explained that social interaction increases thinking levels. This was based on the understanding that humans are social organisms, whereby the surrounding people have an essential role in an individual's learning process. Pritchard and Woollard (2010) clarified that in a classroom environment the performed tasks can be classified into three categories, which are tasks which a student can do independently, tasks that cannot be done even with support and tasks that can be performed with support. They referred to Vygotski et al. (1978) zone of proximal development model to reason the requirement of a social environment for the development of knowledge and abilities at individual and social levels. Building new skills and abilities on an individual level based on social interaction was defined by Vygotski et al. (1978) as an internalization process that consists of a series of changes. These changes include the presence of a certain activity, skill or process that occurs externally and is reconstructed to occur internally. In addition to a change where external communication with people that guide the individual's thinking is switched into internal communication, where an individual follows the thinking process without external guidance. This leads to changing the external rules through which the activity was implemented into internal laws that an individual adopts to start applying the new process or skill independently (pp. 56). Vygotski et al. (1978) clarified that the internalization process is a developed feature that differentiates humans from other animals.

The zone of proximal development theory necessitates that educational research studies should find out various pedagogical strategies that enable internalization of external knowledge and abilities that students are exposed to during their learning experiences. This research study investigates classroom interactions to demonstrate students' understanding through utilizing prior knowledge and social interactive activities within biology IBL instructions. Hence, this study requires observing the scaffolding mechanisms in biology classrooms and following communication pathways among students and between students and their teacher. Data collected from lesson observations would help to find classroom practices that create suitable social context, in which students are able to perform difficult tasks with assistance from their teacher and their peers. It is expected to see students achieving understanding through their teacher's questioning techniques, application of reasoning skills and emotional encouragement (Slavin, 2011; Long et al, 2011; Vygotskiĭ and Cole, 1978).

The social cognitive development theory is the fundamental theory that supports the expected results from the current study, as it explains how the interactions within the classroom environment affects the way students build their understanding of new concepts and gain from the learning experiences of their colleagues.

2.1.2 Dewey’s Reflective Thinking

Dewey, (1910) defined reflective thinking as “active, persistent and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it, and the further conclusions to which it tends” (pp. 6). Elements of reflective thinking, as described by Dewey, include a state of uncertainty and an act of inquiry to find evidence that leads to either accepting or rejecting an idea. Subsequently, this type of thinking can lead to belief. Based on these elements, Dewey, (1910) clarified that reflective thinking is a process that is driven by the need to find a solution (pp. 11). He also explained how human beings used reflective thinking throughout the development of human civilization, as most of the achievements throughout history were made based on the judgment of available evidence and acting accordingly (pp. 18). Dewey also linked the development of the human mind to its ability to organize concepts in a logical manner (pp. 39), simultaneously relating that to the schema theory and the requirement of fitting information in a specific schemata in order to create a logical relationship between existing knowledge and the newly gained information. This proves that Dewey’s ideas are aligned with the constructivism theory of learning. The reflective thinking process as described by Dewey (1910) can lead to correct or wrong acts, therefore it needs guidance. The role of education as per Dewey is to adjust all the wrong beliefs that students may produce due to the interaction with their environment. This can be done through training students to test their produced beliefs and differentiate actual beliefs from other wrong assumptions or opinions. Accordingly, training students to use reasoning and inquiry skills to come up with conclusions would help them develop a habit of using these skills in their daily activities (pp. 28). Dewey (1919) strongly emphasized that it is not enough to provide pure knowledge for students, instead, education must provide a suitable learning environment that helps the students develop thinking habits, as he called it "Training of Mind". Yet, Dewey (1910) highlighted that an individual should have the basic ability to think in order to be trained on how to think well. The teacher's role in this case is to identify the basic skills each student has first, before training them on how to think well. As per Dewey (1910) three important basic elements are required for good thoughts, which are curiosity, suggestions and orderliness. Curiosity, as a present trait in all children, is a character that is developed in a social context and as a strong intellectual force that leads the ability to solve a problem. Despite that, curiosity is a trait that may be lost if it was not utilized in a suitable manner, as the individual may lose interest and stop asking questions. The teacher's role is to protect students' spark of wonder. This can be done through utilizing their curiosity in selective instructional situations and not overusing it as a routine exercise during insignificant settings. For suggestions, Dewey (1910) explained that when applying the concept of suggestion in an educational context, three main scopes should be considered: the promptness, variety and persistence (pp.34). Students vary in the speed of their responses, some are "alert" and respond quickly with suggestions, while others are "dull" and absorb information passively and do not respond. In this regard, Dewey (1910) stressed that students may be dull in school disciplines and alert in other situations based on their interests. This implies that students should be treated using different methods that relate to real-life applications, to ensure that they develop appropriate responsive actions (pp. 35). Given suggestion may also vary in quantity, sometimes individuals produce few suggestions that may indicate poor mind habits to generate more ideas, and other individuals produce a greater variety of suggestions. As per Dewey (1910) "the best mental habit" is the balance between the quality of the ideas produced and the number of provided suggestions. The depth of the suggestion is the dimension that is least influenced by the environment, as Dewey (1910) explained that people vary in the level of their responses which can be superficial or deeply thought. For example, a student that responds slowly could produce a better quality and well-thought response than a student who responded quickly with an irrelevant idea. In conclusion, suggestions that are produced as a result of thinking should be judged based on the quality and speed of students' individual responses, and thinking should be treated as a unique process that would help in guiding students to a significant inquiry process and meaningful reflection (pp. 39). Finally, the last element necessary for the cultivation of good thoughts is the orderliness or organization of thoughts. When responses are organized, each suggestion provided by the student is connected to the main topic of inquiry and the ideas are not randomly scattered in the discussion. This means that thinking activity should be focused on a single trend of responses to come up with one conclusion that will lead to an action. Dewey (1910) distinguished between mature thinking habits in adults and those in children and youth. In the case of adults, real situations in their professions that require their intervention will provide intrinsic motivation for them to keep thinking and progress in their careers. However, this is not the case with children, as the lack of necessity of the thinking process leads to the loss of intrinsic motivation to think, which makes thinking activities theoretical and difficult to achieve. Dewey (1910) identified the role of education in order to help students develop mind habits by creating good-natured activities that are suitable to the immature stage of development. The IBL activities explored in this study are examples of such activities that prepare students as adults in the future with specific responsibilities and can simultaneously be an appropriate context for the development of thought habits such as observations and sequential inference. Besides, Dewey (1910) pinpointed three main factors that influence the development of thinking habits in education, including “the mental attitudes and habits of the persons with whom the child is in contact, the subjects studied and the current educational aims and ideals” (pp. 47). This implies the essential role of the teacher in influencing the students’ thinking habits, which is investigated in the current study. Teachers can negatively affect students’ development of mind habits when they set standards related to their own mental processes and judge the students’ accordingly. The impact of this act is that students will respond only to satisfy the teacher’s requirements and not to learn the subject. As for the impact of the type of the subject taught, Dewey (1910) clarified that the process in which knowledge is gained and the stages of thought a student passes through are to be considered the product of learning any subject instead of focusing only on content information. The effect of current educational aims is summarized by Dewey (1910) as the focus on external gained knowledge and quick progress rather than the focus on the process of learning.

In Jorgensen’s (2015) work about revitalizing the foundations of education, he clarified that effective thinking must be trained during teaching and learning activities. To adopt Dewey's theory of reflective thinking, teachers can use the five distinct stages of reflective thinking, which include feeling a difficulty, locating and defining the difficulty, suggesting possible solutions, reasoning and then making the decision to either accept or reject the given solutions. This strategy can be utilized whenever a new concept is introduced.

Based on Dewey's theory, IBL instructions provide suitable context to train students to develop mind habits, as IBL instructions satisfy the three conditions specified by Dewey for educational activities; they are suitable for the immature stage of thinking process, specify roles and responsibilities for the students and provide a suitable context for observation, inferring and finding solutions. While moving through the inquiry steps, students can practice thinking and provide suggestions that can be assessed and filtered by their teachers to help them gain the required mind habits. This research study investigates the interactions that occur during IBL instructions to describe students' gained skills and answer the first research question regarding students' reflection upon their experiences when they implement IBL. It is expected to observe that students can identify problems, suggest solutions and make final decisions when they are implementing IBL activities. In addition, they are expected to reflect upon their understanding and identify pros and cons during their learning experience. These activities are meant to train students' mind habits to become critical thinkers.

2.1.3 Paul's Model of Critical Thinking (CT)

CT as per Paul (2014) involves three interrelated stages of thinking including analysing, evaluating and improving thoughts. It is self-directed, monitored and corrected Paul and Elder (2006). People can develop critical thinking skills by learning how to think, interpret ideas and avoid bad thinking habits such as generalization, making decisions without evidences, deciding based on patterns or neglecting and accusing point of views that are opposing theirs (Paul 2014). When individuals practice critical thinking skills, they implement critical thinking in everything they do and live as critical thinkers that are continuously improving the quality of their lives (Paul 2014). As per Paul, Critical Thinking is a "tool of mind" that people can use in everything they do in their lives, it entails the process of analysing and evaluating for the purpose of development and enhancement of thinking. Paul (2014) defined CT as a "mode of thinking about any subject, content or problem, in which thinkers improve the quality of their thinking by skilfully analysing, assessing and reconstructing it".

Individuals develop intellectual traits as a result of analysing and assessing. Figure 2.2 adopted from Paul and Elder's model (2006) explains the application of Universal standards on elements of learning to develop intellectual traits. To analyse thinking, people must identify the elements of thought beginning from the purpose of thinking, to reaching a certain point of view. To assess thinking, they need to find a universal intellectual standard. CT must include improvement of thinking to build such intellectual traits.

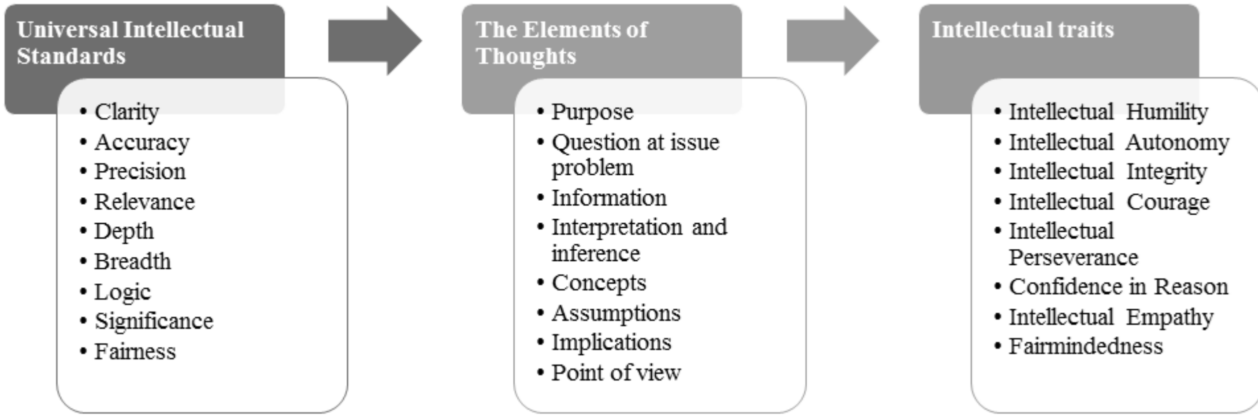


Figure 2.2Application of Universal standards on elements of learning to develop Intellectual traits" (Paul & Elder 2006).

Paul (2014) differentiated between weak and strong critical thinkers based on the application of the elements of thought mentioned earlier. Weak critical thinkers do not consider the point of view of others, unlike strong critical thinkers or fair-minded thinkers, who emphasize the viewpoints of others. Paul (2014) explained the meaning of each intellectual trait for the purpose of recognizing whether a person has developed these traits or not. For instance, a person develops intellectual humility if he/she was aware of the human nature of egocentrism, and the existence of bias due to prejudice. This awareness would help people to develop their thinking and avoid quick judgement without sufficient evidence. Intellectual autonomy entails that critical thinkers do not accept beliefs of others passively; they assess traditions, values and practices to develop their own beliefs. Intellectual integrity necessitate that critical thinkers hold themselves accountable at the same standards that they hold others, where they admit mistakes and take responsibility of their decisions. Intellectual courage is indicated by overcoming the inner fear of rejection and questioning existing rules and beliefs. Intellectual perseverance is eminent through dedication and determination despite various challenges, as critical thinkers do not give up, they are realistic in their vision and understand sources of struggle and frustration. Confidence with reasons requires critical thinkers to look for the truth using facts, evidence and reasoning, which they base their judgment on. Intellectual empathy warrants that critical thinkers understand the viewpoints of others and consider different contexts and situations before making decisions. The integration of all the intellectual traits promotes building fair-mindedness (Paul 2014).

In education, schools in general do not emphasize intellectual traits (Paul 2014). For example, students often lack intellectual perseverance, as they always prefer the easy way out from any challenge or educational struggles, which is a character of human nature. In addition, perseverance is not enforced in school systems, teachers mostly value students who complete the assignment quickly, not the students who might be late due to deep thinking and questioning of the facts or trying to build logical reasoning for the conclusions (Paul 2014). Similarly, if intellectual humility was addressed in education, students will be able to distinguish between deep learning and superficial learning, which will help them understand the main goal of studying a specific concept in any discipline, which is weighing the achievements accomplished by people when they discover a certain concept, the problems that were solved, and the data that was collected and how it was collected and finally, how studying that concept changed the students' view of the world (Paul 2014). Likewise, when students gain intellectual courage, they will be vigilant in the way they build beliefs about a concept, they may introduce a strange explanation or conclusion without the fear of being rejected (Paul 2014). In addition, when students gain intellectual empathy and confidence in reasoning, they become open to discuss others' beliefs, depend on logical reasoning with evidence and consider the opposite view points when making conclusions. Furthermore, when students gain intellectual autonomy, they become independent thinkers able to look at each concept from different perspectives. CT is the procedure in which students gain content knowledge in different disciplines (Paul and Elder 2007a), it also involves self-correction and development of thoughts (Zohar and Dori 2012). For students to build intellectual skills, teachers must address concepts in various disciplines, as systems of thoughts that include all the elements; students are to be directed to a specific question, to process relevant information then interpret certain assumptions, and reason implications to reach a final point of view (Paul and Elder, 2007b). Teachers also need to be aware of the intellectual traits and train students to think, discuss and be open to change their decisions based on logical reasons and evidence to become fair-minded thinkers (Paul 2014).

This study utilizes biology instructions to identify CT practices within the classroom and answer the second research question regarding the development of CT skills through IBL instruction. The study highlights the practices that reflect the application of the elements of thought and emphasizes the development of intellectual traits, which result from developing CT skills (Paul and Elder 2007b). This research study investigates whether current high school biology instructions promote students' CT abilities by answering the third question regarding high school biology teachers' perceptions on the use of IBL and development of CT.

2.1.4 Banchi's model of Inquiry-based Learning (IBL)

The model that supports this study is the IBL model. Inquiry-based learning (IBL) is defined as an active learning method used to boost students' higher cognitive aptitudes in a student-centered classroom (Forawi and Liang 2011). The IBL approach is supported by the constructivist theory discussed in section 2.1.1. Applying IBL instructions provides opportunities for students that satisfy the constructivism learning theory, as it allows students to actively use their previous knowledge, to investigate natural phenomena and communicate with their peers to explore new concepts. This medium of instructions also satisfies the conditions set by Dewey in order to train the mind to develop thinking habits. The definition of inquiry that is used in this study is focused on the implementation of the scientific inquiry process in science classroom; IBL activities can be implemented based on four different levels of complexity, illustrated in Figure 2.3, adapted from Banchi and Bell (2008). The teacher can control the level of inquiry in the activity based on the tasks that students are required to do. Context and the students' readiness are factors that should be considered when designing IBL activities (McComas 2013). The continuous extended arrow in Figure 2.3 represents

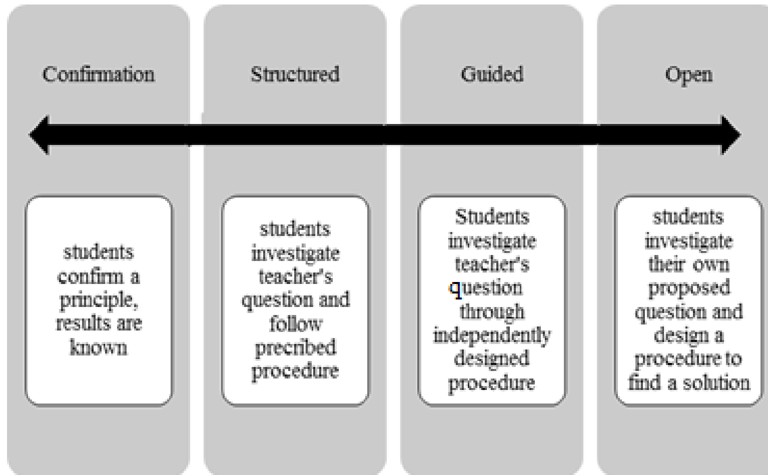


Figure 2.3 "Inquiry levels of complexity" modified from (Banchi and Bell 2008)

the teaching continuum, where students' ownership of their own learning increases from left to right (Llewellyn, 2011).

McComas (2013) summarized the benefits of IBL instructions and the positive impact expected on students' learning. Since students will have the opportunity to understand scientific concepts deeply, they will be encouraged to research and find innovative solutions for the given problems. This will also give them a chance to identify their learning gaps and learn how to close them. Despite the numerous benefits of IBL instructions, students' readiness and time constraints are major challenges that hinder the implementation of this type of instruction. Particularly when the students are required to satisfy the huge requirement of standardized assessment (McComas 2013).

The current research study aims at identifying the links between the application of the IBL instructional cycle and the practice of core CT skills that leads to the development of CT. The implementation of all stages of the learning cycle of IBL instruction necessitates the development of active learning activities that create opportunities for students to practice interpretation, evaluation, inferring, explanation and self-regulation skills, which are the core critical thinking skills.

2.2 Literature Review

In this section, the empirical studies that discuss science education are analyzed to identify the gap in existing research studies. Thus, the purpose of the current study and research questions aims to address the identified gap. Three main themes are investigated. The first one discusses the definition of CT, instructional practices that affected CT, tools to assess CT and CT in science education. The second theme presents the research studies related to inquiry-based leaning; it elaborates on inquiry instructions, meta-analysis studies related to inquiry and the implementation of IBL in the Arab rejoin. The third theme discusses studies that are specifically related to biology instructions, including high school biology and how biology is taught in the Arab region.

2.2.1 Critical Thinking (CT)

2.2.1.1 Definition of CT

CT is defined as an activity that involves analyzing and evaluating thinking to improve it and make decisions (Fisher 2001; Paul 2013; Facione 2016). Another definition by Ennis (1993) considers CT as a type of reflective thinking that concentrates on what a person believes and does. Dwyer Hogan and Stewart (2014) proposed a framework to explain the relation between CT, self-regulatory learning and metacognition in Figure 2.1 below. They considered that the foundation of CT development is the self-regulation that enables an individual to analyze, evaluate and infer to make a reflective judgment.

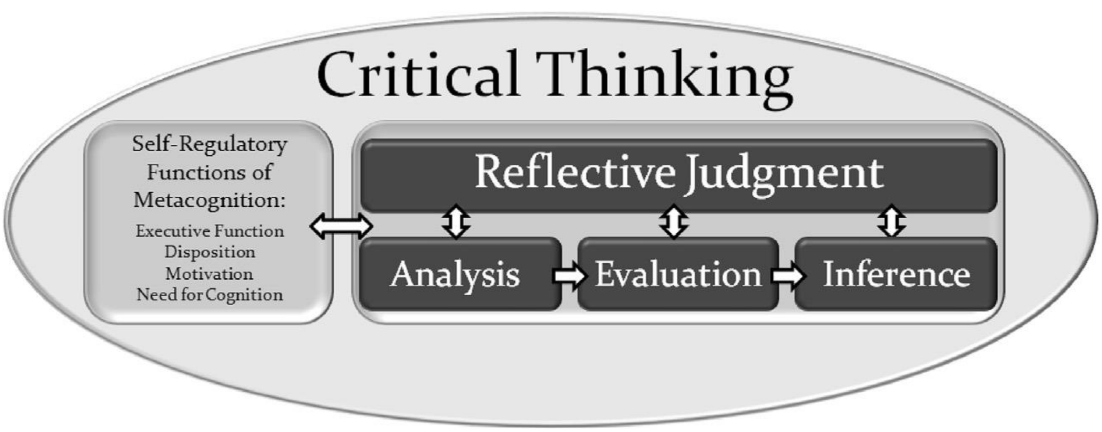


Figure 2.4The Interdependencies among the self-regulatory functions of metacognition, CT skills and reflective judgment adopted from Dwyer Hogan and Stewart (2014)

Dwyer Hogan and Stewart (2014) proposed that basic comprehension and application skills must integrate analysis, evaluation and inference to build the ability to make reflective judgments. With that, they confirmed that there is a considerable relation between CT development and reflective judgment. Yet, further research is recommended to support the link between CT development and the ability to make reflective judgements. In a later study, Demir, (2015) described critical and reflective thinking skills as interrelated skills that support each other, meaning that learners need to develop both skills to be able to apply observation, questioning, and research skills to reach conclusions and communicate their results. The study's results indicated that pre-service science teachers were likely to perform critical and reflective thinking. However, their responses reflected the need to develop their critical and reflective thinking skills, in addition to their self-efficacy. Demir, (2015) recommended further research to identify and develop reflective and CT skills of pre-service science teachers during their education.

An additional framework to develop CT skills based on bloom's taxonomy was proposed by M. Zapalska et al., (2018), as they related the sequential development of thoughts aligned with the six stages of bloom's taxonomy to CT skill development. They argued that if students were guided through a series of thinking processes starting from remembering and gradually develop to reach creating, they will develop CT skills. One more study by Larsson (2017) introduced the phenomenographic theoretical learning approach as a method to understand and apply CT. The study utilized an empirical research to prove that following phenomenography in designing classroom tasks can promote students' CT skills.

In a pilot study to explore students' and teachers' perceptions about CT development, Barnaby (2016) pointed out that teachers and students had different understandings of the CT dimensions, which leads to a mismatch between their expectations about the development of students' CT skills. The results of their study revealed that students reported that their CT skills have developed since they joined higher education, while the teachers reported that no significant improvement in students' CT skills was realized. Further research was recommended to explore educators' and students' understanding of CT dimensions. Another study in Indonesia, Amin and Adiansyah, (2018) investigated lecturers' perception on the development of students' CT skills. Their descriptive study revealed that only 32% of the lecturers were able to evaluate their students' CT development. Which indicated that teachers lacked the correct understanding of CT when most of their lectures required interactive activities that should promote students' CT abilities. Therefore, Adiansyah, (2018) recommended further professional development for lecturers to adopt learning models that would improve students' CT skills. Consequently, to gain more insights on teachers' and students' perceptions of CT development, the current study utilizes teachers' interviews and lesson observations to answer the question related to high school biology teachers' perceptions on the use of IBL and development of CT. This would facilitate the identification of essential elements that should be included in a professional development program that will enable teachers to utilize CT aspects in their instructional strategies.

2.2.1.2 Instructional practices that affect CT development

A large and continuously growing body of literature has investigated the effect of adopting instructional strategies on the development of students' CT skills. Previous studies focused on several instructional models including collaborative learning, reflective strategies, real-life applications, developed assessment strategies, technology integration, explicit teaching of CT concepts and the adoption of Project-Based Learning (PBL) strategies (Erdogan 2019; Karunanayaka et al. 2017; Fong et al. 2017; Fung, 2017; Johanns, Dinkens and Moore 2017; ŽivkoviĿ 2016; 2016; Kong 2015; Dwyer Hogan and Stewart 2014). The results of the research studies indicated that the adoption of a new instructional method always had a positive influence on students' ability to develop CT skills. The section below provides a detailed description of the results and recommendations of the research studies related to the effect various instructional strategies on the development of students' CT skills.

Much of the current literature on CT development pays attention to the essential role of collaborative leaning in developing students' CT skills (Erdogan 2019; Fung 2017; Karunanayaka et al., 2017). The study of Fung (2017) showed the importance of collaborative leaning in association with teachers' guidance to cultivate and develop students' CT skills. He performed a quasi-experimental research to investigate the effect of three different teaching strategies on students' CT dispositions. The results of Fung's (2017) study revealed that students who worked in collaborative groups reflected better development of CT dispositions than students who were exposed to whole class discussions. In addition, students who were supported by their teacher's guidance presented higher levels of CT and self-confidence than students who were exposed to self-directed instructions. However, the research study did not consider the effect of teacher training on the development of students' CT dispositions.

More examples of collaborative learning instructional strategies were found to positively affect students' ability to develop their CT skills. Those strategies include giving time for group discussions, providing an opportunity for student to practice reflective thinking through writing journals, online discussions and creating concept maps in addition to employing self-evaluation tools (Erdogan 2019; Karunanayaka et al., 2017; ŽivkoviĿ 2016).

In a quasi-experiment Erdogan (2019) proved that students in the experimental group that followed the collaborative learning method supported by reflective practices in mathematics showed significant development in their CT skills, while students in the control group di

d not show any significant difference between the pre-test and the post-test results. The study recommended further research in K-12 education to utilize qualitative methods to analyze classroom interactions, particularly during the implementation of reflective thinking activities in different disciplines. Likewise, ŽivkoviĿ (2016) proposed a teaching model that utilizes CT skills and subskills proposed by Facione (2016) to design classroom instructions. Their model was based on in-class discussion that aimed at increasing students' participation, improving their communication skills and fostering their conceptual understanding of the main topics discussed. They recommended a change in instructional strategies to provide better opportunities for students to develop CT skills and learn in a social, productive environment.

With respect to reflective practices Karunanayaka et al., (2017) performed a case study in higher education exploring the factors influencing educators' reflective practices. The results indicated that incorporating learning activities such as concept mapping, online discussions and reflective journal writing enhanced participants' CT skills. However, participants' engagement during reflective activities was hindered by some challenges, including time constraints, expectation of more feedback from instructors and high cognitive demands.

Additionally, introducing real life applications of concepts discussed in class within the course could influence students' development of CT skills, which was discussed in a study focused on community college students by Fong et al. (2017) who reviewed 27 research studies regarding the factors affecting students' CT. The study confirmed the existence of a positive relationship between students' CT skills and their success in college, especially when the students' focus was vocational, where they experienced real life situations and resolved problems by utilizing higher order thinking skills. The result of this research may suggest that if students were to experience real life situations during their learning process, they could have a greater opportunity to develop CT skills.

The role of improving assessment strategies in developing students' CT skills was investigated by Johanns, Dinkens and Moore (2017). Their study investigated the effect of open-book and closed book examinations on developing CT skills in a nursing program. Their results revealed that in order to help students develop analysis and synthesis skills, open-book exams must be incorporated with the traditional way of assessment.

The effect of utilizing technology in a flipped classroom to develop students' CT skills was investigated by Kong (2015). His three year-long trial study included designing group-based activities that merge content knowledge with the dimensions of CT skills. The results revealed that the flipped classroom pedagogy supported students' CT skill development, particularly when students were involved in group activities to discuss content-related concepts, then present their reflections and receive feedback from teachers and their peers. Kong (2015) recommended that future research studies related to CT development should consider utilizing pedagogical strategies that combine content knowledge, CT skill development and technology to provide individual learning opportunities, in addition to support from peers and teachers. The current study intends to answer a question about students' development of critical thinking skills through the use of high school biology IBL activities as a pedagogical strategy that supports students' learning. Despite numerous reviewed articles related to instructional practices that affect students' CT development, future recommendations included further investigation of the detailed interactions that take place in K-12 classrooms adopting qualitative methods. Therefore, the current study intends to utilize qualitative and quantitative tools to identify the best instructional practices that have been shown to improve students' CT skills.

Explicit teaching of CT was proposed by Dwyer Hogan and Stewart (2014) as they suggested that the best environment to develop CT skills is including them directly in classroom instructions, making the students aware of the meaning of CT and how they are expected to apply them. Explicit teaching of CT was also examined by Cargas, Williams and Rosenberg, (2017) where they designed performance task rubrics that assess CT skills without depending on a certain discipline, then carried out both a pre-and a post-test to examine the effect of teaching CT to students on their actual CT development. Similarly, a study in a higher education context by Michaluk et al., (2016) used Paul and Elder's CT model to design assignments for students in the first year of an Engineering program. The results of both studies confirmed that students' CT abilities improve if they were explicitly taught across disciplines. Therefore, they recommended incorporating the elements of thought in Paul and Elder's model in course objectives and including them in the rubrics of any given assignment, followed by providing appropriate feedback.

Problem-based learning (PBL) was discussed in previous studies as a good tool to cultivate CT skills. For example, Cowden and Santiago (2015), implemented a model of an interdisciplinary nature to promote students' CT skills via problem-based learning (PBL). They used a pre-and post-test to identify any improved skills after implementing their model, which integrated library resources with literature reviews in a PBL approach. Their results showed that their implementation improved students' research skills and interdisciplinary thinking. They recommended further research studies to investigate how the PBL approach affects students' CT abilities. Similarly, Siew and Mapeala (2016) investigated the effect of PBL using thinking maps on fifth graders' CT in science classes and recommended that further research studies use a mixed-method approach to assess the use of thinking maps in PBL to improve students' CT skills. Locally, a related study conducted in the UAE by Abuzaid and Elshami, (2016) investigated the impact of introducing scenario-based simulation in radiology education on students' critical thinking development. Their results revealed that scenario-based learning promoted students' learning and critical thinking abilities. Another study related to teacher training by Vong and Kaewurai, (2017) proposed instructional strategies to foster CT skills by considering two main issues: enhancing trainers' CT skills and increasing their ability to teach CT skills to their students. They pointed out the need for further research to create a professional development program that helps teachers utilize CT during in their teaching pedagogies. Therefore, it is intended that the results of the current study are used to design a series of professional development workshops that help teachers utilize CT dimensions in biology IBL activities.

A considerable amount of literature investigated the demographic factors that may affect students' CT development including gender, age group, type of school management, the curriculum offered and nationality. (Bećirović et al, 2019; Devika and Soumya 2016; White et al. 2015; Austin 2014; Piaw, 2014).

The previous literature studies have reported three different contradicting results related to the effect of gender on students' thinking abilities and academic performance. The first type of results indicated that female students reflected better CT development such as a study by Howard, Tang and Austin (2014). The study's results indicated that female students were more capable to develop CT skills from the pre-test to post-test, while male students performed better than females in the pre-test and didn't show any improvement in their post-test results. This was reasoned as female students taking their academic achievement more seriously than male students, and male students tending to be careless if the test scores were not considered in their final score. The second type of results indicated that male students reflected better thinking abilities as reported by Piaw's (2014) study, which reported that male students reflected better creative thinking abilities than female students, particularly in the elaboration component. Further research was recommended to investigate the influence of gender on thinking skills. Also, a study by Bektasli and White (2012) investigated the relation between logical thinking, gender and interpreting kinematics graphs. They reported that male students reflected better logical thinking skills than female students, a possible cause was that male students tended to be more interested in studying sciences. The third type of results stated that there is no significant difference between male and females in their thinking abilities, as reported by a study by Piraksa, Srisawasdi and Koul, (2014). The study investigated high school students' scientific reasoning skills, and the results revealed that there is no significant difference between male and female students in their ability to apply reasoning skills. A later study by White et al. (2015) used The Watson-Glaser Critical Thinking Appraisal to investigate the effect of demographic factors on the students' CT development in animal science undergraduate course, their results revealed that CT development is not affected by gender, age or level in the university. The only factor that may improve CT development is the training on evaluation during the course. It worth mentioning that effect of gender on learning biology is not clear yet, as Patall et al., (2018) confirmed in his study about the differences between girls and boys in their engagement in high school science classrooms. The results of his study reported that girls reflected less engagement in chemistry and physics courses than boys, while in biology there was no significant difference. However, a previous study by Hadjichambis et, al (2015) reported that girls presented higher motivation and engagement during high school biology courses than the boys.

The variation between existing results necessitates further research to confirm whether there is a strong relationship between students' gender and their thinking abilities. Therefore, the current study intends to identify the effect of demographic factors, including gender on the development of students' critical thinking skills when applying IBL biology activities.

Preliminary work on the effect of Grade level and nationality on the development of students' CT skills was undertaken by Bećirović et al, (2019) as they investigated the students' CT level in a high school in Turkey. The independent variables they investigated included the grade level in the high school, in addition to the students' nationality which was either Turkish or Bosnian studying in Turkish high schools. With respect to grade level, their study indicated that the students' grade level significantly affects their ability to develop CT skills. The students in the senior high school grade levels presented lower levels of CT compared to students in the first and second grades in the high school. They explained their findings by referring to the curriculum for each grade level, which may include less opportunities to practice CT skills at senior high school grade levels. Additionally, the nationality of the students also had a significant effect on their ability to develop CT skills, as the Turkish students demonstrated higher abilities to develop CT than Bosnian students. This finding supports the idea that students with different nationalities demonstrate different levels of CT abilities based on the social context that they were raised in and different interactions they were exposed to during their early stages of development, which is supported by the social cognitive development theory by Vygotsky, (1978).

The effect of the type of management of schools was investigated by Devika and Soumya (2016). Their study revealed that students who were enrolled in private schools reflected a better ability to develop CT skills, whereas students in governmental schools were not offered the same opportunities to practice CT skills. They explained that the students in private schools have improved learning facilities and are given opportunities to participate in club activities that support the development of their CT skills. This is also supported by the social cognitive development theory, as providing more opportunities for students to interact with their peers or their teachers enrich their opportunities to practice core CT skills and become critical thinkers.

The current study considers investigating the effect of grade level and the location of the school on the students' abilities to develop CT skills to confirm that the students' social context affects their learning and their abilities to demonstrate CT skills.

2.2.1.4 Tools to assess CT

Several existing tools are used in literature to measure students' abilities to develop CT, including the critical thinking scale, which was a tool used by Demir, (2015) who adopted the critical thinking skill measurements in the "California Critical Thinking Disposition Inventory and Reflective Thinking for Problem Solving Scale", which was originally developed by Kızılkaya and Aşkar (2009) to evaluate pre-service teachers' critical thinking abilities. An additional tool, the Health Science reasoning test (HSRT) was utilized by Cone et al., (2016) to assess pharmacy students' critical thinking abilities before and after exposure to an explicit critical thinking curriculum. Their results presented significant improvements in students' critical thinking abilities after their exposure to such a specific curriculum. They recommended incorporating elements of critical thinking in curriculum design to promote the development of student' critical thinking abilities. This is in line with Weil and Kincheloe (2004) as they explained in their tool about critical thinking and learning that for a teacher or a student to develop CT, they need to learn how people think and process information. This includes postformal learning, which is a foundation for complex critical thinking skills such as questioning the origin of knowledge, finding patterns and identifying relationships.

In an additional study, Stupple et al., (2017) developed a similar tool called the Critical Thinking Tool Kit (CriTT) which can be used to identify students' misconceptions about CT and measure their attitudes and perceptions towards it. In the context of higher education, a study by Liu et al., (2016) was conducted to validate a tool to assess students' critical thinking skills in higher education (HEIghten). They correlated CT assessment results with students' academic scores in high school and their freshman and senior years in college. The result of their study provided preliminary validity of the HEIghten tool, which can be utilized to assess students' critical thinking in higher education institutions. The reviewed tools were utilized in this study to validate and compare CT items in the students' questionnaire, in addition to The Critical Thinking Attribute Survey (CTAS) developed by Forawi (2012) that was developed to evaluate the CT attributes in the National Science Education Standards.

2.2.1.5 CT in Science Education

In science education, CT is addressed as an explicit concept that should be introduced to students as a required process to achieve better results. In addition, it is implicitly addressed in all science disciplines (Forawi, 2016). Vieira, Tenreiro-Vieira & Martins (2011) suggested a framework that guides science teachers to utilize CT to develop students' scientific literacy. Their framework demonstrates the relation between scientific literacy, competency and CT development. Additionally, a study by Forawi, (2012) identified science content objectives that would require students to utilize their critical thinking skills as perceived by pre-service teachers. The result of the study identified the science standards that would enhance students to develop critical thinking skills. A related study by Forawi, (2016) examined CT attributes of US national science and mathematics standards. Based on his research recommendations, the tool developed in the research can be utilized in future studies to examine whether science curricula and instructions foster CT. This implies the need to focus on daily classroom activities and interactions that build students' CT skills. Several research studies focused on the implicit teaching of CT through investigating the effect of certain instructional pedagogies on the development of CT skills. One example is a semi-experimental research study by Duran (2016) which investigated the effect of IBL activities of the development of students' CT. The study's findings showed a significant difference between students' CT development in the experimental group and the control group. It was evident that IBL activities allowed interactive discussion and questioning that improved students' CT skills. Yet, these results were related to science education at an elementary level. A similar study related to high school students was done by Nisa, Jatmiko and Koestiari, (2018) in which they developed guided inquiry physics materials to help students improve their CT skills. The result of their study also proved that utilizing IBL material in physics positively influenced the development of students' CT skills. In a recent study related to physics in higher education by Kurniawati, (2019) PBL teaching material was developed and proved to be effective in developing students' CT skills. Further research was recommended to create subject-related material that will contribute to developing students' CT skills. Despite the numerous studies reviewed about the effect of IBL on the development of students' CT skills, literature is still lacking research in terms of CT skill development in the context of biology for high school students. Based on the recommendations on the implicit teaching of CT, this study will explore the implementation of IBL in biology instructions, noting that the IBL approach requires students to undertake PBL, reading, mind-mapping, questioning, contributing in group discussions and sharing their ideas to achieve conceptual understanding.

2.2.2 Inquiry based learning (IBL)

National Science Education Standards (NSES) defined scientific inquiry as "diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" and inquiry in the classroom as "the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (NRC, 2000). This definition includes the explicit meaning of inquiry that defines the inquiry process, how it is done, and why. Applying the inquiry process in the classroom refers to the interactive activities that consist of seven stages of the inquiry process including exploring a phenomenon, focusing on a question, planning and conducting an investigation, analyzing data and evidence, constructing new knowledge and communicating the knowledge to others (Llewellyn, 2011). The NSES definition also includes the implicit meaning of inquiry, which involves classroom activities that guide students to understand the scientific research processes and help them recognize how scientists work and think (Enger, & Yager, (2009). In addition, the implementation of IBL instructions at different levels, starting from structured to guided and then to more open inquiry helps students gain autonomous skills and become self-independent learners (Llewellyn, 2011). The subsections below analyse the empirical studies related to inquiry-based learning instructions applications, it's effectiveness to improve CT skills and how IBL instructions are implemented in the Middle East.

2.2.2.1 The inquiry-based learning instructions

Several empirical studies aimed at investigating the effectiveness of IBL instructions in science education. In general, the results indicated that utilization of IBL activities improved students' performance in addition to students' gain of scientific skills. (Kang and Keinonen, 2017; Fuad et al., 2017; Hardianti and Kuswanto, 2017; Ellwood and Abrams, 2017; Pérez, and Furman, 2016; Arnold, Kremer and Mayer, 2014).

Kang and Keinonen, (2017) investigated the effect of four types of student-centred activities on students' achievement. They reported that guided inquiry-based activities and selecting topics that are relevant to students' real life had a positive effect on students' performance. While open inquiry-based instructions and class discussions had a negative influence on students' performance. Students proved to have better conceptual understanding when they received appropriate support from their teachers to learn the scientific procedures required to perform the given IBL activities. They recommended further in-depth research about teachers' and students' perceptions of their implementation of IBL instructions. Moreover, Fuad et al., (2017) conducted a quasi-experiment to compare the effect of three learning models: differentiated inquiry combined with mind maps, differentiated inquiry alone, and the traditional model on students' development of CT skills. The results indicated that utilizing differentiated IBL combined with mind-maps led to a significant improvement in students' CT skills. A similar study in Indonesia by Hardianti and Kuswanto, (2017) followed a quasi-experimental method to contrast the effect of implementing three different levels of inquiry on students' process skill development. Scientific process skill development is the ability to apply the scientific method stages that would require students to reflect and verify their results and then further develop their product. In their experimental setup, the experimental groups applied the third level of inquiry, with some students performing it independently. They also applied the fourth level of inquiry, which facilitates open inquiry, with minimal interference from the teacher. The control group applied the second level of inquiry, while depending more on the teacher's guidance. The results revealed that students in all groups were able to improve their scientific process skills. However, the most effective implemented inquiry level was the third, followed by the second then the fourth, which reflected less impact on students' skill development.

The researchers explained that the difference was due to the nature of the fourth level of inquiry, which requires independent work with minimal support from the teacher. The current study will build on this result and identify the role of scaffolding and guided reasoning to develop better CT skills as one of the scientific process skills. Ellwood and Abrams, (2017) investigated the effect of social interaction during IBL activities on students' motivation and academic achievement. The qualitative case study research involved recording students' interactions in two different groups. The grouping was based on the approach followed to apply the IBL activity. The first group was required to complete the activity inside the classroom within school timing as the "On Campus group", while the other group was the "Off campus group", who were given the opportunity to develop their research question during a field trip. Consequently, they were allowed two hours and a half of extra time outside the classroom throughout the implementation of the project. Even though the two groups were given the same curriculum by the same teacher within the same classroom, the results clearly proved that when students were given the opportunity to discuss research questions, plan the procedure and data collection methods, receive timely feedback from teachers and peers and act as a scientist, they experienced discussion at a higher cognitive level and demonstrated the correct flow of information throughout their learning experience. They also showed higher motivation towards their learning and achieved higher academic scores

(Ellwood and Abrams, 2017). A related study by Sever and Güven, (2014) investigated the effect of IBL activities on middle school students' behaviour and the positivity of their attitude towards learning science. Their independent variable was the use of IBL activities and the dependent variable was the change in students' negative behaviours such as isolation, disrespecting teachers and seeking attention. The result of their research indicated that students who were exposed to IBL instructions were less resistant to science classroom instructions and achieved better in their final assessments. The researchers recommended further research to identify the effect of social interactions on students' performance during IBL instructions. They also suggested designing professional development programs to support teachers to provide timely feedback themselves and allow peer feedback during IBL instructions, which would result in an appropriate flow of information in the science classroom.

In an earlier study, Arnold, Kremer and Mayer (2014) reported that students lack in-depth procedural knowledge related to following the scientific method. Students were not able to identify confounding variables or provide explanations for some steps required in a scientific procedure. Hence, teachers are required to provide support and timely feedback for students to guide them through the correct application of a scientific experiment. The study recommended further research to gain a deeper understanding of students' responses and designing support material to help students better implement IBL activities.

Additionally, an instrument to measure the effectiveness of IBL activities in biology textbooks was developed by Yang and Liu, (2016). In their study, Yang and Liu,

(2016) focused on four main criteria that must be available in all IBL activities to achieve their expected function: enabling students to understand the scientific concepts, practice their inquiry skills, exhibit an understanding of inquiry process, and practice higher order thinking skills. Yet, Yang and Liu's, (2016) study did not investigate how IBL activities are to be implemented in class; it was limited to evaluating the quality of the resource content. Therefore, further research studies were recommended to use the tool and evaluate more IBL tasks in different disciplines.

In a recent study, Grob, Holmeier and Labudde (2017) explored teachers' opinions regarding formative assessment strategies followed during IBL and how they would enhance the development of students' thinking skills. Their research came up with the main challenges faced in applying formative assessment in IBL, and some best practices suggested by teachers to resolve these challenges. Their study did not consider students' input and they recommended further research to test the effectiveness of the proposed results. Previous studies by Clarck, (2010) and Chow, (2010) called for the active implementation of formative assessment strategies to ensure active engagement of students in the learning process and their contribution to their own learning experiences. Their findings indicated that informative and comprehensive feedback provided by teachers increased students' awareness of their own strengths and areas of improvement, which had a positive effect on their commitment to their learning, and positively influenced their final test results. The implementation of effective formative assessment methods is also expected to promote students' self-regulatory learning skills (Clark, 2010). A considerable amount of studies in literature addressed the factors that would promote students' self-regulatory learning skills. The findings of these study revealed that the use of instructional practices that provide students with opportunities to practice metacognition by providing effective feedback and self-assessment practices to help students to monitor their own progress are indeed essential tools that help students to build self-regulatory learning skills and reduce anxiety prior to summative assessments (Lee, Lim, and Grabowski, 2010; Clark 2010; Lam, 2012; Jahangard, Soltani, and Alinejad, 2016)

Implementing the identified instructional practices related to formative assessment are addressed in the current study as factors used in IBL activities to build up self-regulatory learning skill as one of the core CT skills. The current study will consider students as the main subject of the research and will track their development after implementing IBL activities.

With respect to project-based learning (PBL) and its effect of students' achievement, a study by Haridza and Irving, (2017) investigated through an action research the effect of using a PBL approach that depends on the constructivism theory, and IBL instructions in science classrooms, on the development of middle school students' CT abilities. The study concluded that utilizing a PBL approach in science lessons has stimulated students' preliminary CT skills, such as identifying problems and proposing solutions. Yet, solutions presented by students were based on scientific reasoning and were insufficient to solve the problems. The recommendations included an effective facilitation of the PBL approach to enable students to analyse results accurately and find appropriate solutions for the given problems.

Two other examples of studies discussed the effect of the enhancement of IBL instructions on students' CT abilities, such as Memiş, (2016) who investigated the effect of integrating argument as a language component in scientific learning procedures on students' ability to develop CT skills. The study's findings confirmed that using an argument-based approach positively affected students' ability to develop CT.

Arsal, (2017) conducted a quasi-experiment that investigated the effect of IBL instructions on pre-service teachers' CT dispositions. The results indicated a minimal difference between pre-teachers' CT dispositions in the experimental group and the control group. Yet, recommendations for further studies included the combination of IBL instructions with other methodologies to create a significant impact on the pre-service teachers' CT dispositions. A recent related study by Saputro, Rohaeti and Prodjosantoso, (2019) concluded that utilizing IBL instructions has a significant positive effect on the development of CT and scientific process skills of pre-service elementary school teachers. Another study regarding teachers' readiness to implement IBL activities was done by Gutierez, (2015) in the Philippines. The study revealed three main challenges that hinder teachers from using IBL in their instructions, including lack of teachers' support, the focus on content instead of the learning process and the misconception about time constraints. Gutierez, (2015) proposed a professional development model to support teaching practices, which was based on "lesson study" a form of collaboration between science teachers to discuss lesson plans and modify them to implement IBL activities. The study also recommended further adjustment to pre-service teacher preparation programs to ensure that science teachers are exposed to IBL instructions as students, then they will be able to use them in their classrooms. A related study by Papaevripidou et. al (2017) also confirmed that teachers gain the ability to design instructional practices that are based on IBL activities when they are enrolled in professional development programs focused on utilizing IBL activities.

In the scope of IBL teaching practices, a study by Zervas et al, (2015) proposed a framework to align the phases of IBL activities and problem-solving steps addressed in the PISA assessment. They recommended further research studies to identify methods to assess students' problem-solving skills during IBL instructions. In addition, they highlighted the necessity of professional development programs that empower teachers to apply authentic assessments of problem-solving skills during scientific inquiry activities. In the same context, a recent study by Peffer and Ramezani (2019) established a relationship between teachers' views about inquiry and their actual practices. The study focused on using authentic inquiry simulation to improve instructions and using the simulation to assess teachers' and students' practices during inquiry activities and suggest individualized instructions that will positively affect students' scientific literacy. The study recommended further research studies on a larger scale to investigate the impact of teachers' and students' practices during IBL instruction on the generation of new scientific knowledge.

On another note, Škoda et al, (2015) proved that the effectiveness of IBL instructions is influenced by students' motivation styles. In their research, students who reflected better scientific knowledge in their post-test results were characterized by being explorers, other motivation types are either less affected or affected for a short period of time. They recommended considering the impact of different motivation styles when planning to implement IBL. This implies that the application of IBL should be over a long period of time, in order to allow all students to adapt to the change and benefit from this implementation. The current study will take this factor into consideration during data collection and interpretation.

The effect of IBL instructions on male and female students' attitudes towards science and their role in society was investigated by Kekule et al (2017). Their study concluded that IBL instructions generally influenced girls' attitudes towards science education more than males, which was explained by assuming that female students were more influenced by educational systems, followed by a recommendation to conduct further research to identify factors that cause female students to be influenced by IBL instructions. Investigating the effect of demographic factors on the use of an instructional pedagogy was also investigated by Hossain and Tarmizi (2012) as they performed a quiz experiment to identify the effect of a group learning pedagogy on male and female students' achievement in mathematics. Their results revealed that female students reflected significant improvement in their post-test scores, they concluded that the use of group learning pedagogy is more effective with female students. They recommended further research studies to compare other teaching strategies in other disciplines, which is addressed in the current study. Locally, a study in Abu Dhabi investigated male and female students' interests in physics by Badri et al. (2015). The results of this study revealed that in general, female students reflected less interest in physics topics. In addition, the topics that girls were found to be interested in were related to topics such as life outside Earth and astronomy, while male students were interested in topics related to electrical and mechanical equipment that are directly related to the physics content taught in class. Badri et al. (2015) recommended further research studies to identify instructional practices that can influence students' interests in sciences and investigate other science subjects including biology. Therefore, the current study intends to identify the effect of demographic factors on the development of CT skills through IBL instructions.

2.2.2.2. The effectiveness of IBL instructions to improve CT skills

There is an unambiguous relationship between IBL instructions and CT skill development (Brown 2017; Buchanan et al. 2016; Aktamiş et al, 2016). IBL instructions and their relation to sociocultural responses were investigated through a meta-synthesis study performed by Brown, (2017). The results of reviewing 52 studies revealed that the three least discussed IBL practices are directly related to students' CT development. In a similar study, Buchanan et al., (2016) concluded in their literature review that few research studies focus on students' skill development after implementing IBL and recommended further in-depth research on IBL to identify the skills and abilities that lead to acquiring a deeper understanding. Moreover, Aktamiş et al, (2016) also performed a meta-analysis study by reviewing nineteen empirical studies that compared between the effect of IBL and traditional instructional methods on students' academic performance, attitudes and process skill development. Their results proved that adopting IBL instructions would enhance students' academic performance more than their scientific process skills and their attitudes. They recommended further studies to reveal the effect of IBL on students' process skills. The current study will identify the effect of IBL instructions on students' CT skills, which is a main part in developing scientific process skills.

On the other hand, Rizzo and Taylor, (2016) performed a similar metanalysis study focused on nineteen quantitative research studies related to IBL instructions. The result of their study concluded that IBL instructions had a positive influence on students' academic achievement, process skills development and attitudes towards science. They recommended further analysis of qualitative studies to explore the detailed interactions during IBL instructions.

Another study that addressed the guidance required during IBL instructions was performed by Lazonder and Harmsen (2016), who conducted a metanalysis research by analysing 72 research studies and Dobber et al., (2017), who reviewed 186 studies investigating teachers' role in the IBL approach. Their conclusions implied that the effectiveness of IBL activities depends on the appropriateness of the guidance provided. Their results indicated the need for more qualitative research to explore practices within the classroom and measure the effect of IBL instructions on the development of lifelong skills. Further research was recommended to study IBL in senior high schools, and focus on the development of students' problem-solving skills, which is the intention of the current research. Therefore, the current research study intends to measure the effectiveness of IBL activities on the development of CT abilities, which would improve students' self-regulatory learning abilities.

2.2.2.3 Implementation of IBL instructions in the Middle East

Several attempts have been made to investigate areas related to the application of IBL in the Middle East. The main topics investigated included empirical studies to prove the effectiveness of IBL instructions and research studies to investigate teachers' perceptions and beliefs with regards to IBL and science education in the Middle East (Sabri and Forawi 2019 b; Eltanahy and Forawi, 2019; Indraganti 2017; Almuntasheri, Gillies and Wright 2016; Dickson Kadbey and McMinn 2016; El Tanahy, 2015; Kassir, 2013; Areepattamannil, 2012; Al-Naqbi, 2010)

A comparison between traditional teaching methods and IBL instructions was conducted by Almuntasheri, Gillies and Wright (2016) Saudi Arabia. Their study included the use of a pre- and a post-test, with both qualitative and quantitative sections to compare between students' understanding of the same concept after receiving either traditional teaching or IBL instructions. They concluded that students who received IBL instructions had presented a better depth of understanding of the discussed concept than their colleagues who were exposed to traditional teaching methods. They recommended the development of teacher-training programs to encourage science teachers to adopt the IBL approach. A previous study by Al-Naqbi, (2010)

investigated science activities with Grade 5 and Grade 6 through analyzing their science workbooks. Al-Naqbi was able to identify items related to data collection and interpretation. Yet, the workbook activities lacked evidence on the improvement of students' skills to design questions and communicate scientific results. A later study by Indraganti (2017) who performed an action research on the effect of IBL workshops on students' achievement in an interior design course. The research results revealed that the IBL workshop improved students' academic performance, self-confidence and reduced their anxiety towards the examinations. This improvement also bridged the gap in students' learning, in addition to their communication skills. In Qatar, a study investigated students' motivation towards science and their performance in the assessment after the utilization of IBL instructions. The results of the study revealed that although students reflected poor performance in the science assessment, they expressed a high interest in science. This was explained by the researchers to be due to the low level of students' fundamental literacy and numeracy skills, which are essentially required to learn scientific concepts (Areepattamannil, 2012).

A study related to science education was conducted in Oman by Al-Balushi, and Al-Abdali, (2014) demonstrated the importance of designing professional development workshops for teachers using Moodle to promote distant learning, which helps teacher gain professional knowledge and develop their instructional practices. The results of their research identified significant improvement in science pedagogies, and they recommended further research to identify other effective methodologies to develop science educational practices.

In the UAE, an example of studies related to IBL instruction by Kassir, (2013), addressed elementary students and investigated the effect of IBL on students' achievement and motivation, without discussing CT abilities. Another study by El Tanahy, (2015) investigated the effect of the IBL approach on students' achievement in the TIMSS assessments in chemistry. This study will identify specific requirements to utilize IBL instructions efficiently and promote students' CT abilities.

With respect to teachers' beliefs and their perceptions, a preliminary work done by Dickson and Kadbey (2014) investigating elementary school teachers' perceptions about IBL instructions. They found that pre-service teachers were not exposed to IBL activities during their school education but are more exposed to them as they progress through teaching school. They compared between year one and year four students' knowledge and skills regarding the utilization of IBL activities in science instructions and concluded that students in year four had gained the required knowledge and skills to use IBL instructions in their teaching practices. Hence, their experience in the teaching college where they received student-centred instructions and IBL opportunities helped them gain this experience and replicate it in their own teaching. A later study by Dickson Kadbey and McMinn (2016) performed a case-study research to determine the beliefs of Abu Dhabi private school teachers regarding how students best learn science, and whether this aligns with the reported practice by the teachers. The results of the study indicated several discrepancies between teachers' beliefs and their actual practices. On the other hand, recent studies reflect development in IBL instructional implementation in the UAE. For example, Sabri and Forawi (2019) investigated science teachers' perceptions regarding the implementation of formative assessment to evaluate IBL instructions, the results of the study indicated that physics and chemistry teachers reflected better application of the IBL and formative assessment teaching skills than biology teachers. Both studies recommended professional development for science teachers to help them overcome the challenges that hinder the implementation of IBL instructions in their classrooms. A similar study by Eltanahy and Forawi (2019) investigating middle school teachers' perceptions regarding IBL instructions, teachers reflected good knowledge of IBL instructions, yet were unable to implement different types of inquiry. The study recommended the use of science textbooks that provide suitable guidance for teachers on the type of inquiry that can be used for each activity. They recommended further research on inquiry application in the UAE. This study adds to the efforts done to support science teachers, as the outcome of the current study is a suggestion of a series of professional development workshops and trainings designed for existing new science teachers, in addition to the production of specific rubrics to effectively investigate the authentic implementation of IBL activities in science instruction.

2.2.3 Biology Instructions

2.2.3.1 High School Biology

Previous studies have reported that the biology subject is a suitable context to implement IBL instructions and that it provides several opportunities for students to develop CT skills (McComas 2007; Abell and Lederman 2010; Tsybulsky 2018). McComas (2007) stated that the biology course serves as a keystone science for other sciences, especially if it was introduced during middle school and high school. Students are expected to learn how actual scientises work and think to come up with new scientific theories. McComas (2007) emphasized that biology is a suitable context to apply IBL instructions and undertake laboratory work away from traditional cookbook activities. Abell and Lederman (2010) clarified that the biology curriculum contained seven levels of biological organization, including molecular, cellular, tissue and organ, organism, societal, communal and the biome. Throughout the curriculum, inquiry-based investigations were integrated to require students to question facts, perform investigations and reach conclusions, which required students to use critical thinking and problem-solving skills (Abell and Lederman 2010). Recent evidence suggests that the high school biology course is a suitable context to apply IBL instructions and improve students' understanding of the Nature of Science (NOS), where the study proved that utilizing authentic university laboratory visits within high school biology courses would significantly increase students' understanding of the NOS (Tsybulsky 2018).

2.2.3.2 Applying IBL instructions to improve CT Skills

Several attempts have been made to investigate the content of high school biology textbooks, and interpreting explicit teachings of scientific inquiry (Campanile, Lederman and Kampourakis 2013; Yang, Liu and Liu, 2019). Campanile, Lederman and Kampourakis, (2013) investigated the explicit and implicit explanations of scientific inquiry in the genetics sections in seven different biology resources. Their results revealed that textbooks include more implicit indications to scientific inquiry than explicit explanations of the process of scientific inquiry. Similarly, a recent study in China by Yang, Liu and Liu, (2019), analysed the content of biology textbooks to evaluate IBL tasks incorporated within the lessons. Their results revealed that the textbooks lacked a balanced distribution of the process skills required to perform IBL activities, needed better inclusion of higher-order thinking skills and were mostly structured or guided activities that do not encourage the kind of independent learning that allows students to design their activities. Further research studies were recommended to identify an ideal distribution of the process skills that should be included in IBL activities in high school biology textbooks. In addition, recommendations included focusing on how teachers use textbooks to implement scientific inquiry, to create professional development programs that enable teachers to implement IBL effectively, and include the explicit meaning of scientific inquiry during IBL activities. One recent study investigated the utilization of CT skills in a high school biology curriculum by Sabri and Forawi (2019). The study used qualitative methods to evaluate the utilization of CT skills in biology curriculum documents form the teachers' perspective. The results indicated that the biology curriculum included attributes of CT skills and needed more improvement for better utilization of CT in all the discussed biological concepts. In addition, the findings related to teachers' perceptions indicated the importance of teachers' professional development to clarify the explicit meaning of CT concepts and enable teachers to better read and interpret the outcomes that promote CT skills included in the curriculum documents. The effect of the use of instructional material that utilizes IBL instructions along with visual reasoning tools was investigated by Schramm et al., (2017), their study highlighted the importance of IBL instructions in coordination with logical reasoning to help students to overcome all their misconceptions related to photosynthesis and cellular respiration topics in the biology curriculum.

There has been a number of research studies that investigated the effect of different instructional practices in high school biology courses on the development of students' content knowledge and their process skills (Nash, Cox and Prain 2018; Strimaitis et al., 2017; Boleng et al, 2017; Muhlisin et al., 2016; Hadjichambis et al., 2015). Nash, Cox and Prain (2018) investigated the effect of structured inquiry instructions in a biology senior high school course on students' conceptual understanding and academic achievement. Their study required students to construct representations and communicate their understanding of biological concepts. The results revealed that utilizing structured inquiry activities paired with appropriate support from teachers significantly increased students' academic performance, in addition to providing opportunities for students to develop their scientific process skills (Nash, Cox and Prain 2018). Similarly, Strimaitis et al., (2017) proved that when students are given the opportunity to apply scientific practices during practical activities in high school general and honour courses, they gain the required scientific content and show significant development in their academic performance. They recommended further research to identify best practices that allow students' engagement in science practices. In addition, Boleng et al, (2017) performed a study about the effect of learning models on biology CT skills of high school students by applying a quasi-experiment, using a non-equivalent pre-test – post-test control group design. The results showed that PBL improved students' CT skills. Furthermore, a quasi-experiment was conducted by Muhlisin et al., (2016) also with a pre- and post-test setup to investigate the effect of using the Reading, Mind mapping and Sharing (RMS) model on students' CT development. The results indicated that the RMS model enhanced students' CT skills. Yet, CT development was not correlated with students' academic abilities. The researchers recommended the use of the RMS model to introduce basic concepts in biology and recommended further research to measure the effect of this model in senior high school courses. On another note related to scientific inquiry in biology, Hadjichambis et al., (2015) conducted a study to investigate the effectiveness of IBL activities in specific biological topics on increasing students' motivation and conceptual understating. The result revealed a positive effect of IBL on female students; male students required more guidance to achieve better conceptual understanding. Their study raised a concern related to Biology curriculum development that would require better inclusion of IBL activities regarding human development topics.

The effect of IBL and interactive instructions on students' performance in biology courses was also investigated in higher education (Tamari and Shun Ho, 2019; Hacisalihoglu et al. 2018; Rosier, 2017; Gardner and Belland, 2017; Nybo and May 2015; Nargundkar, Samaddar and Mukhopadhyay, 2014). The latest study by Tamari and Shun Ho, (2019) compared the effect of utilizing IBL activities in two levels of biology courses (introductory and upper level) in a community college. Their study proved that IBL activities positively affected development of students' CT and problem-solving skills at both levels. However, utilizing IBL activities in the introductory level had a larger influence, as it helped students build essential skills that enable the scientific thinking process, which is needed in upper-level courses. An additional study by Hacisalihoglu et al. (2018) investigated the effectiveness of an active learning model in teaching an undergraduate general biology course. The study showed that the utilizing active instructions had a positive impact on students' learning. The active instructions utilized in the study adopted a flipped classroom pedagogy, which depends on students' preparation before the class, in-class discussions and after class assignments. They recommended further research studies on methods to promote students' engagement in the classroom.

Gardner and Belland, (2017) and Nargundkar, Samaddar and Mukhopadhyay (2014) investigated the effect of making use of supplement instructions that follow a problem-centred approach on students' conceptual understanding and their development of CT skills. Gardner and Belland's, (2017) results revealed that the students who followed the problem-centred approach through the three main stages (activation, demonstration and application) improved their recall abilities and gained problem-solving skills. Nargundkar, Samaddar and Mukhopadhyay (2014) also concluded that the use of project-based learning instructions improved the group's task performance by 6%. However, students who were exposed to a traditional learning approach only improved their recall abilities. A related study by Nybo and May (2015) investigated the effect of IBL instructions on students' ability to understand subject-specific learning outcomes in a physiology course. Their results revealed that when students were given IBL instructions during laboratory activities, they were able to recognize and interpret the concepts being explored. However, utilizing interactive activities is not always effective to engage students, as per a study by Rosier, (2017) who notes that planning and implementing interactive instructions is time-consuming and may not be useful in every class. The study recommended further research on the relation between students' tendency to learn individually or in social groups and their preferred biology instructions. These results indicate the need to understand detailed interactions during IBL activities in a classroom setting to identify actions that provide opportunities for students to develop their CT skills.

Regarding teachers' readiness to use IBL instructions in biology courses, an essential criteria was set by Abell, and Lederman (2010) which implies that in order to achieve a significant change in any educational practice, it is required to change teachers' beliefs and values towards that specific practice. This suggests that programs that effectively prepare teachers and in-service professional development for teachers should include items related to the constructivist approach of learning, to incite a change in teachers' conceptions, which has been shown to lead them afterwards to change their instructional practices. A recent study in the UK, Glackin and Harrison (2017) addressed this issue by exploring pre-service high school biology teachers' perceptions regarding the possibility of introducing IBL courses outdoors. Their results revealed that pre-service teachers are aware of the main requirements needed to include IBL in their instructions. However, the timeframe and introductory stages to inquiry before implementation are required. In addition, the teachers expressed their concerns regarding the ability to deliver diverse learning outcomes and to monitor students' progress considering the degree of students' independence in achieving the inquiry activities. This study recommended further research to create professional development programs that would enable teachers to overcome the identified challenges. In a supportive study by Silm et al. (2017) a professional development program was designed and offered to 497 teachers from 10 countries. The study investigated the effect of three phases of training on teachers' attitudes towards the implementation of IBL instructions. Their results revealed that trained teachers reflected a positive attitude towards the implementation of IBL instructions and helped teachers to form a network of supportive teams to apply IBL instructions. However, the actual implementation of IBL activities in the classroom was not aligned with the planned IBL activities in the curriculum. Hence, teachers still need effective professional development to help them overcome the obstacles they face during IBL application, such as time constrains and resources restrictions. Additional studies in the field of preparing science teachers included one by Aydın, (2016) and Yakar and Baykara, (2014) who designed experimental set-ups utilizing pre-and post-tests to inspect the effect of the utilizing IBL activities in teaching programs on the development of pre-service teachers' communication skills. The study findings indicated that IBL instructions positively affected the preservice teachers' communication skills as they demonstrated better listening and collaboration skills, in addition to the development of their process skills, creative thinking and attitudes towards scientific experiments. A related study exclusively investigated the communication skills of science pre-service teachers in the USA by Riegle-Crumb et al., (2015) and related between pre-service teachers' achievement in science subjects and their attitude towards science, they hypothesized that if teachers used hands-on and inquiry activities, their students' understanding and performance in science subjects will increase and consequently will positively affect their attitudes towards science. However, the study results were not able to identify which characteristics of IBL instructions were supportive to the pre-service teachers and called for further research to identify the best practices to apply IBL in science education for all grade levels.

This has been shown to be efficient, as an earlier study by Hughes and Ellefson (2013) revealed significant results regarding the impact of training biology teaching assistants to utilize IBL instructions on students' learning experiences and standardized assessments. They performed a quasi-experiment to compare between two training approaches: the IBL pedagogy and general best practices in teaching biology laboratory course. Their results confirmed that when teachers implement IBL instructions, students gain better understanding of the concepts, have better relations with their teachers and achieve better results in their academic performance than when teachers use traditional practices in teaching the biology laboratory course. These results also imply that utilizing IBL instructions would allow better understanding of biological concepts and improve students' academic achievement. The current study intends to prove that utilizing IBL instructions at a high school level would lead to the same results and help students develop CT skills.

Several studies in the literature addressed a common issue: whether teachers believe in the importance of active learning strategies in science education, such as IBL instructions. However, the actual daily instructions are still following the traditional way of curriculum delivery, which indicate the urgency of finding various professional development means that empower teachers and promote their collaboration to create new effective interactive instructional methodologies (Hong and Vargas 2016; Selçuk et al., 2015). One of the suggested professional development strategies by literature is the implementation of an action research in which teachers undertake a research at the scale of their classroom to identify areas of improvement and prepare an action plan that support their students using different means. It is also recommended to suggest the action research implementation as a requirement to earn a teaching licences in some countries (Nolen and Putten, 2007; Capobianco, and Feldman, 2010). Capobianco, and Feldman, (2010) described action research as a kind of investigative procedure that teachers perform to identify areas of improvement in their teaching practices and adjust them accordingly. In a previous study also done by Capobianco, and Feldman, (2006) they highlighted the importance of collaborative work between teachers to implement an action research and develop teaching strategies, where teachers are encouraged to collect data about their pedagogical methods from different resources, while considering their students' perceptions in order to gain an objective view of the areas of improvement in their teaching practices. One of the studies that show the importance of action research to develop teaching practice is the study of Udeanl, Atagana, and Esiobu, (2016) where they implemented an action research strategy to help high school biology teachers to develop their teaching strategies. The result of the teachers' action research led them to develop new curriculums utilizing redesigned course material, which improved students' learning outcomes and their final scores in the biology subject.

Another study in Turkey by Isiksal- Bostan et al., (2015) related between science teachers' years of experience and their preferable method of teaching. They investigated whether they leaned more towards the traditional teaching method or using technology to integrate IBL instructions. The results of their study revealed that regardless of the years of experience, science teachers prefer the use of IBL instructions. Yet, the results of their research did not identify other factors that may affect teachers' actual implemented practices using technology to design IBL activities in the classroom. Therefore, they called for further research to identify other requirements for teachers to have such preferences, such as content knowledge and competence in using technology in designing IBL instructional activities.

2.2.3.3 Teaching Biology in the Arab region

In Arab and Middle Eastern countries, educational reform efforts are utilized to shift education towards new developments in teaching strategies implemented globally (Karami Akkary, 2014). These practices include the requirement of transforming biology education, by making the necessary changes to biology courses for them to be implemented through IBL instructions, and teaching biology more as a quantitative science that focuses on experimentation and data collection, rather than relying heavily on qualitative description (Kremer et al., 2013). Reviewed literature included studies performed in the Arab region related to biology education, and the main themes analysed included teachers' perceptions on teaching biology through inquiry and the effectiveness of instructional strategies on the development of students' CT skills. Regarding teachers' perceptions on teaching biology through IBL strategies, Qablan et al, (2009) conducted a study in Jordan where they investigated pre-service biology teachers' perceptions towards the implementation of IBL instructions. The results of the study revealed that the participating teachers believed that IBL provided better opportunities for students to learn biology concepts. However, their responses to their future teaching practices reflected less confidence in their ability to use it in their instructions. The study recommended further research to design professional development programs to enhance teachers' competencies in implementing IBL in science instruction. An additional study was conducted in Oman also investigated science teachers' attitudes towards science teaching practices, including classroom preparation, hands-on activities and their satisfaction about their students' learning development. The research study investigated the difference between male and female teachers and considered the years of experience (Ambusaidi and Al-Farei, 2015). The result of the study indicated that male science teachers who have less than 6 years of teaching experience reflected poor teaching practices and recommended professional development workshops to help the teachers improve their practices in the science classroom. However, one of the obstacles that may hinder teachers from seeking professional development is found to be the workload given for a teacher in this part of the world (Forawi, 2015)

Cooperative learning was also investigated in a school in Lebanon. Chatila and Husseiny, (2016) studied the effect of cooperative learning on the development of students' scientific process skills in the biology curriculum; they conducted a quasi-experiment targeting grade levels 7 and 10. Their results indicated improvements in grade 10 students. However, no significant changes were found in Grade 7 students' results. They recommended further studies to investigate the effect of cooperative learning on students' scientific process skills at a larger scale, and for a longer period of time.

Based on the studies reviewed, there is a lack of evidence that demonstrates the best IBL instruction practices, which are meant to positively impact subject-specific aspects of CT in high school biology lessons in the UAE. The intention of this study is to describe students' experiences with IBL implementation in a high school biology course, identify the extent to which students develop critical thinking skills through the use of IBL activities within the biology course, and present the perceptions of high school biology teachers on the use of IBL and development of CT skills.

3. Methodology

This chapter illustrates the approach and methods followed in this study. This entails providing the rationale behind selecting the research approach, methodological choices, strategies and study design. In addition to explaining their relation to the purpose of the study, which was to investigate the effectiveness of inquiry-based learning in biology on the development of high school students' critical thinking abilities. The chapter also includes a detailed explanation of the site, sampling method, data collection instruments, techniques and ethical considerations.

The chapter consists of four main sections with subsections. The first section presents the research approach and the philosophy followed, while the second section describes the methods including site, sampling and subject selection, instruments and data collection methods including the quantitative nonexperimental questionnaire describing the pilot study and the validity of the questionnaire. In addition to a description of the qualitative tools, including lesson observations, document analysis and the structured interview. The third section elaborates on ethical considerations during the research study, and the fourth section presents the study limitations.

3.1 Research Approach

This study followed the constructivist and postpositivist paradigms. Constructivism is defined as a philosophy in which data is socially constructed, where human interpretations and explanations of lived experiences are used to explore the application of a certain phenomenon (Johnson and Christensen 2008; Meriam 2009). The post-positivism philosophy recognizes the possibility of studying the social world in the same way scientific phenomena is explored. Yet, it is not fixed and allows for the presence of various possible factors that may affect the research results (Johnson and Christensen 2008; Fraenkel and Wallen 2009). Following these philosophies, both qualitative and quantitative views of human behavior are considered as positive values (Johnson and Christensen 2008; Fraenkel and Wallen 2009). Thus, to answer the main research questions, data was collected through both quantitative and qualitative methods (Johnson and Christensen 2008; Muijs 2011). Following the constructivist and postpositivist paradigms suits the nature of the current research problem; it allows for creativity through combining several approaches, as it considers assumptions, ideas and explanations collected through various methods (Johnson and Christensen 2008). The main purpose of this study was to explore the implementation of IBL and whether it leads the students to the development of core CT skills. To answer the four main research questions, a case study was employed with the use of both quantitative and qualitative methods. However, since the value of the qualitative data was found to be greater than the quantitative data in the research results, the constructivist and the post positivist paradigms were followed.

The reason this research did not follow the positivist and constructivist philosophies in isolation is because the positivism paradigm suggests that the only way to confirm facts about natural phenomena is through observation and experimentation (Cohen, Manio and Morrison 2007). This is because positivism depends on the realism that implies that reality exists, and the role of the researcher is to uncover it in a confirmatory manner. It implies the use of scientific experimentation or quasi-research methods to confirm what exists in reality (Fraenkel and Wallen 2009). Following the positivism paradigm alone would not have fulfilled the investigative nature of this research study, which cannot be purely objective, especially considering that multiple interpretations and viewpoints were considered and valued in the research results. In addition, positivism is not preferred in social science studies, since the complexity of human nature makes it difficult to control and measure many variables when applying scientific method requirements on a social phenomenon, particularly the interactions of teaching and learning in a classroom (Cohen, Manion and Morrison 2007).

The opposite of positivism is interpretivism. Interpretivism is based on the idea that human nature is controlled by general global laws that include consistent fundamentals, thus it postulates that social phenomena can only be understood through the viewpoints of the people who are in that specific situation or context (Cohen, Manion and Morrison 2007). Using the constructivist philosophy relies on interpretivism, which implies that reality is socially constructed, and the interpretation of qualitative data can be made explicit to show valid results, which suits the majority of the data collected in this research study (Fraenkel and Wallen 2009). However, following the constructivist view in isolation from other views could not reflect the confirmatory nature of the current study through the non-experimental questionnaire that aims at testing the implementation of existing educational theories in science classrooms.

The approach used in this study can be described as both deductive (confirmatory) and inductive (exploratory) at the same time (Johnson and Christensen 2008; Cohen, Manion and Morrison 2007), since it was based on the implementation of the social constructivist theory and the inquiry-based learning model in the science classroom, which would lead students to develop CT abilities. The current research explained how a theory was implemented in a real situation, which is considered deductive or confirmatory (UK Essays 2013; Johnson and Christensen 2008; Cohen, Manion and Morrison 2007). In addition, the inductive or explanatory nature of this research included collecting pieces of information that led to rich descriptions of the results (Meriam 2009; Johnson and Christensen 2008). Collecting data about the direct experience of teachers and students in a biology classroom context helped the researcher understand, discover and explain real social behavior as it existed in the eyes of teachers and students, leading to a suitable definition of the effect of inquiry instructions on the development of students' CT skills (Cohen, Manion and Morrison 2007).

The methodological choice most appropriate for this research study was a collective case study design with mixed methods, explained in Figure 3.1. The qualitative instruments in this study had a slightly higher importance than the quantitative instruments. Both qualitative and quantitative methods occurred concurrently,(Johnson and Christensen 2008). Mono-quantitative or qualitative

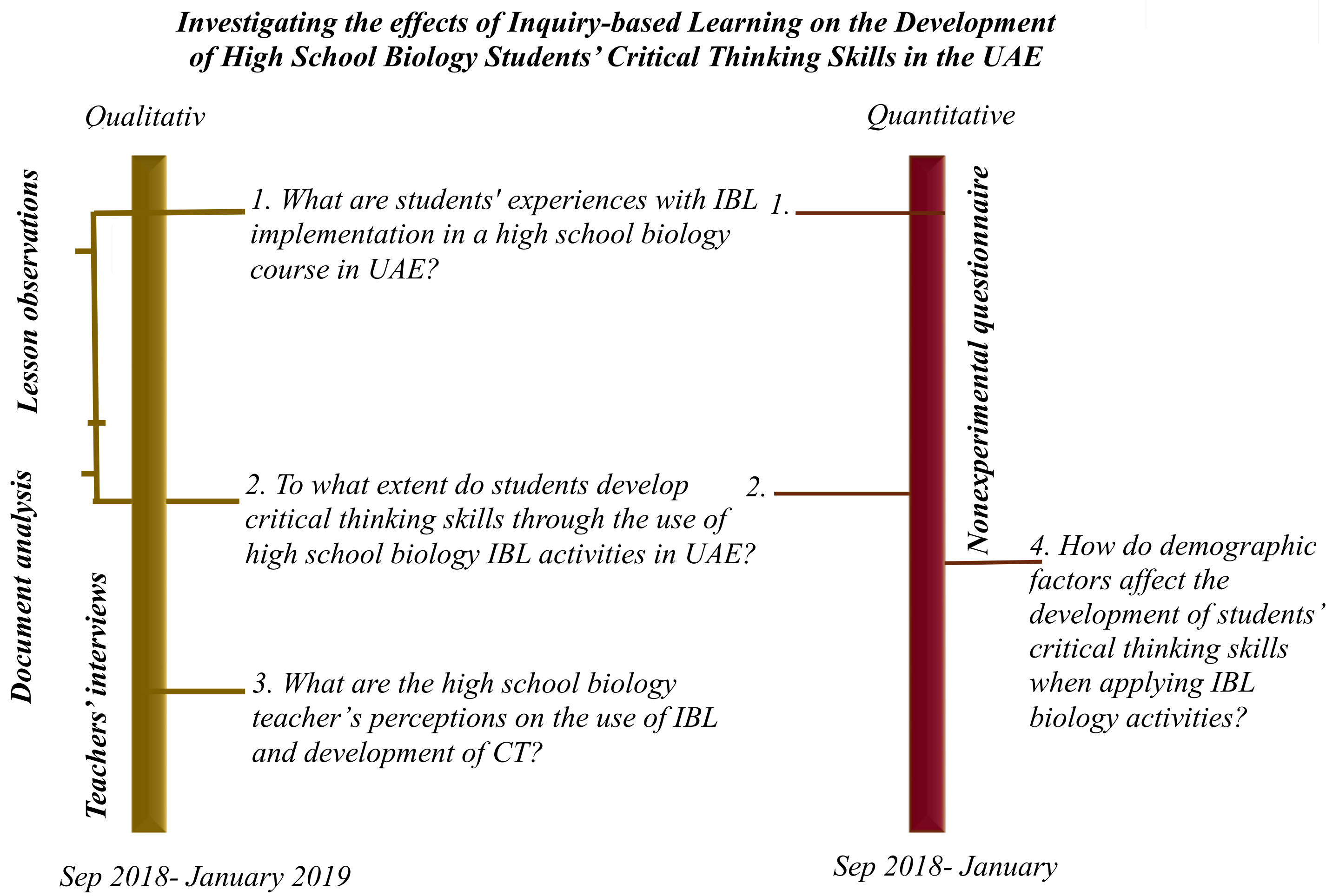


Figure 3.1 The case study with mixed method concurrent design

methodologies where a single data collection method is used do not provide in-depth answers that allow for generalization and do not ensure the validity of the interpreted conclusions for the presented research questions. In addition, utilizing multimethod quantitative-only or multimethod qualitative-only approaches would not have provided complete answers for the research questions. A quantitative questionnaire provided a general idea on how students apply IBL and whether it is related to their thinking skills and helped them become critical thinkers.

The result would not have provided enough evidence to confirm the occurrence of CT discussions during the implementation of IBL. Therefore, associating the quantitative questionnaire with three main qualitative tools such as lesson observations, document analysis and teachers' interviews were expected to support the results, by providing detailed information about actual classroom discussions and the level of students' CT identified in their artifacts and interaction in the classroom.

Since the current research study included the use of quantitative data in addition to detailed descriptions of multiple cases in a bounded system, the selected methodological approach was a collective case study in which a mixed method concurrent strategy was adopted.

The case study strategy implemented was the current study design, which utilized quantitative and qualitative tools to answer the research questions. The mixed method was conducted to provide a complementary strength for both methods used concurrently (Johnson and Christensen 2008). Additionally, quantitative data was collected simultaneously with qualitative data; the quantitative questionnaire was administered over one month in the 12 school campuses across the Emirates. During the same month, classroom visits were arranged, then followed by the interviews with teachers and the collection of students' artifacts. The survey study or non-experimental quantitative method was selected as the quantitative part of the current research study. Taking into consideration the inability to manipulate the variable, the results of this method were considered as tentative and explanatory. Muise (2011) clarified that non-experimental research is suitable to describe real-life situations in an educational context and the variables are used as they appear in practice. In this study, the non-experimental cross-sectional quantitative part was used to describe the implementation of IBL stages, the relation between IBL instructions and students' actual development of CT abilities, as well as the effect of demographic factors on the development of students' CT abilities. Additionally, it was associated with qualitative data collection tools to provide better explanations of the IBL practices and provide guidelines for effective use of these instructions to help students t practice core CT skills.

A variety of data collection techniques and analysis procedures were used throughout the study design, including observations of actual classroom interactions, investigating students' artifacts and exploring students' and teachers' points of view regarding the implementation of IBL and how it could help in CT development. Data collected through quantitative or qualitative means were complimentary to each other and led to justified conclusions.

Research questions were answered through participants' interactions, aligned with the hermeneutics research tradition, which utilized participants' opinions to further understand the situation (Cohen, Manion and Morrison, 2007).

The case study design as per Cohen, Manion and Morrison (2007) and Meriam (2009), is a research model that provides an in-depth description and analysis of a system within specific temporal, geographical and institutional boundaries; it allows for building a clear understanding of concepts and identifying relationships between various variables. Based on their description, case studies can be used to establish cause and effect relationships and observe this relation in real context. This description is aligned with the purpose of this research study, which was to identify appropriate implementation of IBL practices and relate them to the development of students' CT skills. As per Meriam (2009), the case study has specific features, including being particularistic, descriptive and heuristic, which suited the situation of this research. This research was particularistic by focusing on a biology curriculum implemented at a specific level in a specific institute. A case study is descriptive, which means that the final product is a comprehensive description of the findings, which was expected from the current study. Finally, being heuristic means that it extends the readers' experiences about the emerging results and emphasizes existing theories or modifies the existing understanding of different concepts. The study implemented in this research study was an observational case study, given that most of the data gathered was through observation (Cohen, Manion and Morrison 2007; Meriam 2009), as this study focused on lesson observations in a series of schools adopting the same curriculum and instructional strategies. Johnson and Christensen (2008) classified case study research design into three main types: intrinsic, instrumental and collective case studies. The intrinsic design focuses on one specific case, where the result of the study includes detailed descriptions of that specific case. The advantage of an intrinsic study is that it provides comprehensive results about unique cases. However, its results cannot be generalized. The instrumental case study emphasizes the implementation of and provides justification for behaviors based on a certain theory, without focusing on the specific results for the studied case. Thus, the instrumental case study results can be generalized. The third type is the collective case study in which multiple cases are studied in the same research. The purpose of the collective case study is usually instrumental, to gain more insight on the effectiveness of a program or a procedure. The advantages of this type of case study include providing comparative results for different cases, enabling generalization and increasing the confidence of the results. However, working with more than one case would affect the depth of the result analysis, as data is collected from multiple cases. The case study design adopted in the current research was the collective design. Since more than one case is observed concurrently in four different schools, it was expected that a wide range of results was to be obtained, which would allow for comparison and more confidence in the results, providing a strong opportunity for generalization. Meriam (2009), described some limitations that must be considered when selecting a case study design; the main issue concerned the time required to provide a comprehensive description, integrity and bias issues, as the researcher is collecting the data in most cases, and the reliability, validity and generalizability of the results, which was avoided in this research study by including the quantitative nonexperimental part of the study.

Using a mixed method design was expected to serve various purposes that strengthen this research study and lead to solid conclusions. First, a mixed-method design provided a source of triangulation, since it utilizes three different methods to investigate the same phenomena, as explained in Figure 1, which presents the current research design. Triangulation is an important method in assessing the validity of collected data, as it allows for cross-checking the source of information (Fraenkel and Wallen 2009). Second, data collected through the proposed methods allowed for elaboration, in-depth explanations and clarification of results. Merriam (2009) explained that lesson observations provide firsthand data about naturally occurring discussions in the classroom. As such, the data collected was expected to reflect actual classroom interactions that can lead to emerging results regarding the daily IBL practices that would train students to become critical thinkers. In addition, interviews were used to find out details about the research that cannot be observed in the classroom, this includes the teachers' point of view and how they feel towards the impact of IBL on students' development of CT skills. Mining data from documents was also described by Merriam (2009) as a valid qualitative data collection tool, and it was used to provide answers for the research questions. Third, the results of qualitative methods were expected to develop and inform the results of the quantitative methods and vice versa, considering that through qualitative data collection, there is an opportunity for further clarification of responses (Johnson and Christensen 2008).

The mixed method was particularly suitable for this research study. Hence, answering questions that involve investigating how students use IBL activities, the relation between IBL application and CT skill development, and how demographic factors influence CT development all required quantitative nonexperimental methods to construct an overall description of students' implementation of IBL activities that influences their actual CT development (Johnson and Christensen 2008). Simultaneously, qualitative methods were utilized to explore students' and teachers' behavior and interactions within the context of IBL instruction, and answer the research questions in-depth through providing a detailed description of the techniques used by students to reflect upon their understanding and by teachers to encourage the development of students' CT abilities.

Therefore, lesson observations, document analysis, as well as structured interviews provided additional data to elaborate on the relation between IBL activities and creating different opportunities for students to develop CT, while including their written and oral responses. The results of this research study led to identifying the best practices in biology instructions that would enhance the development of students' critical thinking abilities (Johnson and Christensen 2008).

It is worth mentioning that the mixed method design generally has some disadvantages that were considered before undertaking the research; it required a longer time and more resources, there was a need to consult experienced researchers to provide support during implementation and finally, some results could have contradicted each other, which would have led to additional data collection to better reflect the results (Johnson and Christensen 2008).

Traditionally, research strategies in education may include scientific experimentation, action research, development of grounded theory, narrative inquiry, surveying, ethnography and conducting case studies. Each of these strategies is suitable for answering a specific type of educational research question. Ethnography involves describing people's culture, shared values and attitudes, while narrative inquiry requires the use of stories and biographies as data resources. Since the purpose of this study did not require exploring details about people and their culture, narrative inquiry and ethnography were not a selected strategy to conduct the current research study (Merriam 2009). The grounded theory is another qualitative research strategy conducted when a new theory will be generated for the collected data in the research study, since this study did not aim to develop a theory, this research strategy was not adopted as well (Merriam 2009). Action research is utilized to solve an identified problem in educational practices, usually done by the teacher or educator during a short time scale and to solve one identified problem (Creswell 2014; Fraenkel and Wallen 2009) since this research study was done at a larger scale and intended to identify new teaching strategies, an action research was not a suitable strategy to answer all the research questions.

Previous research studies that examined the effect of educational strategies on student development followed a scientific experiment or a quasi-research strategy. This was discussed in studies such as the ones performed by Bati & Kaptan (2015), Memiş (2016), Siew, and Mapeala, (2016) and Boleng et al., (2017) who employed a pre-post test methodology to determine the effect of instructional practices on the development of students' CT skills. The experimental research method aims at developing a causal relationship between two variables. This method entails observing the effect of a certain factor or independent variable on another factor or dependent variable under controlled conditions. This type of research method provides strong evidence of the causative relationship. However, it is extremely difficult to control peripheral variables that may affect the results and reduce the validity of the research (Johnson and Christensen 2008; Fraenkel and Wallen 2009). There are two main reasons that prevented pure experimental research methods from being utilized in the current study: First, the inability to control variables that would affect students' CT development other than IBL instructions, as students are exposed to other experiences inside and outside the school context that may help in developing their CT abilities. In addition to the variability of teachers' efforts in utilizing different activities across all disciplines to improve students' CT abilities. The second reason is the inability to manipulate IBL instructions as an independent variable. The management will not allow an intervention in which the opportunity to study through IBL instructions is limited to one experimental group. The quasi-experiment is another option that is used in research to investigate the effect of an independent variable on another dependent variable. Quasi experimentation is used when it is difficult to follow the scientific method and assign participants into random groups. It is an accepted research method that allows partial control of variables and accept that participants are not grouped randomly. However, this type of research could lead to biased results as participants in their actual groups could be exposed to other factors affecting the results other than the manipulated independent variable (Johnson and Christensen 2008; Fraenkel and Wallen 2009). Quasi-experimentation was not an option for this study because it required manipulating an independent variable, namely IBL instructions, which was not accepted ethically as per the management of the schools. The methodological strategies that suited the aim of this case study and were used to answer the four study questions are summarized in Table 3.1 below. The table provides an outline of the main research questions, presents the approach employed to answer each question, and specifies the quantitative and qualitative tools that were utilized to answer each of the four study questions. In addition, for each of the questions, it identifies the targeted population of students and teachers, the samples of the participants from both populations and the data analysis methods that were followed to analyze the collected data from each instrument.

Table 3.1 Instruments, Approaches and Participant

Question	Approach	Instruments	Population	Sample	Data Analysis
1. What are students' experiences with IBL implementation in a high school biology course in UAE?	Quantitative	Nonexperimental questionnaire	3200 students	1330 students	SPSS software to perform descriptive and inferential data analysis
	Qualitative	Lesson observations Document analysis of students' artefacts		12 lesson observations and a total of 51 samples of students' artefacts	Coding and classifying data according to the evidence identified on the use of IBL.
2. To what extent do students develop critical thinking skills through the use of high school biology IBL activities in UAE?	Quantitative	Nonexperimental questionnaire	3200 students	1330 students	Quantitative data analysis tool, the SPSS software
	Qualitative	Document analysis of students' artefacts		12 lesson observations and a total of 51 samples of students' artefacts	Coding and classifying data according to the evidence identified regarding CT skill development.
3. What are the high school biology teacher's perceptions on the use of IBL and development of CT?	Qualitative	Lesson observations Structured interviews	35 teachers	12 lesson observations 13 teachers to interview	Coding and classifying data according to the evidence identified regarding teaching practices that promote critical thinking skills
4. How do demographic factors affect the development of students' critical thinking skills when applying IBL biology activities?	Quantitative	Nonexperimental questionnaire	3200 students	1330 students	Quantitative data analysis tool, the SPSS software, to undertake a descriptive and inferential analysis of the data to find correlations

3.2 Methods

This section is related to the methodology, it entails a detailed description of the site selected, the sampling method and data collection instruments including qualitative and quantitative tools and methods of data collection. Three main subsections are illustrated, the first subsection provides information about the site in which the study was performed. The second subsection provide details with regards to sampling method and subject selection. The third subsection presents the research tools used and explains how each of them was administered and analyzed. In addition, it discusses the ethical considerations associated with each tool.

3.2.1 Site

This research study was implemented in a semi-governmental context; a system consisting of a series of high schools located in the seven emirates of the United Arab Emirates. As per the students' handbook (2017) the establishment of the schools was in 2005. The main purpose was to graduate students who can enroll in engineering and technological programs in higher education in order to contribute to the industrial and technical development in the country. The vision and mission of the school system is in line with the Abu Dhabi economic vision 2030 that aims at preparing UAE nationals to make up a highly skilled professional workforce (The official portal of UAE government, 2018).

The students in these schools are provided with career-oriented education, in addition to a rigorous academic program. The school system aims to build graduates capable of joining top universities in the country and abroad, who are able to think critically and make informed decisions. The curriculum provided is aligned with the curriculum of the UAE Ministry of Education for all core subjects including Arabic, Islamic, Social studies, Mathematics, Physics, Chemistry and Biology. The courses are provided at three main levels the Advanced Science Program, General and Advanced tracks. In addition to the requirements of the Ministry of Education, including international benchmarks such as College Board Science Standards and Common Core Standards which are also considered in the offered curriculum. Advanced Placement (AP) Courses are offered to students based on their selected cluster program, including AP Computer Science A, AP Physics C, AP Calculus AB and AP Biology. The ASP students are offered the AP Computer Science Principles course where AP Digital Portfolios- a web-based application- are available for students to submit the components of their performance tasks to the AP program via The College Board. In addition to real-life connections that are integrated within the curriculum through STEAM Projects offered for students from grades 6 to 11 and the Graduation Projects required from the seniors before graduation. The projects target developing students' problem-solving skills, allowing for diverse interpretations and providing interdisciplinary contexts for authentic tasks. These encourage and enhance students' interaction with real-life applications and problem-based learning across the different subjects. The career-oriented courses are provided in four main categories, including Engineering Science, Applied Engineering, Computer Science and Health Science and Technology clusters. The courses that are offered within each cluster provide additional preparation for the students that equips them with skills to help them identify their future career pathway, and support them with college-level courses that would enable them to join specific programs in higher education (Schools' Student Handbook 2017).

In this school system, the students are enrolled starting from Grade 9, except for two locations in Al Ain and West Region, where the enrollment begins in Grade 6. In Grade 10, the students are offered introductory courses related to the cluster they have selected. In the senior years, Grades 11 and 12 students are provided with the more specialized courses related to their selected cluster. The students graduate form this system with a high school certificate in addition to the other qualifications related to each cluster program. The system has established articulation agreements with several higher education organizations in the UAE to support the graduates. The qualitative part of this study was performed in four schools including Abu Dhabi Boys, Abu Dhabi Girls, Dubai and Al Ain schools. The targeted population in the four schools consisted of selected sections from Grade 9 and 10 students and their biology teachers. While the quantitative part was administered in all the schools.

Given that the biology curriculum provided in this school system is aligned with the College Board Science Standards for College Success and the UAE Ministry of Education Science Framework. Both frameworks aim at developing students' critical thinking skills and utilize inquiry-based learning activities within instructions (Curriculum Department in the Ministry of Education in the UAE, 2015; Science College Board Standards for College Success, 2009). This context was aligned with the purpose of this study that investigates the effectiveness of IBL activities performed to promote students' thinking skills and it provided a good source of data to evaluate the inquiry-based learning activities in the biology curriculum. Data collection was done during regular school days in the first and second terms of the Academic Year 2018-2019. Biology lesson observations occurred in three periods per week, where a period is 45 minutes. The lessons observed were either one 45 minute-period or a 90-minute block of two periods depending on the topic and the teacher's preference.

3.2.2 Sampling & Subject Selection

As this research followed a mixed method approach, the sample of the students for the quantitative and qualitative parts of the study was the same, and the data was collected concurrently. However, the sample of the teachers was only included in the qualitative part of the study. This is described as a multilevel concurrent relation between the samples (Johnson and Christensen 2008).

Participants were divided into two groups: students and teachers. The total population of the targeted grades of this study (Grade 9 and Grade 10), was 3202 students and 35 biology teachers. An official permission was granted, which allowed access to students, teachers and documents.

The 3202 students were all in in Grade 9 or Grade 10 studying a high school biology course in the high school system. The 35 teachers were biology teachers assigned to teacher either Grade 9 or Grade 10 or both grade levels.

A random sample of the students was targeted based on proportional stratified sampling, in order to have a representative sample of the population that considered grade level, gender and the location of the school (Johnson and Christensen 2008). This was applied by sending the questionnaire to the all the schools and following up with each school's management to encourage students' participation to get the targeted number of responses in proportion to the school's population, and considering three main factors: first, the location of the school. For example, the number of students in the school in Fujairah is 7% of the total number of students in all the schools, Similarly, the number of participants from Fujairah campus was also 7% of the responses in the questionnaire. The second factor was the students' gender, for example 45% of the schools' population is female, similarly, around 46% of the participants' responses was from female students. The third factor was the grade level, 55% of the students are in grade 9, similarly the percentage of grade 9 students participated in the research study was around 54%. Proportional stratified sampling reduces the sampling error and ensures that all the variables in the population are represented in the sample, which would allow for the generalization of the results (Lawson, Fail and Verbist, 2019). Another advantage mentioned by Cohen, Manion and Morrison (2007) that this type of sampling allows for the classification and randomization of subjects, which makes it useful for both quantitative and qualitative research studies. Johnson and Christensen (2008) clarified that in proportional stratified sampling, a population is divided into groups, then simple random sampling is applied. In this study, the population was divided into the 16 schools, then simple random sampling was applied to each school. In this case, the total responses from all schools would reflect the original numbers of male and female Grade 9 and Grade 10 students in the school system. The aim was to get a high response rate that provided significant statistical data to infer relationships and proceed with the research.

To determine the suitable sample size for proportional stratified sampling for both quantitative and qualitative parts of the study, the population size, confidence level and confidence interval must be considered. A larger number of participants in the sample would increase the confidence level and decrease the confidence interval (Cohen, Manion and Morrison 2007).

The recommended quantitative sample number for a population of 3202 students was about 1172 if the confidence level considered was 99% and the confidence interval was ±3 (Creative Research Systems, 2012; Cohen, Manion and Morrison 2007). This number can be considered representative of the population of males and females in Grades 9 and 10 in different school locations.

For the qualitative part, two types of samples were required for students and teachers. Lesson observations, interviews and document collection were conducted in four of the series of the schools, addressing both male and female campuses. Following purposeful sampling in qualitative research, a set of selection criteria relevant to the research focus were developed, including the implementation of IBL activities in the observed lesson, the location of the school and the teachers' agreement to participate in the research study (Johnson and Christensen 2008; Meriam 2009). Therefore, from the 35 biology teachers, the lesson observations and interviews were conducted with 13 teachers who are using IBL consistently in their planning, located in campuses close to the researcher and agree to participate in this research study. Data collection occurred during the first 8 weeks in term two (January and February 2019). The researcher visited the selected campuses after being granted permission from each campus management. A schedule for lesson observations was prepared by the Vice Principal Academic in each campus. Then, interviews with teachers were conducted in the campuses based on the teacher's availability. The students' artefacts and documents were sent afterwards by email.

The qualitative part of the study presented a comprehensive description of the situation in the classroom, including the effect of the actual application of inquiry instructions, the level of questioning, the interactions of students and the thinking skills observed in the classroom. The total number of students present during the 12 lesson observations was 300 students. The smallest class included 17 students, while the largest class included 33 students, amounting to an average of 24 students per class.

Document analysis included collecting samples of the artefacts produced by the students during lesson observations such as lab reports, videos, notes and class worksheets. In addition to samples of summative assessment papers to examine students' responses to the questions that were related to the topics they discussed in the observed class. Three samples of students' artefacts and assessments from each of the lessons observed were collected, which were 23 classwork artefacts and 28 assessment papers in total.

3.2.3 Instruments and Data Collection Methods

Methodological triangulation was used in this research study, as per Cohen, Manion, & Morrison, (2007) it involves "using three different methods on the same object of the study". Collecting data for each research question from different instruments allowed for data comparison and ensured concurrent validity. Therefore, applying methodological triangulation enabled the researcher to gain a comprehensive view of the educational situation studied. In this case, the effectiveness of IBL instructions in the development of students' CT skills.

The subsections below present a detailed discussion of each of the instruments, including the instrument's purpose, design, data collection procedure, how it is related to the aim of the research and how validity and reliability were ensured.

3.2.3.1. Questionnaire

The non-experimental questionnaire was a written response instrument completed by the subject. It included multiple choice, true/false, short answer questions, a checklist and a rating scale (Fraenkel and Wallen 2009; Muijs (2011). The aim of using this tool was to undertake a descriptive and inferential analysis to answer the research questions 1, 2 and 4. It was expected to find the best IBL instructions that would promote critical thinking development and be able to generalize the conclusions of this part of the research.

The questionnaire in the current case study consisted of three main parts. The first included three items related to demographic information, identifying gender, grade level and the location of the school. Students' responses were recorded by selecting from a list. The second part addressed IBL activities; it was adopted from a previous research study done by the researcher. The Formative Assessment of IBL Questionnaire (FAIBAQ) which had a reliability factor of 0.62 consisted of two main parts, one related to IBL and the other focused on formative assessment strategies. The items focus on the main criteria of IBL activities in a classroom, which were adopted from Harlen, Nowak, Tiemann and Belzen (2013) who identified the requirements of IBL. These criteria included observing, following a procedure for collecting data or experimenting, and providing proofs to construct new conclusions and concepts to explain natural phenomena. The items that were related to IBL in the original questionnaire were 10 items, which focused on teachers' perceptions and practices regarding inquiry cycles in science lessons, and the extent to which students contribute in implementing inquiry-based learning activities. This would help to discover the common type of inquiry utilized in classes and where it is located on the inquiry continuum. The items regarding teachers' practices were adopted from the principles of inquiry tool developed by Campbell et al. (2010). The IBL in the current study that was adopted from the FAIBLQ consisted of eight items, the first four being related to the inquiry stages required during the preparation of a scientific investigation, such as the purpose of the question, the hypothesis and the nature of the teacher's instructions. This would help identify the level of inquiry implemented in the class. The latter four items were related to the application of the inquiry activity, which included performing the investigation, data collection, drawing conclusions and relating the implemented activity to the theoretical concept being investigated. Students' responses were collected using a Semantic Differential Scale of six levels (Johnson and Christensen 2008). The third part assessed the use of critical thinking skills. This part was constructed by reviewing three main studies about measuring critical thinking in the curriculum and how it influences students' learning. The first was a research study done by Forawi (2016) about standard-based science education and critical thinking. The second was a study by Cole et al., (2015) about Critical thinking skills in the International Baccalaureate's. The third was a review by Facione (2015) defining critical thinking and explaining its influence on students' learning process. The CT part consisted of 16 items categorized based on five core skills of critical thinking related to its main standards, including interpretation skills related to the clarity standard, analysis related to accuracy and precision, evaluation related to relevance, inference related to depth and breadth, explanation related to significance and self-regulation related to fairness. The items were designed to measure students' opinions on the past use of critical thinking in the classroom. Students' responses were collected through the Likert scale utilizing a fully anchored rating scale of five levels (Johnson and Christensen 2008). Principles of questionnaire construction were consulted (Johnson and Christensen 2008). The questionnaire was developed in line with the research objectives and related to the first, second and fourth research questions. The language of the items was also revised to suit grade 9 and 10 students' reading abilities and translated to Arabic, the students' mother language to ensure the clarity of all the items. Additionally, back-translation was performed by an expert translator to ensure that the original meaning of the statements was not modified due to translation. Furthermore, items were written and reviewed by an expert researcher to ensure that they were precise and relatively short. This was done by avoiding leading questions and ensuring that each item consisted of only one verb or command. Moreover, double negatives were not used, all items included closed-ended questions, and the responses were designed to show a clear distinction between scale levels, so that they do not overlap. Three different types of responses were considered: selecting from a list, using a Semantic scale and a LIKERT Scale. The developed questionnaire was piloted; details about the pilot study are explained in the following subsections.

3.2.3.1.1 The pilot study

One questionnaire was developed for this research, thereby making it necessary to perform a pilot study to ensure its validity, reliability, objectivity and usability (Fraenkel and Wallen 2009; Cohen, L., Manion, L. & Morrison, K. 2007; Johnson and Christensen 2008). The structure of the questionnaire used in the pilot study is enclosed in Appendix 3.1, and the final online form for the pilot study is in Appendix 3.2.

The questionnaire was introduced to a group of 45 female students in Grade 10. The medium in which the questionnaire was conducted was an online google form, which included information about the purpose of the study, the time required to complete the questionnaire and leading instructions to ensure students' understanding of the items. The questionnaire was distributed as a google link only for the students who participated in the pilot study, the students received the link in the presence of the researcher and responded to the questionnaire in the classroom. The researcher was present to observe how the students responded to the questions and if they were able to understand each item and respond in the correct manner. The two sections participating in the pilot study were not required to complete the questionnaire during the final administration (Johnson and Christensen 2008). In addition, a confirmation of the confidentiality and the anonymity of the responses was provided, indicating that they will only be used only for academic research purposes.

Using the SPSS software, reliability was calculated in order to confirm whether the tool will produce consistent results, which would give an indication that the tool can be used with confidence to collect data for the research study. The calculated Cronbach's Alpha for the questionnaire items was high (0.88) which indicated that the results were consistent (Fraenkel and Wallen 2009) and the questionnaire was reliable and can be used in the actual study.

The results of the pilot study questionnaire gave an indication about the use of IBL and how it would develop students' CT skills, which served the purpose of the research study and validated the instrument. The results reflected that students apply IBL in their Biology classrooms as their responses to the items related to preparing for and inquiry activities and conducting an inquiry activity was relatively high. Even though the calculated Pearson Correlation coefficient was (0.8) the relation between students' responses related to IBL and their responses about the use of critical thinking core skills in the classroom cannot be determined. Seeing how the pilot study included 6 levels of the semantic scale for IBL while the LIKERT Scale for CT skills development had 5 levels, this might have affected the accuracy of the calculations, which must be updated in the actual questionnaire. Additionally, since the internal validity is related to the causal relationships between the factors being studied in the research (Johnson and Christensen 2008), the questionnaire was administered in the pilot study with a purpose of checking whether it can lead to a relation between the implementation of IBL and the development of CT skills. However, since the IBL factor cannot be manipulated in the current research study, it is not possible to determine a causal relationship between IBL and CT development.

Descriptive analysis for the items was performed to describe and summarize the results, finding the mean of students' responses to each item indicated how IBL and CT are implemented in the classroom. In addition, the calculation of the standard deviation which measures the spread of the responses from the mean (Frankel, Wallen, Hyun, 2015) indicated the variability of the responses and whether the collected data followed the normal distribution for each item. The table below shows a summary of the pilot study results, considering that the number of valid responses was 45. Detailed results per item is enclosed in Appendix 3.3.

Table 3.2 The pilot study results

Group of items related to IBL and CT	Mean	std. Dev	Minimum	Maximum
IBL-Preparing for investigation	16.16	5.24	4	24
IBL-Application of the inquiry activity	13.89	5.55	4	24
CT-Interpretation (Clarity)	15.78	2.34	9	20

CT-Analysis (Accuracy and precision)	12.36	2.14	8	18
CT-Evaluation (Relevance)	14.33	2.71	6	18
CT-Inference (depth and breadth)	14.4	2.74	8	20
CT-Explanation (significance) self-regulation (Fairness)	13.98	3.11	8	20

The mean and standard deviation results indicated a good implementation of IBL, yet there was less utilization of IBL instructions meant to train students to develop CT skills.

3.2.3.1.2 Validity of the questionnaire

The validity of the questionnaire was considered from different perspectives including internal, external, content and construct validity (Cohen, Manion, & Morrison, 2007). Internal validity or the causal validity was ensured by several means, including face validity through discussing the items mentioned in the questionnaire with a university professor who is an expert in the field of critical thinking and inquiry-based learning, in addition to piloting the questionnaire with Grade 10 students in the presence of the researcher to respond to students' inquires or concerns if any of the items was not clear or was misinterpreted. Content validity refers to the ability of the developed instrument to measure the IBL activities and the implementation of CT skills as required to this research purpose. The best method to ensure the content validity is to pilot the questionnaire and administer it with a small sample of students from the targeted population. The results of the pilot study confirmed content validity of the questionnaire, since the results of the first two item groups in the questionnaire indicated how IBL was utilized in the biology classroom, and the results of four CT item groups provided an indication of the use of CT attributes to develop students' skills (Johnson and Christensen 2008; Lawson Faul, and Verbist, 2019). Furthermore, as per Cohen, Manion, & Morrison (2007), content validity is reflected by distributing the items fairly and comprehensively to cover all the domains of the research study, in this case IBL and CT skill development. Moreover, the items that were selected to indicate the use of IBL and the application of CT skills in the Biology classroom are considered manifest variables, as they can be measured through operational statements that were understood by the students. The statements used in the questionnaire were based on behavioural observations in which the students' actual behaviour in the classroom was recorded, thus, none of the statements relied on students' attitudes or feelings towards IBL or CT application (Johnson and Christensen 2008). Construct validity involves the consideration of construct-related evidence to ensure the validity of the questionnaire. Three main evidences can be considered to ensure construct validity of a questionnaire. First, clarifying the factors being studied in the questionnaire which are IBL and CT. Second, forming a hypothesis that if students were exposed to IBL instructions, they will be given an opportunity to develop their CT skills. Third, testing the hypothesis logically and empirically (Facione 2015). In the current research study, there is a logical connection between the application of IBL and the use of core CT skills. Yet empirical testing was not possible, as manipulating IBL instructions was ethically not applicable. Therefore, construct validity was considered when developing parts of the questionnaire; each construct was operationalized by considering four main items that are related to that specific construct. The structure was then reviewed by a university professor expert in IBL instructions' CT items (Lawson Faul, and Verbist, 2019). The main constructs of this questionnaire were supported by previous literature (Forawi 2016; Cole et al., 2015; Facione 2015) where each construct is understood and operationalized by the items used in the non-experimental questionnaire developed for the current study (Cohen, L., Manion, L. & Morrison, K. 2007; Johnson and Christensen 2008). The external validity was well-thought out when the proportional stratified sampling was selected to reduce errors and enable generalizations (Cohen, L., Manion, L. & Morrison, K. 2007). The results of the pilot study indicated that the students who responded with high agreement to the applications of IBL instructions had also responded with high agreement to the use of CT core skills in biology lessons, which can strengthen the external validity of this instrument (Johnson and Christensen 2008).

Threats to validity were avoided as much as possible by selecting an appropriate timing to administer the questionnaire, which was early in the term and before the first general assessment week. In this time interval, teaching and learning activities are mostly implemented without time constrains related to completing the required material before assessment week. The questionnaire was administered for four weeks, with three reminders. In addition, several steps were taken to increase the response rate, which include communicating verbally with the vice principal academics of the schools to encourage students to participate, then asking grade level teachers to assign 10 minutes at the end of their lessons to allow students to complete the questionnaire. In addition to emphasizing the idea that students were not allowed to make more than one attempt (Cohen, L., Manion, L. & Morrison, K. 2007).

3.2.2.2 Qualitative instruments

To ensure the credibility and consistency of the data collected through qualitative tools, data triangulation was utilized through collecting data from three different sources. The sources all included three different tools utilized by the researcher. The lesson observation was used to identify teacher-student, and student-student interactions, while the document analysis was used to identify elements of CT in students' reflections, both within the classroom as formative feedback and in the summative assessment. Finally, the tools were used in the structured interviews with teachers to identify teachers' points of view regarding encouraging students to perform IBL activities to develop their CT abilities (Meriam 2009; Fraenkel and Wallen 2009; Johnson and Christensen 2008).

3.2.2.2.1 Lesson observations

Lesson observations aim to identify students' and teachers' interactions in the classroom, to answer questions related to how students describe their IBL-related experiences in a high school biology course, and the extent to which students develop critical thinking skills through IBL activities in a high school biology classroom, and finally, which teaching practices can be used to encourage students to implement IBL activities and develop critical thinking abilities. To serve the purpose of this study, the researcher's role will be a complete observer, in which the researcher takes the role of an objective observer and does not interact with the students, or the teacher being observed in the classroom (Cohen, Manion, & Morrison 2007). Yet, in some cases the researcher had to join students' groups to listen to their dialogue and identify the level of the discussion taking place between the students. Merriam (20019) suggested that the presence of a researcher in the classroom could affect students' and teachers' behaviour at the beginning of the observation, but they would later return to their normal setting if the tension was avoided. In this case, the researcher informed the teacher and the students before observing the lesson that the aim of the visit is to collect data for educational research and not evaluative, they were also asked to behave as if the researcher was not in the classroom.

The researcher in the current study used field notes to fill an observation form, noting verbal and nonverbal interactions that occur in the classroom shortly after a behaviour examples of filled forms are enclosed in appendix 3.4. Cohen, Manion, & Morrison (2007) and Merriam (2009) suggested that directly typing in field notes is essential, as information can be easily forgotten. In addition, typing is a faster method and provides clear statements that can be referred to after the observation is over. The pilot lesson observation for grade 9 students was about the stages of the cell cycle and mitosis, the researcher collected field notes and had to observe two periods to ensure that the full cycle of IBL instructions was observed. The field notes collected indicated the requirement to develop a method to reflect on the use of questioning strategies that would promote the development of CT skills. Meaning that there should be a mechanism to record the number of questions that were verbally asked or present in a formative assessment tool used in the classroom and categorize these questions based on the CT core skill needed to answer that question. Falcone (2015) explained that discussion questions must be designed to "fire up critical thinking skills", the same questions were tracked in the lesson observations to investigate whether the interactions during IBL instructions have led to the development of students' critical thinking skills. The field notes were then used to fill out the observation form, which consisted of three main parts. Part I was designed to record observations related to inquiry cycles including orientation, conceptualization, investigation, data collection, conclusion, discussion and reflection. In addition to strategies followed to assess inquiry cycles and interactions among students and between the teacher and the students. Part II was designed to record critical thinking questions posed in the classroom based on core critical thinking skills including interpretation, analysis, inference, evaluation, explanation and self-regulation (Facione 2015; Forawi 2016). Questions were categorized based on which CT skill they address, enabling the calculation of the frequency at which questions promoting a certain skill were asked. For example, to calculate the frequency of using interpretation in the classroom, questions such as “what does this mean?” or “How should we understand that (e.g., what he or she just said)?” are recorded, a filled lesson observation example is enclosed in appendix 3.4. Part III included observers’ comments about the conversations, unplanned activities and nonverbal communications that take place, as they can be useful to explain other results (Meriam 2009). Additionally, the lesson observation form template included a section to record demographic information relevant to the lesson observed, including grade level, lesson topic, setting, location of the campus and number of students in each lesson.

As a qualitative instrument, the trustworthiness of the lesson observation form can replace the validity of the quantitative tools (Cohen, Manion, & Morrison 2007; Johnson and Christensen 2008; Meriam 2009). Elements of trustworthiness include credibility of the tool, meaning that recording the findings using the observation form would actually help in answering the research questions. They also include confirmability, in the sense that using the tool in different settings would lead to the same type of data, and dependability, meaning that the information recorded in the form is accurate and reflects the actual behaviour in the classroom environment.

Finally, trustworthiness also accounts for transferability, which can be confirmed by the end of the research, to check if the findings are applicable in different situations (Cohen, Manion, & Morrison 2007; Meriam 2009). To further validate the lesson observation tool, reflexivity, extended fieldwork, and triangulation were used, as per Johnson and Christensen's (2008) recommendation. Reflexivity was undertaken when the researcher reflected upon the field notes to avoid bias and ensure that all field notes were descriptive facts and not judgmental statements. Extended fieldwork was present by conducting the research through 12 lesson observations across four different campuses, representing Grade 9 and Grade 10 for both boys' and girls' sections. Triangulation was followed by interviewing participant teachers and collecting samples of students' work for document analysis. The data was compared to identify the actual implementation of IBL in the observed classroom and the teachers' responses regarding IBL instructions in the interview, the use of CT questioning in the observed classroom and the teacher' responses to the CT questions in the interview. Then, the responses and observations of each teacher were compared with the artefacts submitted by the students in their class. The protocols used in triangulation focused on the IBL stages and the types of CT questions observed in the classroom and in students' artefacts.

3.2.2.2.2 Document analysis

Data collected from documents included all possible secondary or existing data that would help in formulating the research results (Johnson and Christensen 2008). Meriam (2009) clarified that using documents as source of research data is useful in two conditions. If the documents contain information relevant to the research questions and if they can be collected in a systematic manner. The selected documents were designed to provide specific information that will not be provided by interviews or lesson observations (Meriam, 2009). Secondary documents can be personal documents developed by individuals, official documents developed by organizations, physical documents developed by people and archived research data (Johnson and Christensen 2008). The artefacts submitted by students are considered personal documents. A total of 51 artefacts were collected from 12 lesson observations either by taking photos of students' work during the class or by asking the teacher to send samples of the work by email. The artefacts included in-class quizzes, laboratory reports, class worksheets, students' notebook, students' responses via interactive applications such as online quizzes and created videos or flow charts to reflect students' learning process and summative examination samples. The collected samples included excellent, medium and low performing students' work to ensure the variability of the results. All the selected artefacts provided information about students' reflections about the topic discussed and indicated the level of students' understanding in the observed classroom. This was required to determine the impact of following IBL instructions on the students' thinking level and whether they have developed CT skills (Meriam 2009). Hence, data extracted from the artefacts also provided answers to the first two research questions.

The use of document analysis enabled the researcher to become familiar with the language the participants use, represented objective data that reflects the participants' thoughts, in addition to being a written evidence reflecting participants' responses that were collected in other tools. In addition, collected documents can be easily accessed at the researcher's convenience to get the required information (Creswell, 2011;

Meriam 2009). However, Meriam (2009) explained some limitations exist when using document analysis as a source of data, such as the fact that documents are not usually created for research purposes, thus they may provide incomplete and inaccurate material or unrepresentative samples. In addition, not all participants provide valid or complete material to be used as a data source (Creswell, 2011).

In the current research, the samples of students' class work and summative examinations were collected to analyse students' responses to the questions that were aligned with the topics explained in each lesson observation. These samples were used to relate the effect of the learning process observed during instructions to the level of understanding reflected by students when they complete their assignments or sit for summative examinations. To get the maximum benefit from the collected documents, two different protocols using critical thinking tools as attributes were developed to categorize students' summative assessment and formative assessment work. Then, information in each document type was interpreted to find the IBL application and the level of critical thinking demonstrated (Fraenkel and Wallen 2009). This helped in collecting descriptive information about the level of students' thinking and easing the classification of the qualitative findings from other data collection tools (Meriam 2009).

The document analysis tools were used to categorize students' work. The summative assessment tool was designed based on the number and type of CT questions in the assessment paper. Students' responses were recorded to identify whether the students were able to respond correctly to these questions or not, a sample from the summative assessment tool is enclosed in Appendix 3.5. The formative assessment tool consisted of a checklist to record students' responses for a given question, based on their application of IBL activities and their ability to interpret, relate, analyse, infer and evaluate information in their submitted assignment, the formative assessment checklist tool is enclosed in Appendix 3.6.

3.2.2.2.3 Structured interviews

An interview is an oral response to structured questions aimed at collecting data from the subject and is a good opportunity to clarify questions and explore the respondents' answers further if required. When the interview is performed face to face, it is called an in-person interview (Fraenkel and Wallen 2009; Johnson and Christensen 2008). This tool was utilized in the current research study to answer the third research question. Since the interview is an interpersonal activity, building trust and maintaining a safe discussion environment are important factors to get objective results away from bias (Johnson and Christensen 2008). In the current research, teachers were given an introduction about the research, the researcher provided a safe environment for discussion where their input was valued without giving any judgmental statements. In addition, it was explained that the teachers' input during the discussion will remain confidential for research purposes.

The interview implemented in this study was an in-person qualitative open-ended or semi structured interview. The same wording and sequence of questions was used with all participants. This was to get specific data from all participants, as the interview was guided by a list of questions. Yet, probing questions were used to get detailed explanations for some points, such as asking participants to provide examples from their learning or teaching experience. A standardized open-ended interview was not used, as it would not have allowed for flexibility and individualized responses from the participants. The unstructured or informal interview was not selected as well, as it is suitable for ethnographic studies, or when the phenomena is not clear to the researcher, which is not the case in this research, where the main purpose of the study is to collect specific information about teachers' perceptions about the effect of IBL on CT.

Data collection through interviews provides direct feedback from participants and flexibility in using the questions yields in rich data, details and new insights about the subject of the research (Merriam,2009,). Selecting this type of interview has several advantages, such as providing comprehensive data, making data collection systematic, increasing comparability since all participants respond to the same questions with their own point of view, and facilitating data organization and analysis (Johnson and Christensen 2008; Fraenkel and Wallen 2009). In addition to using the interview as a source of triangulation in this research, as it provides an opportunity for participants to elaborate on their points of view. Hence, leading to the collection of in-depth data about the participants' thoughts, beliefs, knowledge, reasoning and motivation towards the use of IBL activities to develop students' CT skills (Johnson and Christensen 2008). On the other hand, interviews are considered time-consuming and should be well planned to avoid bias, as well as being difficult to analyse. To facilitate the interviews in this research study, interview protocol was prepared and shared with the participants. According to Merriam, (2009) good interview questions should be open-ended and lead to descriptive data. This was considered in preparing the questions of the interview protocol, the types of questions included were questions about the participants' background, knowledge, experience and opinion. Weak interview questions such as why questions, hypothetical questions and multiple questions were avoided when the interview protocol was prepared. The protocol consisted of four sections, the first section explained the purpose of the research study, the aim of the interview and clarified demographic information such as gender, years of experience and grade level taught. The second section discussed teachers' views and practices of IBL activities, including the frequency and the level of implemented IBL activity, students' independence during these activities and the level of discussion between working groups during the activity. The third section investigated teachers' perceptions about CT and how it could be developed through daily instructions. In this section, teachers elaborated on their previous experience with CT and how they knew about it. Their knowledge about the explicit meaning of CT, how they enforce it in the classroom, and the obstacles in the way of bringing CT more explicitly and more deeply into instruction. Questions used in this section were modified from Critical Thinking Interview for Teachers and Faculty Profile from the foundation of critical thinking (2018). The fourth and the final part explored teachers' views on the effect of IBL activities on students' CT development and the factors that hinder the effectiveness of IBL instructions, the interview protocol is enclosed in Appendix 3.7. The interview protocol validity was ensured through having the questions reviewed by an expert professor in the critical thinking field.

The total number of teachers interviewed was 13. The participants volunteered to contribute in the research and reflected a positive attitude towards the discussion. The interviews were conducted by the researcher, the same list of questions was used in all interviews, considering flexibility and probing questions based on the participants' responses. The interview length ranged between 15-20 minutes, they were recorded then transcribed to ensure accuracy (Johnson and Christensen 2008). After transcribing all the interviews, data was categorized based on the section. Then, the participants' responses were coded according to themes, and responses were interpreted and related to the results from other data collection tools to produce descriptive analysis.

3.3 Data Analysis Methods

It is important to analysis data from different instruments to achieve triangulation and support the conclusion of the study (Fraenkel and Wallen 2009). The subsection below explains the data analysis methods that were followed to analyse and interpret the data collected from the nonexperimental questionnaire, lesson observation, documents and teachers' interviews.

3.3.1 The quantitative questionnaire

In the questionnaire analysis, two main tests were done to ensure the reliability, validity and to identify items relevant to the analysis. These tests include Explanatory Factor Analysis (EFA), the reliability test Cronbach's Alpha. The reliability test was performed to ensure the consistency of the questionnaire items. The SPSS analysis was used to calculate the Cronbach's Alpha value. Overall, the reliability of all the questionnaire items was 0.97. The Cronbach's Alpha value being greater than 0.90 indicates that the tool is classified as highly reliable (Cohen, Manion and Morrison 2007). This test was performed to ensure the internal stability of the questionnaire, which means that the questionnaire items reflected high reliability as the students' responses to the items were consistent. Further analysis using the Explanatory Factor Analysis (EFA) was done to ensure that the grouped items in the questionnaire visibly affect the same factor and should be considered in the results. EFA was performed using the SPSS software selecting to perform dimension reduction then selecting factor analysis. The results of this analysis identified two distinct factors presented in scree plot shown in figure 3.2 below.

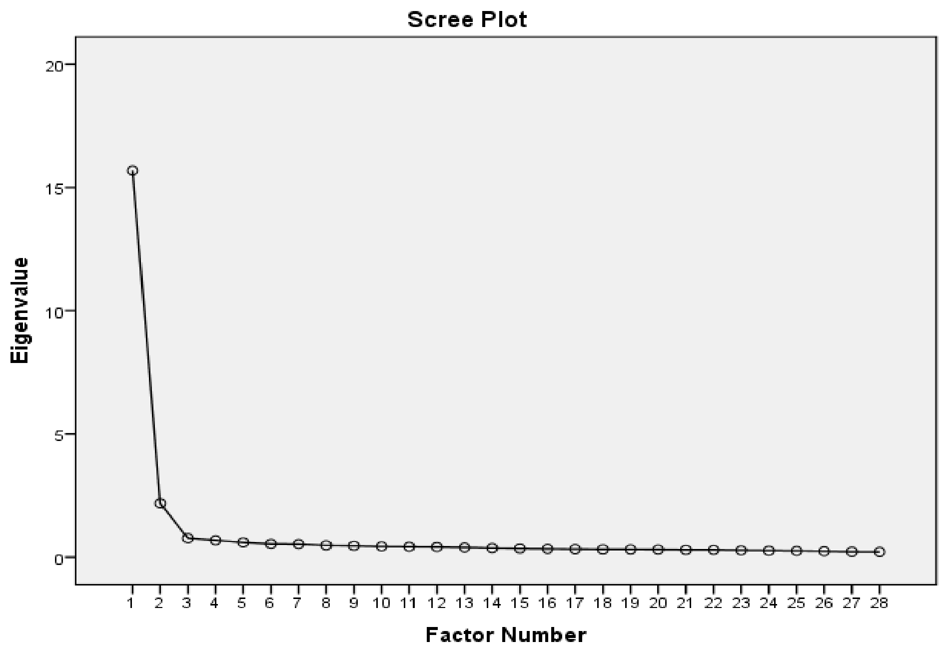


Figure 3.2 Scree Plot illustrating factor numbers

Based on the results, only two factors were identified: one was related to the application of IBL instructions and the other was related to the development of CT skills. The results showed that all the questionnaire items related to IBL had acceptable factor loading values and presented high reliability. Table 3.3 below presents the questionnaire items' factor loadings and Cronbach's Alpha Reliability Scores for the two main constructs in the questionnaire. (Cohen, Manion and Morrison 2007; Frankel, Wallen, Hyun, 2015).

Table 3.3 EFA Factor Loadings of Factors and Reliability figures

Factor	Subitem	Factor loading	Cronbach's Alpha value	Number of items
	IBLPre1	0.771	.923	8
	IBLPre2	0.821		

Inquiry Based Learning Instructions	IBLPre3	0.844		
	IBLPre4	0.839		
	IBLPost5	0.723		
	IBLPost6	0.814		
	IBLPost7	0.825		
	IBLPost8	0.739		
Critical Thinking Skills	CTCla1	0.687		
	CTCla2	0.695		
	CTCla3	0.739		
	CTCla4	0.756		
	CTA5	0.749		
	CTA6	0.743		
	CTA7	0738		
	CTA8	0.798		
	CTE9	0.786		
	CTE10	0.809	.969	20
	CTE11	0.823		
	CTE12	0.813		
	CTI13	0.836		
	CTI14	0.848		
	CTI15	0.812		
	CTI16	0.843		
	CTSR17	0.849		
	CTSR18	0.844		
	CTSR19	0.791		
	CTSR20	0.792		

The independent t-test was done to compare between the means of responses to IBL items and CT items for different groups of students, including different grade levels, gender and different campuses. In addition, the Pearson correlation factor was also calculated to identify any significant relationship between IBL and CT items.

3.3.2 Qualitative tools

To ensure the trustworthiness of the qualitative tools used in the research study, the researcher made efforts to be objective and provided a detailed description while reporting the results of lesson observations and teachers' interviews. For lesson observations, the efforts included using a consistent observation tool, recording the number and type of questions observed in each lesson based on one consistent background depending on Facione's classification of CT question (2015), paying attention to the same details in all the lessons observed, to focus on the same specific set-ups and activities such as students' seating plan, interaction between students together and the interaction between the students and their teacher and recording field notes using the same method in all the observed lessons. However, it is worth mentioning that the observer is a second English language speaker, the teacher in most of the cases was also a second language speaker and the students are second language learners. As per Hatim and Mason (1997) differences in languages may cause individuals to have different interpretations and consequently different assumptions. Therefore, all the assumptions mentioned during reporting the lesson observation results are not definite and are subject for further investigation as they were based on the researcher's interpretation that is affected by the culture and the language spoken. For interviews, the researcher used common interview protocols and asked the same questions with all participants. Yet, similar to the situation in the lesson observations, the researcher and most of the participant teachers were second language speakers, which may cause a difference in interpretations and assumptions recorded.

The subsections below describe in detail the data analysis methods that was followed to report the results of the qualitative tools used in the current research study.

3.3.2.1 Lesson Observations

The data from lesson observations was compiled in an excel sheet based on four main sections of the lesson observation form including the utilization of CT skills during IBL instructions, the main student-student and student-teacher interactions observed in the classroom, the frequency at which CT questions were utilized verbally or in written worksheets during the lesson and the notes that focused on the best practices and the areas of improvement in each lesson observed. The first and the second sections of the observation forms were based on a checklist that noted whether a certain attribute was observed in the lesson or not. Therefore, the data was color-coded to indicate whether each item was evident in the observed lesson or not (red if it was not evident and green if it was evident). Then, the overall frequency of observing each item in all the visited classrooms was calculated. The compiled data from the first two sections provided a general overview about the application of IBL instructions and utilization of CT skills within biology lessons. A sample from the excel sheet that was used to analyse lesson observations is enclosed in appendix 3.8. The comments related to each item in the observed lesson were reviewed and used as examples of the observed item in the class. Key observations for each item were identified, summarized and reported.

The third part of the observation form was related to the use of CT skills in questioning strategies. The frequency of using CT questions was calculated by adding the number of CT questions recorded in each lesson. Then, lessons were categorized into five groups based on the number of CT questions recorded in each 45 minutes. Strengths and areas of improvements were reviewed and classified as either related to lesson planning, instructional activities, or assessment requirements. Then, common themes were identified and reported, including the utilization of CT skills in IBL instructions. This included observations in which the teachers guided students to ask questions with the purpose of interpreting or clarifying ideas, analyse data, infer, evaluate, explain information or practice self-evaluation during classroom interactions. Observations also noted the type and frequency of the use of each question, best practices observed in each lesson observation and the identified areas of improvement.

3.3.2.2 Document Analysis

Documents collected included formative and summative assessment tools. Formative assessment data was compiled in an excel sheet and categorized based on the grade level and section. Then each sample was analysed to indicate whether it included the stages of scientific inquiry or if the questions included in the documents required students to used core CT skills. Then the number of formative assessment documents that stratified each of the IBL and CT items was identified. Then, the percentage of the documents that included each of the inquiry stages and the documents that included application of core CT skills was calculated and reported in Chapter Four. The table in which formative assessment data was classified is enclosed in appendix 3.9.

The summative assessment samples were also classified based on the grade level, then the samples were analysed based on the type of questions listed in the assessment referring to the same classification set by Facione (2015). Then the students' answers were recorded to identify whether the students were able to answer the questions that required the application of core CT skills or not. Colour code was used (red for incorrect answers, green for correct answers and yellow for answers that partially satisfied the required information from the question). The table in which the summative assessment samples were analysed is enclosed in appendix 3.10

3.3.2.3 Teachers' interviews

The analysis of teachers' responses followed Braun and Clarke (2006) and Long, Convey and Chawlek, (1985).The responses for each question item were compiled on an excel sheet, reviewed, then color-coded to identify common themes in the responses. The steps of thematic analysis followed included:

1- Transcribing the data using online application, then reading the information and editing it to ensure accurate transcription and getting familiar with the given responses.
2- Creating colour codes to classify the ideas mentioned in the responses.
3- Collating the main themes mentioned in the teachers' responses.
4- Reviewing the themes and generating the thematic map.
5- Defining the themes and reporting them in the results.

One sample related to the interview question about the link between CT and science education is enclosed in appendix 3.11.

3.4 Ethical Considerations

Ethical considerations include three main areas: "First, the relation between the scientific research and the society. Second, professional issues and third, the relation with the research participants" (Diener and Crandall 1978 in Johnson and Christensen 2008). Several steps were taken to ensure that the first area regarding ethical considerations has been followed; the main purpose of this study is aligned with the UAE society's needs, as explained in the introduction, the UAE's strategic plan targets the development of students' thinking skills to make them able to innovate (Mocaf.gov.ae, 2017). In addition, the American Educational Research Association's ethical standards were consulted throughout the research stages. Accordingly, the researcher conducted the research using their personal expertise, by seeking the required knowledge and skills to conduct this research beforehand and maintaining a suitable level of competence. Additionally, the researcher was alert towards the use of the data and the information revealed from the research and abides by the code of research ethics required (AERA Code of Ethics, 2011). This research also took professional issues into consideration, as it was committed to the professional code of conduct in all research stages, starting from topic selection, until the research was finalized with authentic results. The researcher is committed to authenticity, transparency, and originality throughout all the stages of the research (Johnson and Christensen 2008; Fraenkel and Wallen 2009).

Finally, the attitude towards research participants was also taken into consideration (Johnson and Christensen 2008). The researcher was granted an official permission to access the site and collect data, as is provided in Appendix 3.12. Moreover, the principal of each school was addressed in an official letter explaining the purpose of the study and the role of the participating teachers and students in the research study and asking them for permission to communicate with the staff and students in their respective schools. In addition, an informed consent was shared with all the participants, describing the study, the main purpose, expected benefits and the role of participants in each stage (Johnson and Christensen 2008; Fraenkel and Wallen 2009) Appendix 3.13. The data collection instruments were not expected to pose any sort of physical or emotional threat towards the participants. In addition, the study did not require dividing students to control groups and experimental groups, as all students were asked to complete the same questionnaire and were exposed to the same IBL instructions. During lesson observations and interviews, the researcher was committed to following the ethical code of conduct towards any type of personal details or sensitive information that may be revealed throughout the data collection stage (Johnson and Christensen 2008). Based on the requirement of confidentiality protection by the educational research code of ethics (AERA Code of Ethics, 2011), and the Guidelines for Ethics in Educational Research in the British University in Dubai, four evidences for the communications utilized to seek official permission to perform the research study were submitted to the university including first, the official letter that was sent to the school system directorate to ask for an official permission for data collection. Second, the four separate letters that were sent to the school principals to allow the researcher to collect data from their respective schools. Third evidence was a sample of the formal letter that was sent to all students clarifying their right to maintain anonymity throughout the study and after its completion. The fourth evidence was a sample of the consent letter that was signed by teachers, in which teachers were informed about preserving their information, being anonymous, confidentiality and their right to withdraw their participation at any stage of the research without any penalization (Creswell 2014; Johnson and Christensen 2008).

In qualitative research studies, the ethical issues arise during data collection and finding the results (Merriam 2009). The researcher -participant relationship is a major source of debate related to qualitative research, due to the expected influence of the researcher on the findings. To avoid bias in the current, the researcher considered the "Ethical Issues Checklist" (Merriam 2009). The researcher was committed to explaining the purpose of the study, aimed at being objective when collecting and analysing data and explained data collection boundaries. In addition, raw data related to lesson observations, interviews and document analysis has always been accessible to show the credibility of the research study.

3.5 Limitations

This research study was limited to two high school grade levels (Grade 9 and Grade 10), and the biology curriculum alone was investigated. The study did not measure the actual critical thinking level that students gained after following IBL instructions; the questionnaire and CT attributes used measure critical thinking dispositions, not actual levels of analysis that students would develop. A follow-up study will be required to develop an assessment tool that would measure students' critical thinking skills developed after the implementation of IBL instructions to determine the effectiveness of the utilized instructions.

This study was limited in time, as data collection extended from September 2018 until January 2019. Other inquiry practices and students' skills may be developed after data collection for the current study was completed.

4. Chapter Four

Results and Data analysis

4.1 Introduction

The aim of this study was to investigate the effectiveness of inquiry-based learning in Biology classrooms on the development of high school students' critical thinking skills. The previous chapter presented the research design, methodology and the qualitative and quantitative instruments that were used to collect data. Thus, this chapter presents the resulting two types of data: quantitative results, including participants' demographic information and the data collected from the nonexperimental questionnaire, and qualitative results from lesson observations, teachers' interviews and document analysis of samples from students' artefacts. The revised data intends to answer four major questions:

1. What are students' experiences with IBL implementation in a high school biology course in UAE?
2. To what extent do students develop critical thinking skills through the use of high school biology IBL activities in the UAE?
3. What are the high school biology teachers' perceptions of the use of IBL and the development of CT?
4. How do demographic factors affect the development of students' critical thinking skills when applying IBL biology activities?

In this mixed method research, qualitative and quantitative data collection occurred concurrently (Johnson and Christensen 2008). Therefore, while they were conducted and analysed independently, they remain complimentary to each other and lead to justified conclusions. In the following subsections quantitative results and qualitative results are presented, each with a description of the relevant demographic information pertaining to the participants in it.

4.2 Quantitative Results

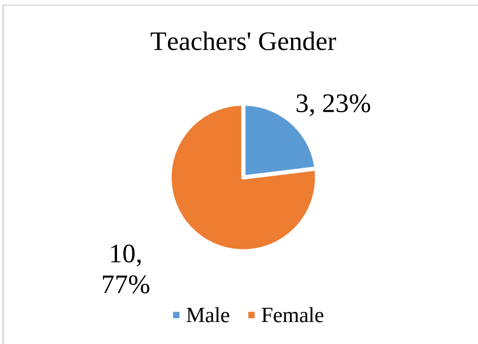
This section presents the results and data analysis of the quantitative part of the research. It includes three subsections; the first section presents the demographic information related to the participants teachers and students contributed in the research study. The second subsection presents data analysis related to IBL and CT including the frequency, mean and standard deviation of IBL and CT items, which help describe general trends in the data. In addition, it presents the results of independent t- test for both IBL and CT. The third section presents the determination of the correlation and association between IBL implementation and the students' development of CT skills. This subsection includes two types of correlation analysis, which are the Pearson correlation coefficient, that indicates whether the variables in the study show significant correlation or not and the scatterplot that provides a visual representation of the data.

4.2.1 Demographic information

Two types of demographics are discussed in this section: those pertaining to teachers who participated in lesson observations and structured interviews, and students who participated in the nonexperimental questionnaire, lesson observations and submitted their work for document analysis.

4.2.2.1Teachers

The total number of biology teachers' population is 35 teachers, including a sample of 13 teachers who volunteered to participate in the research study. In lesson observations, 10 female teachers and 2 male teachers participated. While 13 teachers participated in interviews, 10 female teachers and 3 male teachers. From the 13 teachers, 5 had 5-9 years of experience and 8 had 10-15 years of experience in teaching high school biology courses. Demographic data related to participant teachers is presented in Figure 4.1 below.



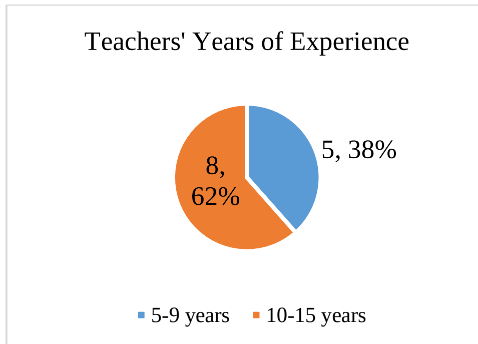


Figure 4.1 Demographic data of the participants from teachers

The information related to the profile of each participant teacher is presented in table 4.1 below.

Table 4-1 the profile of each volunteer teachers

Volunteer teacher	Gender	Years of Experience	Grade levels taught
1-AQB-S	Female	6	9
2-AQB-D	Female	7	10
3-AQB-G	Female	7	9, 10, 11 and 12
4-AQB-M	Male	11	10
5-AUHB-S	Female	12	9 and 10
6-AUHB-H	Female	18	9
7-AUHB-M	Female	8	9, 10 and 11
8-AUHG-L	Female	14	9, 11 and 12
9-AUHG-R	Female	13	10, 11 and 12
10-AUHG-NI	Female	5	9
11-AUHG-NO	Female	10	10
12-DXB-I	Male	12	9 and 10
13-DXB-C	Male	10	9, 10, 11 and 12

4.2.1.2 Students

The total population of the targeted grade levels in this study (Grade 9 and Grade 10), was 3202 students and the total number of students that responded to the quantitative questionnaire was 1330. The data collection method followed proportional stratified sampling based on three main strata: gender, grade level and geographical locations of the schools. The pie charts below in Figures 4.2, 4.3 and 4.4 illustrate a comparison between the actual number of students' distribution and the number of participants' distribution (Kerjecie and Morgan 1970 in Johnson and Christensen 2008), clarifying the alignment between the number of the original population and the number of the sample participants. This is to show the proportional stratified sampling methodology.

Students' numbers based on the Grade Level

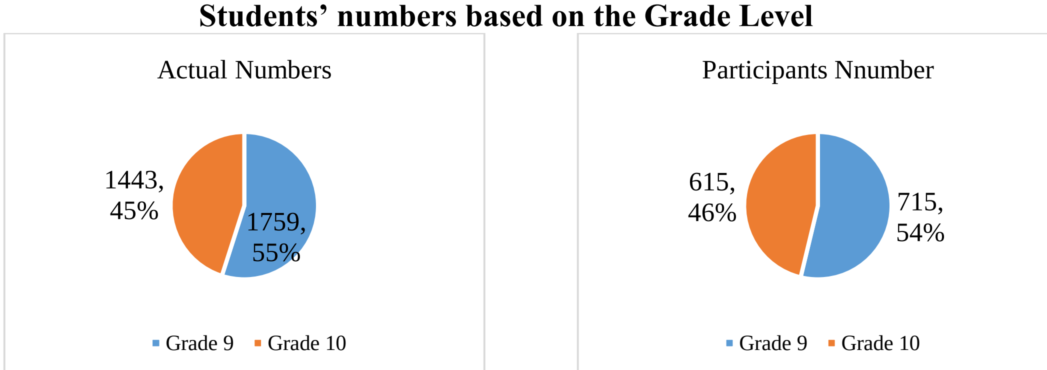


Figure 4.2 Comparison between actual students' number and participants number based on grade level

Students' numbers based on Gender

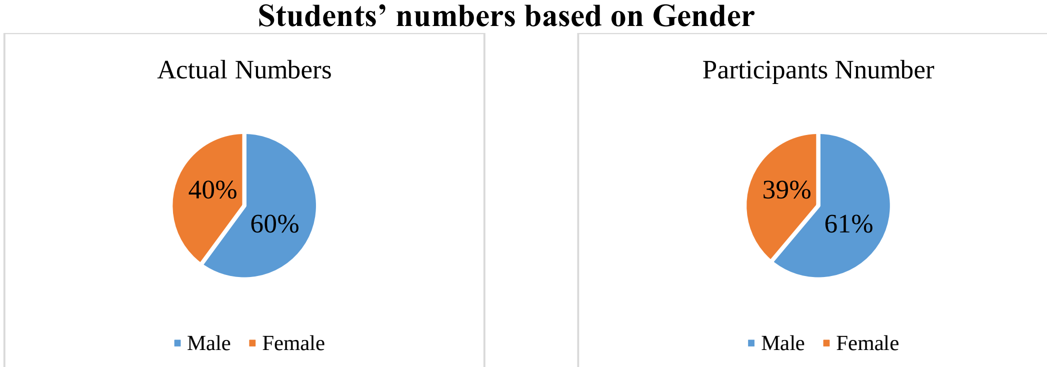


Figure 4.3 Comparison between actual students' number and participants number based on gender

Students' numbers based on the Geographic Location

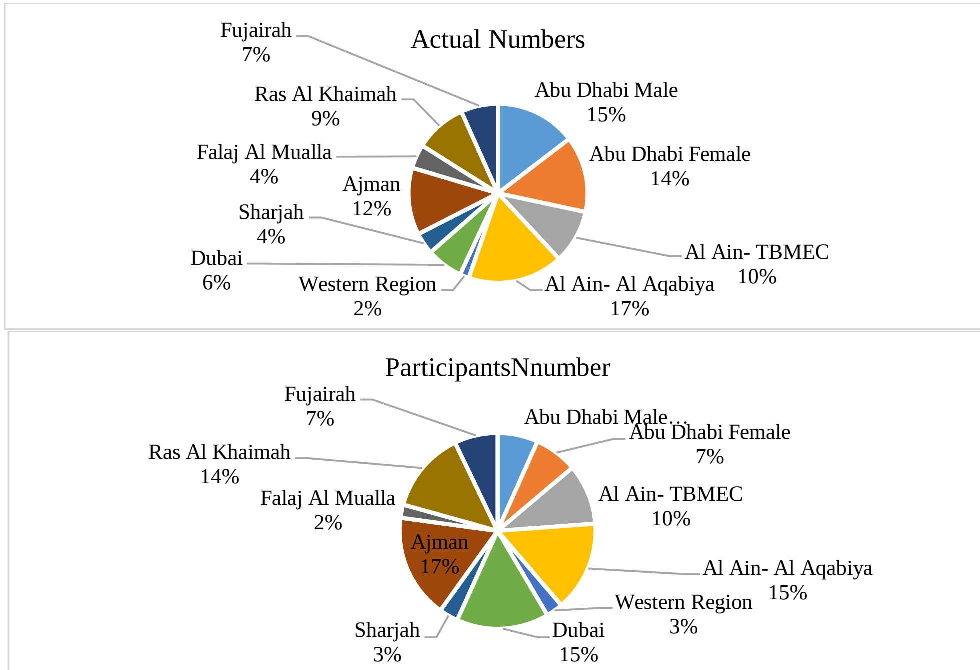


Figure 4.4 Comparison between actual students' population and the sample participated from the location

A total of 1330 students participated in the study, 813 being male and 517 females. About 715 students were in grade 9 and 615 were in grade 10.

4.2.3 IBL and CT Results and Data Analysis

This section presents several descriptive statistics to provide an overview of the results, including any apparent trends. The analysis was performed by assuming parametric statistics, it includes the mean, standard deviation and variance of each item in the IBL and CT factors. In addition, it presents the results of the t-test analysis, which compares the means of the responses of two groups based on gender and grade level and relating them to both IBL items and CT items, to find whether there is a significant difference between the responses of students' groups. Datasets were divided into four main categories, which were the results of independent t- test done to compare between male and female students' responses to IBL items, and compare their responses to CT items, in addition to comparing the responses of Grades 9 and 10 to IBL and CT items.

4.2.3.1 Inquiry Based Learning Items

The mean values for all IBL items are > 3.5 which means that the responses indicated regular implantation of IBL activities. Yet, the highest mean of responses (3.9) was to the item related to receiving step by step instructions before performing an investigation and the lowest mean of responses (3.5) was related to the item related to student's ability to design the procedure of an investigation. The reported results of the variance and standard deviation indicated that the variability of responses to all IBL items is approximately at the same level, the item that reflected the highest variability values was the one related to conducting the procedure for an investigation independently. Table 4.2 summaries students' responses to the main items related to the implementation of IBL activities in the biology classroom.

Table 4.2 Descriptive Statistics of the responses for IBL items

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
Item	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
IBLpre1: I formulate questions to be answered in investigation	1330	1.00	5.00	3.7925	.03805	1.38755	1.925
IBLpre2: I receive step by step instructions before I investigate	1330	1.00	5.00	3.9496	.03735	1.36207	1.855
IBLpre3: I design my procedure for the investigation	1330	1.00	5.00	3.5466	.03921	1.42998	2.045
IBLpre4: My teacher conducts the experiment	1330	1.00	5.00	3.6887	.03880	1.41505	2.002

and I observe							
IBLpost1: I conduct the procedure for an investigation	1330	1.00	5.00	3.5526	.04140	1.50964	2.279
IBLpost2: I decide which data to collect	1330	1.00	5.00	3.7880	.03847	1.40305	1.969
IBLpost3: I develop conclusions for the investigation	1330	1.00	5.00	3.6812	.03887	1.41762	2.010
IBLpost4: I can connect the conclusion with the scientific concept	1330	1.00	5.00	3.7677	.03885	1.41666	2.007
Valid N (listwise)	1330						

The results of t- test that compared between the responses of male and female students is presented in tables 4.3 and 4.4. below. The Levine's test data reveals that equal variances are assumed ($\rho >0.05$) in all IBL items which means that the data in the first row should be considered. Therefore, there was a significant difference in the responses to the IBLpost2 related to students' ability to decide which data to collect, where the female students' responses (M = 3.88, s = 1. 40) is higher than the responses of male students (M = 3.72, s = 1.40) t=1.98 and ρ =0.47. In addition, item IBLpost3 related to students' ability to develop conclusions for the investigation also reflected a significant difference between female students' responses, (M = 3.79, s = 1. 411) which were higher than male students' responses (M = 3.61, s = 1. 418), t-2.24 and ρ =0.25. However, the t test failed to reveal a statistically reliable difference between male and female responses to other IBL items, as the responses to the other IBL items did not show a significant difference. This means that male and female students had responded to these items in the same manner.

Table 4.3 t-test male and female students, group statistics

Group Statistics					
IBL item	Gender	N	Mean	Std. Deviation	Std. Error Mean
IBLpre1: I formulate questions to be answered in investigation	male	814	3.7678	1.39456	.04888
	female	516	3.8314	1.37688	.06061
IBLpre2: I receive step by step instructions before I investigate	male	814	3.9545	1.34709	.04722
	female	516	3.9419	1.38666	.06104
IBLpre3: I design my procedure for the investigation	male	814	3.5086	1.42610	.04998
	female	516	3.6066	1.43543	.06319
IBLpre4: My teacher conducts the experiment and I observe	male	814	3.6658	1.42077	.04980
	female	516	3.7248	1.40659	.06192
IBLpost1: I conduct the procedure for an investigation	male	814	3.5688	1.50098	.05261
	female	516	3.5271	1.52431	.06710
IBLpost2: I decide which data to collect	male	814	3.7273	1.40174	.04913
	female	516	3.8837	1.40113	.06168
IBLpost3: I develop conclusions for the investigation	male	814	3.6118	1.41826	.04971
	female	516	3.7907	1.41105	.06212
IBLpost4: I can connect the conclusion with the scientific concept	male	814	3.7371	1.41323	.04953
	female	516	3.8159	1.42209	.06260

Table 4.4 t-Test between Male and Female Students responses to IBL

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
IBLPre1	Equal variances assumed	.285	.593	-.814	1328	.416	-.06358	.07809	-.21677	.08961
	Equal variances not assumed			-.817	1106.247	.414	-.06358	.07787	-.21636	.08920
IBLPre2	Equal variances assumed	.654	.419	.165	1328	.869	.01268	.07667	-.13773	.16310
	Equal variances not assumed			.164	1072.387	.869	.01268	.07717	-.13874	.16411
IBLPre3	Equal variances assumed	.216	.642	-1.218	1328	.223	-.09799	.08045	-.25582	.05984

	Equal variances not assumed			-1.216	1090.614	.224	-.09799	.08057	-.25608	.06010
IBLPre4	Equal variances assumed	.568	.451	-.740	1328	.459	-.05896	.07964	-.21519	.09728
	Equal variances not assumed			-.742	1104.040	.458	-.05896	.07946	-.21487	.09695
IBLPost5	Equal variances assumed	.380	.538	.490	1328	.624	.04166	.08497	-.12503	.20836
	Equal variances not assumed			.489	1083.382	.625	.04166	.08527	-.12565	.20897
IBLPost6	Equal variances assumed	.529	.467	-1.984	1328	.047	-.15645	.07886	-.31116	-.00173
	Equal variances not assumed			-1.984	1096.269	.048	-.15645	.07886	-.31118	-.00172
IBLPost7	Equal variances assumed	1.423	.233	-2.246	1328	.025	-.17890	.07965	-.33516	-.02265
	Equal variances not assumed			-2.249	1100.046	.025	-.17890	.07956	-.33501	-.02280
IBLPost8	Equal variances assumed	.110	.740	-.988	1328	.323	-.07879	.07972	-.23518	.07760
	Equal variances not assumed			-.987	1090.835	.324	-.07879	.07983	-.23543	.07785

The results of t-test compared between the responses of Grade 9 and Grade 10 students to IBL items are presented in Tables 4.5 and 4.6. The Levine's test data reveals that equal variances are assumed ($\rho > 0.05$) in IBL items 2, 3, 5, 7 and 8. In which the first-row of data should be considered. Additionally, in IBL items 1, 4 and 6, Levine's test data resulted in a significant value ($\rho < 0.05$) which indicates that equal variance is not assumed and the data of the second row should be considered. The t-test values revealed that there is a statistical difference in Grade 9 and Grade 10 students' responses to all items except item 8 related to students' ability to connect the conclusion with the scientific concepts. This means that the students in different grade levels responded differently to items related to IBL activities. To identify which group of students had better implementation of IBL, a comparison of the mean values for each item is presented in Table 4.5 below. The data shows that the responses of Grade 9 students have generally higher means than the responses of Grade 10 students in the items related to IBL implementation.

Table 4.5 t-test Grade 9 and Grade 10 students, group statistics

Group Statistics					
IBL item	Grade	N	Mean	Std. Deviation	Std. Error Mean
IBLpre1: I formulate questions to be answered in investigation	9.00	715	3.9133	1.34759	.05040
	10.00	615	3.6520	1.42084	.05729
IBLpre2: I receive step by step instructions before I investigate	9.00	715	4.0224	1.34083	.05014
	10.00	615	3.8650	1.38265	.05575
IBLpre3: I design my procedure for the investigation	9.00	715	3.6210	1.41534	.05293
	10.00	615	3.4602	1.44315	.05819
IBLpre4: My teacher conducts the experiment and I observe	9.00	715	3.8238	1.35131	.05054
	10.00	615	3.5317	1.47130	.05933
IBLpost1: I conduct the procedure for an investigation	9.00	715	3.6685	1.48873	.05568
	10.00	615	3.4179	1.52376	.06144
IBLpost2: I decide which data to collect	9.00	715	3.8867	1.35443	.05065
	10.00	615	3.6732	1.45021	.05848
IBLpost3: I develop conclusions for the investigation	9.00	715	3.7706	1.41044	.05275
	10.00	615	3.5772	1.42001	.05726
IBLpost4: I can connect the conclusion with the scientific concept	9.00	715	3.8378	1.41381	.05287
	10.00	615	3.6862	1.41676	.05713

The highest difference between Grade 9 and Grade 10 responses was identified in IBL item 4 that indicates guided inquiry instructions in which the teacher conducts the experiment and the students observe as Grade 9 responses (M=3.82, s=1.35) was higher than Grade 10 responses (M=3.53, s=1.47) t=3.77 and ρ =0.001. Additionally, IBL items number 1 and 5 also indicated a high difference in responses for item IBLpre1, where Grade 9 students' responses indicated higher ability to formulate questions to be answered in investigation (M=3.91, s=1.34) compared to the responses collected from Grade 10(M=3.65, s=1.42) t=3.43 and ρ =0.001. For item IBLpost5 related to the students' ability to conduct the procedure for an investigation, Grade 9 responses (M=3.69, s=1.48) were relatively higher than Grade 10 responses (M= 3.41, s=1.52) t=3.03 and ρ =0.003.

Table 4.6 t-test analysis between two grade levels 9 and 10

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
IBLPre1	Equal variances assumed	13.318	.000	3.437	1328	.001	.26125	.07600	.11216	.41035
	Equal variances not assumed			3.424	1275.221	.001	.26125	.07630	.11156	.41095
IBLPre2	Equal variances assumed	2.236	.135	2.103	1328	.036	.15734	.07481	.01057	.30410
	Equal variances not assumed			2.098	1285.663	.036	.15734	.07499	.01023	.30445
IBLPre3	Equal variances assumed	1.297	.255	2.047	1328	.041	.16082	.07855	.00672	.31491
	Equal variances not assumed			2.044	1290.575	.041	.16082	.07866	.00649	.31514
IBLPre4	Equal variances assumed	21.624	.000	3.772	1328	.000	.29207	.07744	.14015	.44398
	Equal variances not			3.748	1258.497	.000	.29207	.07793	.13917	.44496

	assumed									
IBLPost5	Equal variances assumed	2.348	.126	3.028	1328	.003	.25065	.08277	.08827	.41302
	Equal variances not assumed			3.023	1288.947	.003	.25065	.08292	.08798	.41331
IBLPost6	Equal variances assumed	13.432	.000	2.774	1328	.006	.21354	.07697	.06255	.36454
	Equal variances not assumed			2.760	1267.436	.006	.21354	.07737	.06176	.36532
IBLPost7	Equal variances assumed	.799	.371	2.485	1328	.013	.19339	.07781	.04074	.34604
	Equal variances not assumed			2.484	1295.792	.013	.19339	.07785	.04066	.34612
IBLPost8	Equal variances assumed	1.710	.191	1.948	1328	.052	.15158	.07783	-.00110	.30427
	Equal variances not assumed			1.947	1297.624	.052	.15158	.07784	-.00113	.30429

4.2.3.2 Critical Thinking Items

Responses to the items related to CT implementation are summarized in Table 4.7 that presents the descriptive statistics of CT. The mean values of all CT items indicated that students agreed that they were exposed to daily practices that would help them to develop CT skills, the mean values for all items ranged between 3.6 and 4.2. the highest score was to item related to understanding the question before providing an answer.

The least mean was related to assessing claims being made in classroom discussions. The results of variability for the responses to CT items reflected standard deviation values between 1.1 and 1.3, while the variance values were between 1.2 and 1.7. The item with the highest variability was to the item related to performing activities that encourage students to think independently and speak out their opinion, while the items with least variability were related to interpretation to seek clarity, as the students reflected the same experience as they clarify the given questions before providing an answer.

Table 0-7 Descriptive Statistics of the responses for CT items

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
CT item	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
CTCla1: Before giving an answer, I always focus on the question first.	1330	1.00	5.00	4.2361	.03079	1.12294	1.261
CTCla2: I clarify meaning and define terms that are not familiar	1330	1.00	5.00	3.9331	.03206	1.16928	1.367
CTcla3: I express the new question in several ways to clarify its meaning and scope	1330	1.00	5.00	3.9278	.03322	1.21164	1.468
CTCla4: I raise significant questions for more clarification	1330	1.00	5.00	3.8023	.03314	1.20851	1.460
CTA5: I perform activities that encourage me to think independently and speak out my opinion	1330	1.00	5.00	3.6872	.03623	1.32121	1.746
CTA6: I assess claims being made in classroom discussions	1330	1.00	5.00	3.6053	.03572	1.30282	1.697
CTA7: I passively accept claims being	1330	1.00	5.00	3.7496	.03445	1.25632	1.578

made in classroom discussions							
CTA8: I analyse arguments being made and their consequences.	1330	1.00	5.00	3.7632	.03388	1.23542	1.526
CTE9: I draw conclusions about a problem based on the evidence at hand	1330	1.00	5.00	3.8429	.03369	1.22863	1.510
CTE10: I use various processes to resolve, re-address, and re-analyse complex situations to gain new vision	1330	1.00	5.00	3.7962	.03392	1.23706	1.530
CTE11: I develop and use valid criteria to evaluate claims being made in class discussions	1330	1.00	5.00	3.7504	.03410	1.24353	1.546
CTE12: I learn how to distinguish what I know from what I don't know in any new concept	1330	1.00	5.00	3.8368	.03357	1.22416	1.499
CTI13: I restrict my claims only to those supported by the evidence	1330	1.00	5.00	3.7947	.03464	1.26329	1.596
CTI14: I search for information that opposes my position as well as information that supports it.	1330	1.00	5.00	3.8940	.03352	1.22245	1.494
CTI15: I learn how to think within the point of view of those with whom I disagree their opinion	1330	1.00	5.00	3.8008	.03531	1.28784	1.659
CTI16: I consider how my assumptions are shaping my point of view.	1330	1.00	5.00	3.8308	.03307	1.20600	1.454
CTSR17: I can justify the strategies that I used to solve a problem or	1330	1.00	5.00	3.8188	.03392	1.23692	1.530

create an argument							
CTSR18: I can present my argument to others in a way that they will understand.	1330	1.00	5.00	3.8083	.03493	1.27372	1.622
CTSR19: I correct my assumptions and revisit what I mean by certain things before making any final decisions	1330	1.00	5.00	3.8534	.03342	1.21887	1.486
CTSR20: I think precisely about thinking- using critical thinking vocabulary such as analysis and evaluation	1330	1.00	5.00	3.8361	.03411	1.24388	1.547
Valid N (listwise)	1330						

The results of the t- test that compared between male and female students' responses to CT items is presented in Tables 4.8 and 4.9. The data of Levene's Test for Equality of Variances indicated that statistically significant values of $\rho < 0.0$ in all CT items had unequal variances. Therefore, the second row of data must be considered. The results in table 4.9 reflected a significant difference in all items except the 9th item related to students use of various processes to resolve, re-address, and re-analyse complex situations to gain new insights. The highest difference was found in item CTcla3 related to the students' ability to express the new question in several ways to clarify its meaning and scope, the female students responses (M=4.12, s=1.08) were higher than the male students' responses (M=3.80, s==1.26) t=4.9 and ρ=0.001 in that item. Another item CTI15 reflected a high difference in responses which indicates whether students learn how to think within the point of view of those whose opinions they disagree with. The female students' responses (M=3.97, s=1.15) were higher than the male students' responses (M=3.69, s=1.36) t=4 and ρ=0.001. The t-test reflected a minimal difference in the responses to item CTA8 related to the students' practice of analysing arguments being made and their consequences, where the female students' responses (M=3.85, s=1.15) were slightly higher than male students' responses (M=3.7, s=1.28) t=2.15 and ρ=0.031.

Table 4.8 t-test analysis between Male and Female Students

Group Statistics					
Critical Thinking Items	Gender	N	Mean	Std. Deviation	Std. Error Mean
CTCla1: Before giving an answer, I always focus on the question first.	male	814	4.1708	1.21048	.04243
	female	516	4.3391	.96104	.04231
CTCla2: I clarify meaning and define terms that are not familiar	male	814	3.8771	1.20256	.04215
	female	516	4.0213	1.11020	.04887
CTcla3: I express the new question in several ways to clarify its meaning and scope	male	814	3.8022	1.26897	.04448
	female	516	4.1260	1.08727	.04786
CTCla4: I raise significant questions for more clarification	male	814	3.7064	1.24335	.04358
	female	516	3.9535	1.13624	.05002
CTA5: I perform activities that encourage me to think independently and speak out my opinion	male	814	3.6253	1.35411	.04746
	female	516	3.7849	1.26270	.05559
CTA6: I assess claims being made in classroom discussions	male	814	3.5393	1.34751	.04723
	female	516	3.7093	1.22308	.05384
CTA7: I passively accept claims being made in classroom discussions	male	814	3.6646	1.29691	.04546
	female	516	3.8837	1.17830	.05187
CTA8: I analyse arguments being made and their consequences.	male	814	3.7064	1.28135	.04491
	female	516	3.8527	1.15482	.05084
CTE9: I draw conclusions about a problem based on the evidence at hand	male	814	3.7924	1.27224	.04459
	female	516	3.9225	1.15321	.05077
CTE10: I use various processes to resolve, re-address, and re-analyse complex situations to gain new vision	male	814	3.7224	1.28251	.04495
	female	516	3.9128	1.15336	.05077
CTE11: I develop and use valid criteria to evaluate claims being made in class discussions	male	814	3.6794	1.29210	.04529
	female	516	3.8624	1.15517	.05085
CTE12: I learn how to distinguish what I know from what I don't know in any new concept	male	814	3.7568	1.27317	.04462
	female	516	3.9632	1.13231	.04985
CTI13: I restrict my claims only to those supported by the evidence	male	814	3.7273	1.31106	.04595
	female	516	3.9012	1.17742	.05183
CTI14: I search for information that opposes my position as well as information that supports it	male	814	3.8268	1.28219	.04494
	female	516	4.0000	1.11477	.04908
CTI15: I learn how to think within the point of view of those with whom I disagree their opinion	male	814	3.6916	1.35632	.04754
	female	516	3.9729	1.15214	.05072
CTI16: I consider how my assumptions are shaping my point of view.	male	814	3.7617	1.24875	.04377
	female	516	3.9399	1.12788	.04965
CTSR17: I can justify the strategies that I used to solve a problem or create an argument	male	814	3.7629	1.29301	.04532
	female	516	3.9070	1.13850	.05012
CTSR18: I can present my argument to others in a way that they will understand.	male	814	3.7211	1.31118	.04596
	female	516	3.9457	1.20071	.05286
CTSR19: I correct my assumptions and revisit what I mean by certain things before making any final decisions	male	814	3.7752	1.28472	.04503
	female	516	3.9767	1.09697	.04829
CTSR20: I think precisely about thinking- using critical thinking vocabulary such as analysis and evaluation	male	814	3.7555	1.28782	.04514
	female	516	3.9632	1.16110	.05111

Table 4.9 T-test analysis comparing Means of Response of Male and Female Students

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
CTCla1	Equal variances assumed	15.307	.000	-2.671	1328	.008	-.16839	.06304	-.29206	-.04471
	Equal variances not assumed			-2.810	1262.726	.005	-.16839	.05992	-.28593	-.05084
CTCla2	Equal variances assumed	4.665	.031	-2.194	1328	.028	-.14417	.06570	-.27306	-.01527
	Equal variances not assumed			-2.234	1159.612	.026	-.14417	.06454	-.27079	-.01754
CTcla3	Equal variances assumed	21.711	.000	-4.788	1328	.000	-.32376	.06763	-.45642	-.19109
	Equal variances not assumed			-4.955	1214.671	.000	-.32376	.06534	-.45195	-.19557
CTCla4	Equal variances assumed	16.049	.000	-3.650	1328	.000	-.24710	.06769	-.37989	-.11431
	Equal variances not assumed			-3.725	1167.457	.000	-.24710	.06634	-.37726	-.11694
CTA5	Equal variances assumed	4.890	.027	-2.149	1328	.032	-.15958	.07425	-.30523	-.01393
	Equal variances not assumed			-2.183	1151.813	.029	-.15958	.07309	-.30299	-.01617
CTA6	Equal variances assumed	11.300	.001	-2.323	1328	.020	-.16999	.07319	-.31357	-.02641
	Equal variances not assumed			-2.373	1172.655	.018	-.16999	.07162	-.31051	-.02947
CTA7	Equal variances assumed	19.069	.000	-3.109	1328	.002	-.21910	.07047	-.35734	-.08087
	Equal variances not assumed			-3.177	1171.906	.002	-.21910	.06897	-.35442	-.08378
CTA8	Equal variances assumed	8.644	.003	-2.108	1328	.035	-.14632	.06943	-.28253	-.01012
	Equal variances			-2.157	1178.012	.031	-.14632	.06783	-.27941	-.01323

	not assumed									
CTE 9	Equal variances assumed	14.665	.000	-1.884	1328	.060	-.13010	.06907	-.26560	.00540
	Equal variances not assumed			-1.925	1173.667	.054	-.13010	.06757	-.26267	.00248
CTE 10	Equal variances assumed	14.579	.000	-2.742	1328	.006	-.19043	.06944	-.32666	-.05421
	Equal variances not assumed			-2.808	1179.645	.005	-.19043	.06781	-.32348	-.05738
CTE 11	Equal variances assumed	16.600	.000	-2.622	1328	.009	-.18304	.06982	-.32001	-.04607
	Equal variances not assumed			-2.688	1184.042	.007	-.18304	.06810	-.31664	-.04944
CTE 12	Equal variances assumed	19.974	.000	-3.006	1328	.003	-.20642	.06868	-.34115	-.07169
	Equal variances not assumed			-3.085	1187.926	.002	-.20642	.06690	-.33768	-.07516
CTI13	Equal variances assumed	14.561	.000	-2.451	1328	.014	-.17389	.07095	-.31308	-.03470
	Equal variances not assumed			-2.510	1180.673	.012	-.17389	.06927	-.30980	-.03798
CTI14	Equal variances assumed	19.177	.000	-2.523	1328	.012	-.17322	.06865	-.30789	-.03854
	Equal variances not assumed			-2.603	1204.399	.009	-.17322	.06654	-.30377	-.04266
CTI15	Equal variances assumed	43.075	.000	-3.901	1328	.000	-.28122	.07208	-.42263	-.13981
	Equal variances not assumed			-4.045	1220.594	.000	-.28122	.06952	-.41761	-.14484
CTI16	Equal variances assumed	12.273	.000	-2.632	1328	.009	-.17825	.06771	-.31109	-.04542
	Equal variances not assumed			-2.693	1176.375	.007	-.17825	.06619	-.30811	-.04839
CTSR17	Equal variances assumed	16.635	.000	-2.073	1328	.038	-.14408	.06952	-.28045	-.00770

	Equal variances not assumed			-2.132	1195.280	.033	-.14408	.06757	-.27665	-.01151
CTS R18	Equal variances assumed	16.653	.000	-3.144	1328	.002	-.22461	.07144	-.36475	-.08447
	Equal variances not assumed			-3.207	1165.865	.001	-.22461	.07004	-.36203	-.08718
CTS R19	Equal variances assumed	30.348	.000	-2.947	1328	.003	-.20156	.06839	-.33572	-.06740
	Equal variances not assumed			-3.053	1217.057	.002	-.20156	.06603	-.33110	-.07202
CTS R20	Equal variances assumed	13.378	.000	-2.975	1328	.003	-.20765	.06979	-.34456	-.07074
	Equal variances not assumed			-3.045	1177.721	.002	-.20765	.06819	-.34144	-.07386

The analysis of Grade 9 and Grade 10 responses to CT items showed significant difference only in five items 1st and 3rd related to interpretation and clarity, the 5th related to analysis, accuracy and precision skills, 16th related to inference and the 20th item related to self-regulation skill. Tables 4.10 and 4.11 below presents the detailed results.

Table 4.10 t-Test analysis between Grade 9 and Grade 10 Students

Group Statistics					
Critical Thinking Items	Grade	N	Mean	Std. Deviation	Std. Error Mean
CTCla1: Before giving an answer, I always focus on the question first.	9.00	715	4.3357	1.02452	.03831
	10.00	615	4.1203	1.21814	.04912
CTCla2: I clarify meaning and define terms that are not familiar	9.00	715	3.9692	1.13348	.04239
	10.00	615	3.8911	1.20915	.04876
CTcla3: I express the new question in several ways to clarify its meaning and scope	9.00	715	3.9930	1.15892	.04334
	10.00	615	3.8520	1.26693	.05109
CTCla4: I raise significant questions for more clarification	9.00	715	3.8601	1.14863	.04296
	10.00	615	3.7350	1.27223	.05130
CTA5: I perform activities that encourage me to think independently and speak out my opinion	9.00	715	3.7986	1.27517	.04769
	10.00	615	3.5577	1.36242	.05494
CTA6: I assess claims being made in classroom discussions	9.00	715	3.6266	1.28735	.04814
	10.00	615	3.5805	1.32119	.05328
CTA7: I passively accept claims being made in classroom discussions	9.00	715	3.8028	1.19476	.04468
	10.00	615	3.6878	1.32260	.05333
CTA8: I analyse arguments being made and their consequences.	9.00	715	3.7944	1.19451	.04467
	10.00	615	3.7268	1.28135	.05167

CTE9: I draw conclusions about a problem based on the evidence at hand	9.00	715	3.8545	1.20740	.04515
	10.00	615	3.8293	1.25371	.05055
CTE10: I use various processes to resolve, re-address, and re-analyse complex situations to gain new vision	9.00	715	3.8587	1.18979	.04450
	10.00	615	3.7236	1.28700	.05190
CTE11: I develop and use valid criteria to evaluate claims being made in class discussions	9.00	715	3.7958	1.22084	.04566
	10.00	615	3.6976	1.26835	.05114
CTE12: I learn how to distinguish what I know from what I don't know in any new concept	9.00	715	3.8895	1.18124	.04418
	10.00	615	3.7756	1.27046	.05123
CTI13: I restrict my claims only to those supported by the evidence	9.00	715	3.8392	1.22446	.04579
	10.00	615	3.7431	1.30609	.05267
CTI14: I search for information that opposes my position as well as information that supports it	9.00	715	3.9469	1.16074	.04341
	10.00	615	3.8325	1.28873	.05197
CTI15: I learn how to think within the point of view of those with whom I disagree their opinion	9.00	715	3.8266	1.24825	.04668
	10.00	615	3.7707	1.33279	.05374
CTI16: I consider how my assumptions are shaping my point of view.	9.00	715	3.9357	1.13083	.04229
	10.00	615	3.7089	1.27804	.05154
CTSR17: I can justify the strategies that I used to solve a problem or create an argument	9.00	715	3.8406	1.19747	.04478
	10.00	615	3.7935	1.28178	.05169
CTSR18: I can present my argument to others in a way that they will understand.	9.00	715	3.8476	1.23351	.04613
	10.00	615	3.7626	1.31846	.05317
CTSR19: I correct my assumptions and revisit what I mean by certain things before making any final decisions	9.00	715	3.8923	1.17079	.04378
	10.00	615	3.8081	1.27195	.05129
CTSR20: I think precisely about thinking- using critical thinking vocabulary such as analysis and evaluation	9.00	715	3.9063	1.18151	.04419
	10.00	615	3.7545	1.30891	.05278

The data of Levene's Test for Equality of Variances that indicated statistically significant values ρ <0.0 in items 1,3, 4,5,7,10, 12,13, 14, 15,16, 17, 18, 19 and 20 leads to the understanding that equal variance is not assumed and the data from the second row should be considered in the results. However, items 2, 6, 8, 9 and 11indicated that equal variance is assumed and therefore the first row of data should be considered when reporting the results.

Table 4.11 T-test analysis comparing Means of Response of Grade 9 and Grade 10 Students

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
CTCla1	Equal variances assumed	10.142	.001	3.502	1328	.000	.21534	.06150	.09470	.33598
	Equal variances not assumed			3.457	1204.885	.001	.21534	.06230	.09312	.33756

CTCla2	Equal variances assumed	3.169	.075	1.216	1328	.224	.07817	.06430	-.04796	.20430
	Equal variances not assumed			1.210	1269.342	.227	.07817	.06461	-.04858	.20492
CTcla3	Equal variances assumed	11.130	.001	2.118	1328	.034	.14097	.06655	.01042	.27153
	Equal variances not assumed			2.104	1256.269	.036	.14097	.06700	.00954	.27241
CTCla4	Equal variances assumed	11.770	.001	1.885	1328	.060	.12518	.06640	-.00508	.25544
	Equal variances not assumed			1.871	1248.877	.062	.12518	.06691	-.00609	.25645
CTA5	Equal variances assumed	9.763	.002	3.328	1328	.001	.24088	.07239	.09887	.38288
	Equal variances not assumed			3.311	1268.543	.001	.24088	.07275	.09816	.38360
CTA6	Equal variances assumed	.992	.319	.643	1328	.520	.04609	.07167	-.09451	.18668
	Equal variances not assumed			.642	1287.776	.521	.04609	.07181	-.09478	.18696
CTA7	Equal variances assumed	17.410	.000	1.665	1328	.096	.11499	.06905	-.02046	.25045
	Equal variances not assumed			1.653	1249.187	.099	.11499	.06958	-.02151	.25149
CTA8	Equal variances assumed	3.712	.054	.995	1328	.320	.06758	.06794	-.06571	.20087
	Equal variances not assumed			.989	1266.470	.323	.06758	.06830	-.06642	.20158
CTE9	Equal variances assumed	.493	.483	.374	1328	.708	.02528	.06759	-.10732	.15788
	Equal variances not assumed			.373	1282.513	.709	.02528	.06778	-.10770	.15826
CTE10	Equal variances assumed	9.282	.002	1.989	1328	.047	.13516	.06796	.00185	.26848
	Equal variances not assumed			1.977	1262.039	.048	.13516	.06836	.00105	.26928
CTE11	Equal variances assumed	2.843	.092	1.437	1328	.151	.09824	.06836	-.03587	.23235
	Equal variances not assumed			1.433	1282.266	.152	.09824	.06856	-.03626	.23274

CTE12	Equal variances assumed	4.017	.045	1.693	1328	.091	.11390	.06728	-.01808	.24588
	Equal variances not assumed			1.684	1265.089	.092	.11390	.06765	-.01881	.24661
CTI13	Equal variances assumed	8.976	.003	1.383	1328	.167	.09607	.06945	-.04018	.23232
	Equal variances not assumed			1.377	1269.391	.169	.09607	.06979	-.04085	.23299
CTI14	Equal variances assumed	10.972	.001	1.702	1328	.089	.11433	.06718	-.01746	.24613
	Equal variances not assumed			1.689	1247.492	.092	.11433	.06771	-.01851	.24717
CTI15	Equal variances assumed	3.967	.047	.788	1328	.431	.05584	.07084	-.08312	.19481
	Equal variances not assumed			.784	1268.877	.433	.05584	.07119	-.08381	.19550
CTI16	Equal variances assumed	22.489	.000	3.432	1328	.001	.22672	.06606	.09713	.35631
	Equal variances not assumed			3.401	1236.990	.001	.22672	.06667	.09593	.35751
CTSR17	Equal variances assumed	4.275	.039	.692	1328	.489	.04706	.06804	-.08641	.18054
	Equal variances not assumed			.688	1267.584	.491	.04706	.06839	-.08710	.18123
CTSR18	Equal variances assumed	7.813	.005	1.213	1328	.225	.08495	.07004	-.05245	.22235
	Equal variances not assumed			1.207	1268.329	.228	.08495	.07039	-.05314	.22304
CTSR19	Equal variances assumed	7.719	.006	1.256	1328	.209	.08418	.06702	-.04730	.21565
	Equal variances not assumed			1.248	1259.695	.212	.08418	.06744	-.04812	.21648
CTSR20	Equal variances assumed	15.384	.000	2.223	1328	.026	.15182	.06831	.01782	.28582
	Equal variances not assumed			2.206	1248.764	.028	.15182	.06883	.01678	.28687

The results of the t-test proved that there is a significant difference between Grade 9 and Grade 10 responses in 6 main items. In the first item CTCla1, which was related to students' ability to focus on the questions before answering, Grade 9 students' responses (M=4.33, s==1.02) indicated higher focus than their Grade 10 students (M=4.1, s=1.2) t= 3.45 and ρ=0.001. The second item is CTCla3 related to students' ability to express the new question in several ways to clarify its meaning and scope, where Grade 9 students' responses (M= 3.99, s= 1.16) were higher than Grade 10 responses (M= 3.85 , s= 1.26) t= 2.1 and ρ=0.036. The third item, CTA5 expressed the students' ability to perform activities that encourage them to think independently and speak out with their opinion. For that item, Grade 9 students' responses (M= 3.79 , s= 1.28) was also higher than Grade 10 students' responses (M=3.56, s= 1.36) t=3.31 and ρ=0.001. The fourth item, CTE10: related to students' ability to use various processes to resolve, re-address, and re-analyse complex situations to gain new visions, Grade 9 students' responses (M= 3.86 , s=1.189) were higher than Grade 10 students' responses (M=3.72, s=1.28) t= 1.9 ρ=0.048. The fifth item, CTI16 related to students' practices in considering how their assumptions are shaping their point of view, Grade 9 students' responses (M= 3.93 , s=1.13) were yet again higher than Grade 10 students' responses (M=3.71, s= 1.27) t= 3.4 and ρ=0.001. The last item, CTSR20, related to students' self-regulation skills and their ability to think precisely about thinking using critical thinking vocabulary, such as analysis and evaluation, the Grade 9 students' responses (M=3.91 , s= 1.18) were higher than Grade 10 students' responses (M=3.75, s= 1.31) t= 2.2 and ρ=0.028

4.2.3.3 Independent t-Test to compare between IBL and CT responses

The independent t-test was performed to identify the differences in mean values between two different groups of responses regarding the implementation of IBL and the development of CT considering gender as a factor. Table 4.12 shows the summary of the t-test results.

The Levene's Test data for IBL indicates that equal variance is assumed (ρ value =0.79), therefore the data in the first row should be considered in the results. However, items related to CT (ρ value =0.004, ρ < 0.05) indicate that the equal variance is not assumed and therefore data from the second row in the table should be reported.

For IBL, the 2-tailed significance (ρ = 0.259, ρ > 0.05) confirms that there is no significant difference between male and female students' responses related to IBL. Yet, the data presented statistically significant differences between male and female responses to items related to the development of CT skills (t=3.6, ρ = 0.001 ρ < 0.05).

Table 0-12 Relation between Gender and IBL and CT skills-independent Samples T-test

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper
IBL	Equal variances assumed	.086	.769	-1.129	1328	.259	-.58032	.51398	-1.58862	.42797
	Equal variances not assumed			-1.125	1083.504	.261	-.58032	.51574	-1.59228	.43164
CT	Equal variances assumed	8.168	.004	-3.520	1328	.000	-3.87287	1.10012	-6.03103	-1.71472
	Equal variances not assumed			-3.612	1186.507	.000	-3.87287	1.07215	-5.97640	-1.76935

The effect of grade level on the implementation of IBL instructions and CT development was also tested by the independent t-test using the SPSS software. A summary of the independent t-test results is presented in Table 4.13. Based on Levene's Test (ρ = 0.028; ρ < 0.05) the equal variance is not assumed and therefore the data from the second row should be reported. The results reflected that there is a statistically significant difference between Grade 9 and Grade 10 students' responses to IBL activities; the mean of Grade 9 students' responses (M=30.54, s=8.8) is higher than the mean of Grade 10 students' responses (M=28.86, s=9.4) t=1.25 and ρ = 0.001. The results also indicated a statistically significant difference between the means of Grade 9 and Grade 10 responses to items related to the development of CT skills in which the mean of Grade 9 responses (M=77.6, s=18.15) is higher than their colleagues in Grade 10 responses (M=75.35 , s=21.1) t=2.07 and ρ = 0.038.

Table 4 13 Relation between Grade level and IBL and CT skills-independent Samples T-test

Group Statistics

Grade		N	Mean	Std. Deviation	Std. Error Mean
IBL	9.00	715	30.5441	8.80248	.32919
	10.00	615	28.8634	9.43351	.38040
CT	9.00	715	77.6140	18.15524	.67897
	10.00	615	75.3512	21.17379	.85381

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
IBL	Equal variances assumed	4.849	.028	3.358	1328	.001	1.68064	.50045	.69888	2.66240
	Equal variances not			3.341	1266.963	.001	1.68064	.50306	.69372	2.66756

	assume d									
CT	Equal variances assumed	11.955	.001	2.098	1328	.036	2.26277	1.07841	.14719	4.37834
	Equal variances not assumed			2.074	1217.432	.038	2.26277	1.09087	.12258	4.40295

4.2.4 Correlation Analysis

This subsection presents four types of correlational techniques followed in this research study to find a relationship between IBL implementation and the development of CT skills, including the Pearson correlation coefficient, the scatterplot for visual representation of the results.

4.2.4.1 Pearson Correlation Coefficient

The effect of IBL activities on students' CT skill development was identified by using the SPSS software to calculate the Pearson correlation coefficient between students' responses to items related to principles of inquiry and the responses related to CT (Johnson and Christensen 2008; Fraenkel and Wallen 2009). Table 4.14 shows the overall correlation and highlights the items that reflected a moderate positive correlation, where only figures > 0.5 are listed. Most of the other items showed positive moderate correlations between 0.39 and 0.49, and a few items showed a positive weak correlation (0.45-0.38) (Cohen, Manion and Morrison 2007). Item number 8 in IBL instructions, which is the students' ability to connect conclusions to scientific concepts was correlated with five CT skills including students' ability to analyze, evaluate, and infer evidence and become self-regulated.

Table 4 14Pearson correlation coefficient between principles of inquiry and critical thinking application

	IBLPre1	IBLPre2	IBLPre3	IBLPre4	IBLPost 5	IBLPost 6	IBLPost 7	IBLPost 8
CTCla1	.424**	.458**	.392**	.427**	.402**	.432**	.455**	.492**
CTCla2	.442**	.510**	.417**	.441**	.414**	.472**	.462**	.492**
CTcla3	.434**	.449**	.461**	.453**	.380**	.431**	.470**	.488**
CTCla4	.444**	.459**	.441**	.464**	.366**	.463**	.471**	.485**
CTA5	.405**	.406**	.435**	.435**	.393**	.436**	.487**	.499**
CTA6	.426**	.412**	.441**	.451**	.374**	.446**	.490**	.489**
CTA7	.425**	.438**	.446**	.455**	.399**	.466**	.476**	.472**
CTA8	.421**	.435**	.436**	.442**	.416**	.485**	.499**	.520**
CTE9	.440**	.476**	.459**	.485**	.446**	.476**	.500**	.539**
CTE10	.451**	.488**	.476**	.440**	.412**	.479**	.484**	.505**
CTE11	.451**	.459**	.456**	.474**	.387**	.451**	.482**	.532**
CTE12	.442**	.473**	.466**	.466**	.399**	.470**	.519**	.512**
CTI13	.393**	.380**	.389**	.413**	.353**	.399**	.442**	.425**
CTI14	.386**	.408**	.414**	.432**	.397**	.435**	.448**	.487**
CTI15	.386**	.391**	.433**	.458**	.366**	.402**	.454**	.451**
CTI16	.437**	.447**	.438**	.463**	.395**	.453**	.495**	.505**
CTSR17	.440**	.445**	.445**	.447**	.406**	.445**	.470**	.500**
CTSR18	.397**	.394**	.387**	.414**	.356**	.395**	.446**	.462**
CTSR19	.462**	.476**	.438**	.481**	.426**	.482**	.491**	.493**
CTSR20	.457**	.451**	.440**	.443**	.410**	.460**	.485**	.498**

4.2.4.2 Collinearity Statistics

To ensure that the correlational results are valid, multicollinearity tests were performed, the tolerance and the Variance Inflation Factors (VIF) values were acceptable, the tolerance values in all the trials were <0.5, and the VIF was always <or =3. Table 4.15 below presents one of the tests that were performed showing the VIF and tolerance values.

Table 4.15 Collinearity Statistics

Model		Collinearity Statistics	
		Tolerance	VIF
1	IBLPost6	0.433	2.309
	IBLPost7	0.347	2.885
	IBLPost8	0.365	2.738
	IBLPre1	0.479	2.088
	IBLPre2	0.426	2.347
	IBLPre3	0.381	2.622
	IBLPre4	0.369	2.712
	CTCla1	0.415	2.409
	CTCla2	0.390	2.562
	CTcla3	0.379	2.641
	CTCla4	0.390	2.564
	CTA5	0.409	2.446
	CTA6	0.387	2.584

	CTA7	0.400	2.501
	CTA8	0.341	2.932
	CTE9	0.328	3.051
	CTE10	0.314	3.184
	CTE11	0.324	3.086
	CTE12	0.339	2.950
	CTI13	0.415	2.408
	CTI14	0.372	2.690
	CTI15	0.396	2.522
	CTI16	0.328	3.052
	CTSR17	0.314	3.185
	CTSR18	0.396	2.523
	CTSR19	0.324	3.084
	CTSR20	0.363	2.754
a. Dependent Variable: IBLPost5			

4.2.4.3 Scatterplot

Further analysis using the scatterplot was performed to detect linear regression. The scatterplot below provides a visual representation of the relationship between principles of inquiry implementation and application of CT skills. The results shown in the scatterplot show a strong relationship between better implementation of IBL activities and the application of CT skills (Cohen, Manion and Morrison 2007; Fraenkel and Wallen 2009).

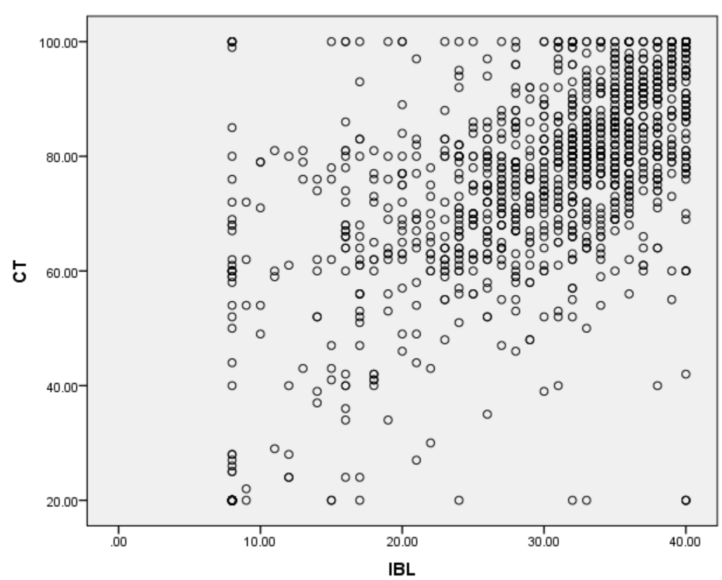


Figure 4..5 Scatterplot shows a strong relationship between better implementation of IBL activities and the application of CT skills

4.2.4. level of variance in students' responses in different locations

The Levene's test data presented in Table 4.16 shows that the significant level for students' responses to IBL items is <0.05 which means that the results must consider that equality of variances cannot be assumed (Cohen, Manion and Morrison 2007). Therefore, multiple comparison of students' responses in different campuses was performed, all the mean differences between campuses was not significant except for the mean difference between AUH-B and Al-Ain AQB in addition AUH-B and Sharjah. The F value in Table 4.17 represents the ratio of the variance between groups to the variance within each group. When the F value < 1, this means that the variance between groups is less than the variance within the groups. However, when F value > 1 this means that the variance between groups is more than the variance within each group for each of the listed items (Cohen, Manion and Morrison 2007).

Table 4.16 Variance in students' responses to IBL items in different locations

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
IBL	7.33	10	1319	0.00

Table 4 17 The Multiple Comparisons students' responses to IBL in different locations

	IBL						
(I) Campus			Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Tukey HSD	AUH B	AUH G	-2.93	1.34260276	0.519	-7.26	1.40
		TBMEC	-2.04	1.246381785	0.865	-6.06	1.97
		AQB	-3.91	1.161472095	0.031	-7.66	-0.17
		WR G & B	-2.80	1.780265753	0.893	-8.54	2.94
		DXB	-3.19	1.157027906	0.176	-6.92	0.54
		SHJ	-6.25	1.703771814	0.011	-11.74	-0.76
		AJM	-3.32	1.136831884	0.117	-6.99	0.34
		UAQ B & G	-3.90	1.945998188	0.645	-10.18	2.37
		RAK	-2.46	1.17934349	0.589	-6.26	1.35
		FUJ	-2.77	1.34260276	0.604	-7.10	1.56
	AUH G	AUH B	2.93	1.34260276	0.519	-1.40	7.26
		TBMEC	0.88	1.222574211	1.000	-3.06	4.82
		AQB	-0.99	1.13588625	0.999	-4.65	2.67
		WR G & B	0.13	1.76367976	1.000	-5.56	5.81
		DXB	-0.26	1.131341558	1.000	-3.91	3.39

		SHJ	-3.32	1.686433676	0.669	-8.76	2.11
		AJM	-0.40	1.110678567	1.000	-3.98	3.18
		UAQ B & G	-0.98	1.930836371	1.000	-7.20	5.25
		RAK	0.47	1.154153896	1.000	-3.25	4.19
		FUJ	0.16	1.320531074	1.000	-4.10	4.42
		AUH B	2.04	1.246381785	0.865	-1.97	6.06
		AUH G	-0.88	1.222574211	1.000	-4.82	3.06
		AQB	-1.87	1.020354329	0.759	-5.16	1.42
		WR G & B	-0.76	1.691582596	1.000	-6.21	4.70
		DXB	-1.15	1.01529262	0.989	-4.42	2.13
		SHJ	-4.21	1.610882965	0.244	-9.40	0.99
		AJM	-1.28	0.992215835	0.971	-4.48	1.92
		UAQ B & G	-1.86	1.865211644	0.996	-7.87	4.15
		RAK	-0.41	1.040652006	1.000	-3.77	2.94
	TBMEC	FUJ	-0.72	1.222574211	1.000	-4.67	3.22
		AUH B	3.92	1.161472095	0.031	0.17	7.66
		AUH G	0.99	1.13588625	0.999	-2.67	4.65
		TBMEC	1.87	1.020354329	0.759	-1.42	5.16
		WR G & B	1.12	1.630031151	1.000	-4.14	6.37
		DXB	0.73	0.909048391	0.999	-2.20	3.66
		SHJ	-2.33	1.546122181	0.917	-7.32	2.65
		AJM	0.59	0.883199941	1.000	-2.25	3.44
		UAQ B & G	0.01	1.809575737	1.000	-5.82	5.85
		RAK	1.46	0.93728676	0.900	-1.56	4.48
	AQB	FUJ	1.15	1.13588625	0.995	-2.51	4.81
		AUH B	2.80	1.780265753	0.893	-2.94	8.54
		AUH G	-0.13	1.76367976	1.000	-5.81	5.56
		TBMEC	0.76	1.691582596	1.000	-4.70	6.21
		AQB	-1.12	1.630031151	1.000	-6.37	4.14
		DXB	-0.39	1.62686745	1.000	-5.63	4.86
		SHJ	-3.45	2.052028879	0.845	-10.07	3.17
		AJM	-0.52	1.612566544	1.000	-5.72	4.68
		UAQ B & G	-1.10	2.257186982	1.000	-8.38	6.18
		RAK	0.34	1.642813195	1.000	-4.95	5.64
	WR G & B	FUJ	0.03	1.76367976	1.000	-5.65	5.72
		AUH B	3.19	1.157027906	0.176	-0.54	6.92
		AUH G	0.26	1.131341558	1.000	-3.39	3.91
		TBMEC	1.15	1.01529262	0.989	-2.13	4.42
		AQB	-0.73	0.909048391	0.999	-3.66	2.20
		WR G & B	0.39	1.62686745	1.000	-4.86	5.63
		SHJ	-3.06	1.542786422	0.660	-8.04	1.91
		AJM	-0.13	0.877347299	1.000	-2.96	2.69
		UAQ B & G	-0.71	1.806726459	1.000	-6.54	5.11
		RAK	0.73	0.931773909	0.999	-2.27	3.74
	DXB	FUJ	0.42	1.131341558	1.000	-3.23	4.07
		AUH B	6.25	1.703771814	0.011	0.76	11.74
		AUH G	3.32	1.686433676	0.669	-2.11	8.76
		TBMEC	4.21	1.610882965	0.244	-0.99	9.40
		AQB	2.33	1.546122181	0.917	-2.65	7.32
		WR G & B	3.45	2.052028879	0.845	-3.17	10.07
		DXB	3.06	1.542786422	0.660	-1.91	8.04
		AJM	2.93	1.52769863	0.707	-2.00	7.85
		UAQ B & G	2.35	2.197358714	0.993	-4.74	9.43
		RAK	3.79	1.559592075	0.347	-1.24	8.82
	SHJ	FUJ	3.48	1.686433676	0.603	-1.96	8.92
		AUH B	3.32	1.136831884	0.117	-0.34	6.99
		AUH G	0.40	1.110678567	1.000	-3.18	3.98
		TBMEC	1.28	0.992215835	0.971	-1.92	4.48
	AJM	AQB	-0.59	0.883199941	1.000	-3.44	2.25

		WR G & B	0.52	1.612566544	1.000	-4.68	5.72
		DXB	0.13	0.877347299	1.000	-2.69	2.96
		SHJ	-2.93	1.52769863	0.707	-7.85	2.00
		UAQ B & G	-0.58	1.793859988	1.000	-6.36	5.20
		RAK	0.87	0.906573647	0.997	-2.06	3.79
		FUJ	0.55	1.110678567	1.000	-3.03	4.14
	UAQ B & G	AUH B	3.90	1.945998188	0.645	-2.37	10.18
		AUH G	0.98	1.930836371	1.000	-5.25	7.20
		TBMEC	1.86	1.865211644	0.996	-4.15	7.87
		AQB	-0.01	1.809575737	1.000	-5.85	5.82
		WR G & B	1.10	2.257186982	1.000	-6.18	8.38
		DXB	0.71	1.806726459	1.000	-5.11	6.54
		SHJ	-2.35	2.197358714	0.993	-9.43	4.74
		AJM	0.58	1.793859988	1.000	-5.20	6.36
		RAK	1.45	1.821098018	0.999	-4.43	7.32
		FUJ	1.13	1.930836371	1.000	-5.09	7.36
	RAK	AUH B	2.46	1.17934349	0.589	-1.35	6.26
		AUH G	-0.47	1.154153896	1.000	-4.19	3.25
		TBMEC	0.41	1.040652006	1.000	-2.94	3.77
		AQB	-1.46	0.93728676	0.900	-4.48	1.56
		WR G & B	-0.34	1.642813195	1.000	-5.64	4.95
		DXB	-0.73	0.931773909	0.999	-3.74	2.27
		SHJ	-3.79	1.559592075	0.347	-8.82	1.24
		AJM	-0.87	0.906573647	0.997	-3.79	2.06
		UAQ B & G	-1.45	1.821098018	0.999	-7.32	4.43
		FUJ	-0.31	1.154153896	1.000	-4.03	3.41
	FUJ	AUH B	2.77	1.34260276	0.604	-1.56	7.10
		AUH G	-0.16	1.320531074	1.000	-4.42	4.10
		TBMEC	0.72	1.222574211	1.000	-3.22	4.67
		AQB	-1.15	1.13588625	0.995	-4.81	2.51
		WR G & B	-0.03	1.76367976	1.000	-5.72	5.65
		DXB	-0.42	1.131341558	1.000	-4.07	3.23
		SHJ	-3.48	1.686433676	0.603	-8.92	1.96
		AJM	-0.55	1.110678567	1.000	-4.14	3.03
		UAQ B & G	-1.13	1.930836371	1.000	-7.36	5.09
		RAK	0.31	1.154153896	1.000	-3.41	4.03

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

A comparison between mean scores and standard deviation of IBL and CT responses in different campuses is reported in appendix 3.

The Levene's test data presented in Table 4.18 shows that the significant level for students' responses to CT items is <0.05 which means that the results must consider that equality of variances cannot be assumed (Cohen, Manion and Morrison 2007). Therefore, multiple comparison of students' responses in different campuses was performed, the data is displayed in table 4.19. The mean difference data was not significant for CT in all the locations.

Table 4.18 Variance in students' responses to CT items in different locations

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
CT	5.71	10	1319	0.00

Table 4 19 The Multiple Comparisons students' responses to CT in different locations

	CT						
(I) Campus			Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	AUH B	AUH G	-4.6515671	2.8828915	0.8767066	-13.9470297	4.643895455
		TBMEC	-3.6861536	2.6762819	0.9538099	-12.3154337	4.943126483
		AQB	-7.4124390	2.4939603	0.1026561	-15.4538498	0.628971844
		WR G & B	-4.3209839	3.8226593	0.9888832	-16.6465907	8.004622872
		DXB	-4.6604860	2.4844176	0.7331674	-12.6711276	3.350155686
		SHJ	-9.4355270	3.6584084	0.2606883	-21.2315307	2.36047669
		AJM	-7.5573819	2.4410519	0.0729348	-15.4281971	0.313433343
		UAQ B & G	-10.0693530	4.1785268	0.3609402	-23.5424024	3.403696447
		RAK	-3.9775905	2.5323345	0.8944327	-12.1427333	4.187552303
		FUJ	-0.8094619	2.8828915	1.0000000	-10.1049244	8.486000718
	AUH G	AUH B	4.6515671	2.8828915	0.8767066	-4.6438955	13.9470297
		TBMEC	0.9654135	2.6251613	0.9999996	-7.4990356	9.429862707
		AQB	-2.7608719	2.4390214	0.9887621	-10.6251400	5.103396277
		WR G & B	0.3305832	3.7870452	1.0000000	-11.8801910	12.54135746
		DXB	-0.0089188	2.4292628	1.0000000	-7.8417220	7.82388429
		SHJ	-4.7839599	3.6211793	0.9652241	-16.4599236	6.892003821
		AJM	-2.9058148	2.3848944	0.9804745	-10.5955584	4.7839289
		UAQ B & G	-5.4177858	4.1459707	0.9677665	-18.7858630	7.95029127
		RAK	0.6739766	2.4782464	1.0000000	-7.3167669	8.664720157
		FUJ	3.8421053	2.8354983	0.9586290	-5.3005448	12.9847553
	TBMEC	AUH B	3.6861536	2.6762819	0.9538099	-4.9431265	12.31543366
		AUH G	-0.9654135	2.6251613	0.9999996	-9.4298627	7.49903564
		AQB	-3.7262854	2.1909465	0.8353386	-10.7906724	3.338101586
		WR G & B	-0.6348303	3.6322352	1.0000000	-12.3464424	11.07678177
		DXB	-0.9743324	2.1800778	0.9999971	-8.0036748	6.05501005
		SHJ	-5.7493734	3.4589537	0.8544867	-16.9022645	5.403517619
		AJM	-3.8712283	2.1305264	0.7700559	-10.7407994	2.998342841
		UAQ B & G	-6.3831994	4.0050586	0.8850894	-19.2969260	6.530527263
		RAK	-0.2914369	2.2345305	1.0000000	-7.4963542	6.913480319
		FUJ	2.8766917	2.6251613	0.9912569	-5.5877574	11.3411409
	AQB	AUH B	7.4124390	2.4939603	0.1026561	-0.6289718	15.45384984
		AUH G	2.7608719	2.4390214	0.9887621	-5.1033963	10.62514003
		TBMEC	3.7262854	2.1909465	0.8353386	-3.3381016	10.79067241
		WR G & B	3.0914551	3.5000695	0.9985045	-8.1940077	14.37691793
		DXB	2.7519530	1.9519458	0.9460908	-3.5418113	9.045717309
		SHJ	-2.0230880	3.3198967	0.9999460	-12.7276101	8.681434041
		AJM	-0.1449429	1.8964430	1.0000000	-6.2597463	5.969860577
		UAQ B & G	-2.6569140	3.8855949	0.9998443	-15.1854474	9.871619449
		RAK	3.4348485	2.0125804	0.8322830	-3.0544231	9.924120115
		FUJ	6.6029771	2.4390214	0.1975711	-1.2612910	14.46724529
	WR G & B	AUH B	4.3209839	3.8226593	0.9888832	-8.0046229	16.64659068
		AUH G	-0.3305832	3.7870452	1.0000000	-12.5413575	11.88019103

		TBMEC	0.6348303	3.6322352	1.0000000	-11.0767818	12.34644241
		AQB	-3.0914551	3.5000695	0.9985045	-14.3769179	8.194007749
		DXB	-0.3395021	3.4932762	1.0000000	-11.6030611	10.92405701
		SHJ	-5.1145431	4.4062002	0.9863929	-19.3216923	9.092606027
		AJM	-3.2363980	3.4625688	0.9975877	-14.4009452	7.928149285
		UAQ B & G	-5.7483691	4.8467241	0.9840038	-21.3759230	9.87918493
		RAK	0.3433934	3.5275156	1.0000000	-11.0305655	11.71735226
		FUJ	3.5115220	3.7870452	0.9977438	-8.6992522	15.7222963
	DXB	AUH B	4.6604860	2.4844176	0.7331674	-3.3501557	12.67112762
		AUH G	0.0089188	2.4292628	1.0000000	-7.8238843	7.841721988
		TBMEC	0.9743324	2.1800778	0.9999971	-6.0550101	8.003674816
		AQB	-2.7519530	1.9519458	0.9460908	-9.0457173	3.541811254
		WR G & B	0.3395021	3.4932762	1.0000000	-10.9240570	11.60306113
		SHJ	-4.7750411	3.3127340	0.9377594	-15.4564681	5.906386009
		AJM	-2.8968959	1.8838760	0.9069370	-8.9711788	3.177386991
		UAQ B & G	-5.4088670	3.8794769	0.9499075	-17.9176735	7.099939541
		RAK	0.6828955	2.0007430	0.9999998	-5.7682081	7.13399906
		FUJ	3.8510241	2.4292628	0.8885985	-3.9817790	11.68382725
	SHJ	AUH B	9.4355270	3.6584084	0.2606883	-2.3604767	21.23153073
		AUH G	4.7839599	3.6211793	0.9652241	-6.8920038	16.45992362
		TBMEC	5.7493734	3.4589537	0.8544867	-5.4035176	16.90226449
		AQB	2.0230880	3.3198967	0.9999460	-8.6814340	12.72761009
		WR G & B	5.1145431	4.4062002	0.9863929	-9.0926060	19.32169226
		DXB	4.7750411	3.3127340	0.9377594	-5.9063860	15.45646811
		AJM	1.8781451	3.2803369	0.9999698	-8.6988221	12.45511241
		UAQ B & G	-0.6338259	4.7182584	1.0000000	-15.8471610	14.57950915
		RAK	5.4579365	3.3488198	0.8695059	-5.3398439	16.2557169
		FUJ	8.6260652	3.6211793	0.3789220	-3.0498986	20.30202888
	AJM	AUH B	7.5573819	2.4410519	0.0729348	-0.3134333	15.42819709
		AUH G	2.9058148	2.3848944	0.9804745	-4.7839289	10.59555841
		TBMEC	3.8712283	2.1305264	0.7700559	-2.9983428	10.74079942
		AQB	0.1449429	1.8964430	1.0000000	-5.9698606	6.259746335
		WR G & B	3.2363980	3.4625688	0.9975877	-7.9281493	14.40094523
		DXB	2.8968959	1.8838760	0.9069370	-3.1773870	8.971178804
		SHJ	-1.8781451	3.2803369	0.9999698	-12.4551124	8.69882212
		UAQ B & G	-2.5119711	3.8518494	0.9998990	-14.9316971	9.907754892
		RAK	3.5797914	1.9466320	0.7565770	-2.6968391	9.856421843
		FUJ	6.7479200	2.3848944	0.1480268	-0.9418236	14.43766367
	UAQ B & G	AUH B	10.0693530	4.1785268	0.3609402	-3.4036964	23.54240238
		AUH G	5.4177858	4.1459707	0.9677665	-7.9502913	18.78586296
		TBMEC	6.3831994	4.0050586	0.8850894	-6.5305273	19.29692602
		AQB	2.6569140	3.8855949	0.9998443	-9.8716194	15.18544738
		WR G & B	5.7483691	4.8467241	0.9840038	-9.8791849	21.37592305
		DXB	5.4088670	3.8794769	0.9499075	-7.0999395	17.91767353
		SHJ	0.6338259	4.7182584	1.0000000	-14.5795092	15.84716104
		AJM	2.5119711	3.8518494	0.9998990	-9.9077549	14.93169707
		RAK	6.0917625	3.9103361	0.8994271	-6.5165451	18.70006997
		FUJ	9.2598911	4.1459707	0.4812014	-4.1081860	22.62796822
	RAK	AUH B	3.9775905	2.5323345	0.8944327	-4.1875523	12.14273333
		AUH G	-0.6739766	2.4782464	1.0000000	-8.6647202	7.316766941
		TBMEC	0.2914369	2.2345305	1.0000000	-6.9134803	7.49635417
		AQB	-3.4348485	2.0125804	0.8322830	-9.9241201	3.054423145

		WR G & B	-0.3433934	3.5275156	1.0000000	-11.7173523	11.03056548
		DXB	-0.6828955	2.0007430	0.9999998	-7.1339991	5.768208146
		SHJ	-5.4579365	3.3488198	0.8695059	-16.2557169	5.339843889
		AJM	-3.5797914	1.9466320	0.7565770	-9.8564218	2.696839116
		UAQ B & G	-6.0917625	3.9103361	0.8994271	-18.7000700	6.516545064
		FUJ	3.1681287	2.4782464	0.9723838	-4.8226149	11.1588722
	FUJ	AUH B	0.8094619	2.8828915	1.0000000	-8.4860007	10.10492443
		AUH G	-3.8421053	2.8354983	0.9586290	-12.9847553	5.300544778
		TBMEC	-2.8766917	2.6251613	0.9912569	-11.3411409	5.587757444
		AQB	-6.6029771	2.4390214	0.1975711	-14.4672453	1.261291014
		WR G & B	-3.5115220	3.7870452	0.9977438	-15.7222963	8.699252199
		DXB	-3.8510241	2.4292628	0.8885985	-11.6838273	3.981779027
		SHJ	-8.6260652	3.6211793	0.3789220	-20.3020289	3.049898558
		AJM	-6.7479200	2.3848944	0.1480268	-14.4376637	0.941823637
		UAQ B & G	-9.2598911	4.1459707	0.4812014	-22.6279682	4.108186007
		RAK	-3.1681287	2.4782464	0.9723838	-11.1588722	4.822614894

4.4 Qualitative results

Data collected from lesson observations, interviews with teachers and document analysis of samples of students' artefacts and the summative assessment all comprise the qualitative results. The data collected from the qualitative tools answer two research questions:

- To what extent do students develop critical thinking skills through the use of high school biology IBL activities in UAE?
- What are the high school biology teachers' perceptions on the use of IBL and development of CT?

The total number of students observed during classroom visits was 281, the classroom visits were conducted over one month, and the researcher was observing 4 to 5 lessons every week. Then through follow-up communication with the observed teachers, the students' artefacts samples were collected. In total, 23 samples of formative assessment artefacts were collected. In addition to 28 summative assessment samples related to the topics that were explained in the observed lessons.

4.4.1 Lesson observations

The lesson observation form used in this study included four main sections: a check-list with comments that report observations regarding the utilization of CT skills in IBL instructions, a check-list with comments to record interactions in the classroom, a section to record the type and frequency of CT questions utilized in class discussions and a final section that summarizes the best practices and areas of improvement in the observed classes. The form was designed to collect data related to actual teaching practices and interactions among students and between teachers and students in the classroom.

A total of 12 lessons were observed during January, the first month of term two, 11 of which were 45 minutes long, and one 90-minute-long lesson taking place in the Abu Dhabi school for the volunteer teacher (AUHG-L). An equal amount of male and female classes was observed, one lesson per teacher. In addition, 6 lesson observations were conducted for Grade 9 and 6 observations for Grade 10.

The participant teachers were previously informed to conduct a lesson that includes IBL activities, as the study is specifically investigating the effect of IBL activities on the development of students' CT skills.

The general outline of the all the lessons observed included an orientation or introduction to the main topic to be discussed, and the expected learning outcomes form the lesson. Then learning activities were implemented to achieve the lesson objectives, and finally assessment practices were performed to evaluate students' understanding.

Despite that all the lessons observed were required to show IBL instructions, not all the teachers were able to successfully plan and implement IBL activities. Consequently, they presented various instructional practices that varied from a totally teacher-centred approach to open inquiry lessons. the IBL activities observed per teacher are listed in table 4.20 below and indicates if the activity observed was an IBL activity or not with justification.

Table 4.20 IBL activities observed

Volunteer teacher	Topic	IBL activity present	Justification
1-AQB-S	Cancer	Guided IBL activity	Students asked a question, researched, discussed solutions and presented results.
2-AQB-D	Plant transport	Structured IBL	Questions proposed by the teacher and students research, discussed and presented solutions.
3-AQB-G	Mendel Genetic	Not IBL activity	The worksheet solved didn't include actual research
4-AQB-M	Cancer	Guided IBL activity	Students followed given steps to answer questions, analyse data and communicate results
5-AUHB-S	Roots	Not IBL activity	The worksheet solved didn't include actual research
6-AUHB-H	Chromosomes	Not IBL activity	The worksheet solved didn't include actual research
7-AUHB-M	Stem	Guided IBL activity	Students asked a question, researched, discussed solutions and presented results.
8-AUHG-L	Mitosis	Guided IBL activity	Students were required to answer given questions and make a video to explain the process
9-AUHG-R	Leaves	Open IBL activity	The students investigated the effect of environmental factors on the number of open stomata in the leaves.
10-AUHG-NI	Mitosis	Guided IBL activity	Students were required to answer given questions and make a video to explain the process
11-AUHG-NO	Roots	Structured IBL	Questions were proposed by the teacher and students researched, discussed and presented solutions.
12-DXB-I	Leaves	Structured IBL	Questions were proposed by the teacher and students researched, analysed data, discussed and presented solutions.

The number of students in each lesson ranged between 17 students in the AUH-L grade 9 lesson to 33 students in the AUH-B-S lesson. The general layout of the classes visited was based on grouping students into groups of 4 or 5, depending on the total number of students in the class. Students were given various opportunities to work collaboratively to perform tasks in the observed lessons. However, the activities implemented ranged in terms of the autonomy and independence of the students, where some were simple like directly solving a given worksheet, or giving students the opportunity to discuss questions in a provided task, asking them to prepare a presentation or sometimes included something complex like undertaking a complete inquiry-based learning investigation.

Utilization of critical thinking skills in IBL

The first section of the lesson observation form reported the teaching practices and actions that reflected the implementation of the inquiry cycle, including orientation, conceptualization, data collection, data analysis and drawing conclusions. It also reported the practices that show the application of CT skills during class discussions and students' reflections on their learning experience. Table 4.21 summarizes the frequency at which each of the items was observed during the 12 lessons.

Table 4.-21 Frequency of IBL and CT practices in the 12 lessons observed

		frequency in the lessons observed	
Utilization of critical thinking skills in IBL	**Inquiry implementation**	**YES**	**NO**
	Orientation	12	0
	Conceptualization (Raise and pursue significant questions, hypothesis,)	9	3
	Investigation (Exploration, experimentation)	9	3
	Data collection and organization	10	2
	Data analysis	3	9
	Conclusion (Generate and assess solutions)	9	3
	Discussion (Make arguments, interpretations, beliefs, or theories, and their implications)	8	4

	Reflection (Think precisely about thinking, using critical thinking vocabulary)	5	7
	Assessment of Inquiry Cycles		
	Questioning strategies allow students time to process information and formulate appropriate responses	11	1
	Note-taking supports understanding of objectives and represents synthesis of learning	12	0
	Inquiry cycles are assessed frequently after each step	5	7
	Develop and use valid criteria for evaluation (i.e. rubrics) are clearly communicated and understood by students	1	11

The teachers introduced a new concept or the inquiry activity that was supposed to take place in the classroom. Nine teachers introduced the lesson through direct instructions and three teachers began their lesson with an interactive activity that required students to have a certain role in the learning process. Conceptualization through raising questions or formulating a hypothesis was observed in nine lessons. Students were guided to raise questions in three of the lessons observed, while questions were raised by teachers in the other six.

Example 1 (AQB-S): The lesson is about cancer for grade 9. For the orientation, the teacher displayed photos of celebrities who were diagnosed with cancer, and asked students about their disease and what they know about it, as an introductory activity for the lesson about uncontrolled cell division. Then, for the conceptualization students were guided to work collaboratively to discuss what they want to know about the disease. They were asked to come up with a question about cancer. However, the questions written by the students were not discussed to decide if the question can be scientifically investigated or not, e.g. How does cancer start? and why do cancer cells divide faster than normal cells?

Example 2 (AQB-D): The lesson was about the relation between plant parts and their functions. In the orientation stage, the teacher started with a brainstorming activity *and asked students to record any word that might be associated with water movement from roots to leaves. For the conceptualization stage, students were divided into three large groups and each group was given a task to investigate a question provided by the teacher. The three questions were: 1- How do transpiration and root pressure affect water movement? 2- Explain what cohesion and adhesion are and how they impact water movement in plants. 3- What is capillary action and how does the structure of the xylem affect water movement? These questions were then answered by the three groups of students as part of the orientation stage of IBL activity.*

Investigation was also required in nine of the observed lessons. In seven lessons, investigation was applied in the form of research and exploring the information related to the proposed research question. The other two lesson investigations were observed in the form of scientific experiments using laboratory tools.

Example 1 (AUHB-M): In grade 10 biology lessons about plant stems, students were directed to research or design an experiment to answer questions that they developed about the topic. The students worked collaboratively to perform the inquiry steps. However, no clear procedure or plan for investigation or experimentation was identified during the class observation. In addition, the tools provided in the classroom were not sufficient to perform a scientific investigation. A sample of students' notes taken during the lesson is shown in figure 4.6.

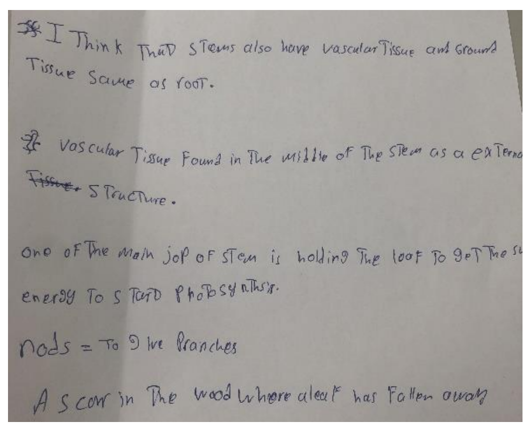


Figure 4.6 Sample of students notes in AUHB-M observation

Example 2 (DXB-I): In a Grade 10 lesson about plant adaptations, as part of the lesson, a single activity in which students were required to investigate a question and present information to the class. Three plant samples were illustrated, and students were given 5 minutes to research through the internet and find out how the three plants adapted to live in a specific environment, students then complied the information needed and communicated their findings to the classroom..

Example 3 (AUHG-R): During the open inquiry lesson about stomata in plant leaves, the students used lab tools to investigate the answer of their proposed question, they were given a guideline to prepare microscopic slides and count the number of stomata pores in the slide. Different groups in the class had different questions, one group for example investigated the effect of water availability on the number of opened stomata in the leaf. The students were able to identify the dependent and independent variables in addition to the procedure that they will follow. Figure 4.7 shows the experimental design prepared by the students during the lab.

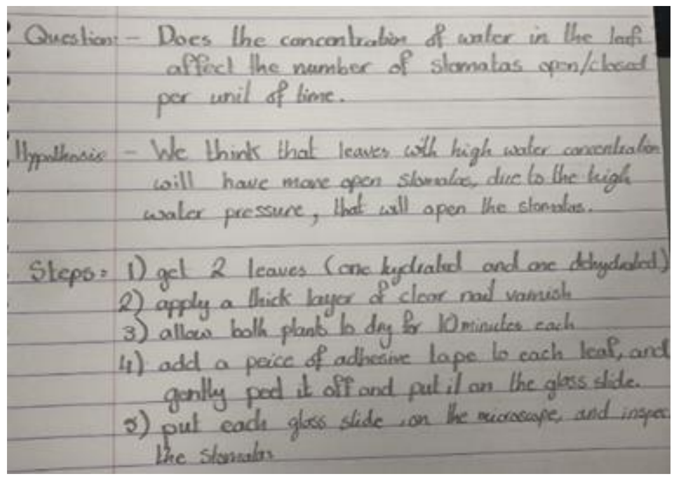


Figure 4.7 Students' notes during open inquiry lesson

Data collection, organization and drawing conclusions were also observed in most of the classes. However, a common issue was also identified, where students were not asked to analyze the collected data. With the exception of the open inquiry lesson observed in the laboratory, the students in all other lessons were compiling data and presenting them without any kind of further analysis.

Example 1 (AQB-S): In the grade 9 lesson about cancer, students were asked to organize their findings and create a presentation to discuss them. The presented data was compiled from external resources, the discussion within groups was to complete the task. Students were observed copying information form the resources, some students were questioning the information and confirming any findings from the web.

Example 2 (AQB-M): In the Grade 9 lesson about regulating the cell cycle, the teacher provided guided inquiry worksheets in which each group of students had assigned questions. Students were asked to investigate their questions and provide detailed answers and prepare themselves to explain it to their classmates. Students were searching the web to find the answers for the sequenced questions provided. They collected facts to answer their assigned questions. Only one group was asked to analyze given data and draw a conclusion about monitoring the cell cycle to prevent cancer. The groups compiled all their findings and were asked to add their own thoughts. The students in the group responsible for the analysis question were required to link between their previous knowledge and the data provided to provide a detailed explanation. At the end of the activity, group leaders were asked to present their findings to the class. The teacher initiated a discussion about the presented results with all the groups and asked them "why", "how" and "what" questions to help them to evaluate their own work.

In the discussion stage during the IBL activities observed, it was evident that teachers utilized questions that encouraged students to use higher cognitive skills in eight of the observed lessons. This was recorded mainly when students were asked to present their findings to their classmates. However, the reflection stage was observed only in five lessons, in which teachers asked the students to describe their learning experiences. Generally, various questioning strategies and note-taking practices were observed in most of the lessons, whereas assessing inquiry cycles and sharing specific rubrics were observed only in one class.

Example 1 (AQB-S): at the end of the lesson, students were asked to reflect on their learning experiences. They were guided to answer questions such as: "Today I discovered what I could do better". The teacher initiated a discussion on utilizing interpretation questions for each group to help them think deeper about the information they learned. This activity was assessed at the end of the lesson using specific rubrics that were shared with the students. The rubrics helped the students form a clear idea about the expected outcome, thus, prepare their task according to the rubrics and also evaluate each other's work based on the rubrics.

Example 2 (AUHB-S): During the Grade 10 lesson about plant tissues, the task was to answer a guided worksheet collaboratively. The level of discussion observed within groups was at the comprehension level, the teacher's guidance during group work was limited. Students were using notes to record their answers. This lesson included answering worksheet questions in which the students used their textbooks as a resource to find the answers without actual research. Although rubrics were not discussed with the students, the teacher specified that the group that gets all the answers correct and is able to demonstrate collaboration will be awarded at the end of the lesson.

The data collected from lesson observations provided the required information to answer the research question related to the implementation of IBL strategies and how it affects the development of CT skills. The listed examples provided an evidence for social learning activities such as collaboration between classmates, guidance from the teacher to facilitate learning, class discussion and opportunities for students to reflect upon their understanding. Results show that students apply IBL in biology lessons, however, they do not perform appropriate data analysis and are not assessed after each inquiry stage.

Interactions in the classroom

The second section of the lesson observation form included items related to classroom interactions, including the teaching practices that encourage students to engage in cooperative learning activities, acquire independent thinking and decision-making skills and enforce the development of CT skills. and the students' interaction with their colleagues to discuss the questions related to the topic. Table 4.22 shows the frequency at which the items related to teacher-student interactions were observed in the 12 lessons.

Table 0-22 Frequency in which teacher-student interactions related to CT development were observed

		Frequency in the lessons observed	
Interactions in the classroom	**Students' Interactions**	**YES**	**NO**
	Classroom routines are established and facilitate cooperative learning	11	1
	Students are encouraged to think independently and develop intellectual courage	10	2
	Students are encouraged to suspend judgment or prior conceptions	10	2
	Teacher's students' Interactions		
	Teachers utilize various processes to resolve, re-address, and re-analyze complex situations to gain new insight	11	1
	Teachers lead discussions to analyze arguments, interpretations, beliefs, or theories, and their implications	6	6

	Teachers lead discussions to help students to explore how egocentricity and sociocentric affect feeling, thought and behaviour	0	12
	Feedback is constructive and specific, help students to identify strengths and weakness points	11	1

The majority of the observed classes satisfied the three attributes related to students' interactions including: "Classroom routines are established and facilitate cooperative learning, Students are encouraged to think independently and develop intellectual courage, Students are encouraged to suspend judgment or prior conceptions" This indicated that students were trained to work collaboratively, guided through the correct thinking process, and encouraged to learn independently, think deeply and make decisions.

Example 1 (AQB-M): Collaborative learning was established in the classroom environment. During the last part of the activity, students were given the opportunity to reflect on their understanding and discuss their opinions. The general flow of the lesson encouraged students to investigate facts, gain good understanding and then make judgements.

Example 2 (AUHG-L): Grade 9 students were asked to produce a video to explain the process of mitosis and cytokinesis. The observer can easily recognize that students are trained to work in collaborative groups. In addition, students were discussing, researching and trying to explain the concepts independently, while the teacher's role was to observe students' interactions. During the first task, students did not ask for her help as they write their own notes. The teacher was asking the students about the consequences of their selections and how each selection would help them complete *the activity. The teacher's questions were guiding students to adjust their thinking process and correct their design.*

In most of the classes observed, the teachers encouraged students to interpret questions. They were able to identify learning gaps and guide students to reach the correct answers and avoid misconceptions. However, the teachers utilized questioning techniques to encourage students to apply CT skills in only half of the observed lessons. Although the observed discussions didn't help students explore personal and social effects of the discussed concepts, a constructive feedback was provided to the students in most of the observed lessons.

Example 1 (AQB-M): during collaborative work, the teacher passed by each group and explained the main task required from them. The teacher's role in leading the discussions to analyze students' thoughts and question interpretation during the group work and the discussion with the class as one group. He asked each group leader to justify the presented answer and explain how the group reached the presented conclusion. The feedback that was provided for the students during the group work helped the students to understand the concepts that they are explaining.

Example 2 (DXB-I): during class discussion, the teacher never provided a direct answer to the students, he was always returning the question to the students. This was encouraging students to collaborate and volunteer to answer in a safe environment as the teacher did not blame them for making mistakes. The students were able to get the correct descriptions by collaborating with each other. In this lesson the teacher assigned homework based on students' mistakes in the quiz to review the main concepts they missed.

The data collected from this section of the lesson observation form provided the required information to answer the research question about students' development of critical thinking skills through the use of high school biology IBL activities.

Type and frequency of the use of CT questions

The third section of the lesson observation reported the type and number of CT questions asked in the observed lessons. Based on the check-list used, a total of 150 questions were recorded in 13 periods (45 minutes), the lessons were then classified into five groups according to the frequency of the use of CT questions in the lesson, the results as shown in Table 4.23, indicate that the use of CT questioning in the classroom is limited as it is evident that CT questions were recorded more than 20 times throughout the 45 minutes only in one of the lessons observed. In 50% of the observed classes CT questions were rarely raised.

Table 4-23 Number of CT question in the observed lessons

Number of CT questions recorded in 45 minutes	Number of the observed lessons
1-5	3
6-10	3
11-15	2
16-20	3
More than 20	1

The type of CT questions was determined based on the categorization provided by Facione (2015) including interpretation, analysis, inference, evaluation, explanation and self-regulation. Table 4.22 shows the percentage distribution of the types of CT question that were recorded in the observed lessons. The result shows that 60% of the CT questions that were asked in the classroom are interpretation questions that help students to clarify their understanding of the concepts. This data helps relate between the application of IBL activities and the use of CT questions. The results show that the discussion in the classroom during IBL instructions focused on interpretation skills.

Yet, it also lacked in practice on analysis, inference, evaluation, explanation and self-regulation skills.

Table 4.24 Types of CT question that were recorded in the observed lessons

Type of CT question	Average percentage in the observed lessons
Interpretation	60.7
Analysis	16.7
Inference	8
Evaluation	1.3
Explanation	4
Self-regulation	9.3

Best practices and areas of improvement

The fourth section of the lesson observation form reported the best practices and areas of improvement in the observed lessons. Some common best practices observed included utilizing questioning techniques to initiate discussion, giving the students opportunities to contribute in class discussions and gain a deeper understanding of the concepts discussed. Other good practices were hardly observed, such as providing rubrics for students to evaluate their classmates' work, and good time management that allowed students to complete all inquiry stages with self-reflection.

Example 1(DXB-I): the teacher was utilizing questioning techniques to begin discussions; he used probing questions and was always redirecting the questions for other students until the idea is clarified. In the activity related to ways in which plants are adapted to their environment, the students were given the opportunity to present their findings, the teacher guided further discussion to help students interpret information and conclude how each plant adapted to its environment.

Example 2 (AQB-S): The teacher shared specific assessment rubrics, explained how they are used and gave the students an opportunity to evaluate the presentations of the other groups. This allowed students to identify the strength points and the areas of *improvements in their own presentations, as they were able to identify what should be adjusted in their activity.*

Identified areas of improvement included the need to discuss the type of questions asked by students and ensure that they are proposing investigative questions. Sharing rubrics before each inquiry activity helped students identify the expectations of the activity and assess their own performance. They also included increasing check points to discuss and assess students after each distinct inquiry stage and providing more opportunities for students to reflect upon their understanding and evaluate their own performance and poor utilization of questioning within the instructions to guide students to deeper thinking.

Example 1 (AUHB-S): The lesson was about specialized plant tissues; the students were given a task to answer worksheet questions in groups; the discussion among the groups was basic. In general, the practice was that one student finds the answers and the others were only copying. The correct answers were directly shared with the students without further discussion to identify the cause of the mistake.

Example 2 (AUHG-L): The lesson was about mitosis; students were required to create a video and explain the process of the cell cycle including mitosis and cytokinesis. The students were given a long time to complete the task without positioning consistent checkpoints to evaluate students' progress and ensure the completion of the task on time. A 90-minute block ended before the completion of the task. In addition, students were not given clear rubrics at the beginning of the task, so they were not clear about what was expected of them by the end of the class. In the same class another example of self-regulation was observed. The teacher was asking students about the *consequences of their selections and how they decisions would help them to complete the task, her questions were guiding students to correct their thinking process and adjust their design.*

Table 4.23 below summarized the key findings from lesson observations.

Table 4.23 Key findings from lesson observations

Lesson observation themes	Key finding
Inquiry implementation	Two main types of inquiry implementation were recognized: - Short guided inquiry activity as a part of the lesson - Long open inquiry activity as a practical scientific investigation In the case of the short-guided inquiry activity, students were not given an opportunity to complete the inquiry stages such as data analysis and self-reflection. However, when the lesson is planned as open inquiry, the students were required to do a practical activity, which allowed more opportunities to implement data analysis and self-reflection.
Assessment of Inquiry Cycles	In general, the teachers utilized questioning strategies and allowed students to participate in discussions. Yet, two main points were identified: - Fformative assessment after each inquiry step was not implemented in all the observed lessons - Specific assessment rubrics were not shared with students, which caused unclarity of the expectations.
Students' Interactions	In most of the observed lessons, classroom routines facilitate cooperative learning, students were encouraged by their teachers to interpret questions and utilize evidence before making decisions. Yet, in most cases discussions among the students in the groups were limited and aimed at obtaining direct knowledge.
Teacher's students' Interactions	In most of the lessons observed, the teachers provided effective feedback for their students and guided them to adjust their thinking. However, only half of the teachers were leading discussions to help students analyze their opinions and their implications.
Promoted CT skill	The frequency of using CT questions in the observed lessons was limited as the number of recorded CT questions in half of the classes observed was less than 10 questions in 45 minutes.

Strength	The best practices that were observed in most of the classes observed include: - utilizing questioning techniques to initiate discussion - redirecting the questions during class discussions
Areas of improvement	The areas of improvements identified included: - lack of specific rubrics for inquiry activities that ensure clarity of the expectations - lack of time management and the need to assign check points to follow up students' progress - Absence of systemic evaluation of each step of the inquiry activity - Poor utilization of CT practice questions that would help students to develop CT core skills

4.4.2 Interviews

The open-ended semi structured interview tool was used to conduct interviews with 13 biology teachers. Interview questions were divided into four main sections: demographic information about the interviewees, their current implementation of IBL instructions, their understanding of CT and their perceptions on the relation between IBL and students' CT development. The aim of using the interviews was to answer the second and third research questions

The interviewees participating in this part of the research were from four schools, two located in Abu Dhabi, one in Al Ain city and one in Dubai. The demographic information related to the participants is shown in Table 4.24 below.

Table 4-24 Demographic information related to volunteer teachers

Volunteer teacher	Gender	Years of Experience	Grade levels taught
1-AQB-S	Female	6	9
2-AQB-D	Female	7	10
3-AQB-G	Female	7	9, 10, 11 and 12
4-AQB-M	Male	11	10
5-AUHB-S	Female	12	9 and 10
6-AUHB-H	Female	18	9
7-AUHB-M	Female	8	9, 10 and 11
8-AUHG-L	Female	14	9, 11 and 12

9-AUHG-R	Female	13	10, 11 and 12
10-AUHG-NI	Female	5	9
11-AUHG-NO	Female	10	10
12-DXB-I	Male	12	9 and 10
13-DXB-C	Male	10	9, 10, 11 and 12

Inquiry-based learning

IBL activities implementation

The interviewees were all familiar with IBL instructions and the main inquiry cycles, as indicated by their responses where they mentioned that they were familiar with types of IBL activities and were using structured, guided and open inquiry based on their instructional needs. Teachers' responses to the question about the frequency of implementing IBL activities varied based on their students' academic level and their readiness to work independently in an IBL activity. In addition to the nature of the subject and how IBL activities can be integrated to the instructions. Most of the teachers agreed that IBL instructions can be applied as part of a lesson. According to the teachers, it is easy to ask students to investigate a single idea related to the topic and assign limited time to complete the task. This type of inquiry can be implemented in every biology lesson. However, planning a whole lesson as an inquiry investigation cannot be done more than once every two weeks in most cases. Even then, some teachers applied this type of inquiry only once in the first term. Teachers provided various responses related to how frequent they use IBL activities in their instructions, for example: one teacher commented that it depends on the grade level and the subject taught:

> *"It depends on the grade… which grade we are teaching and what topics we are teaching. But in average you can say that somehow if it is not fully done … but somehow in every lesson,*

> *we do a part of it, [for example, students are asked] to evaluate, to analyze, to do your [student's] own opinions. So somehow we are involving them in critical thinking" (AQB-M).*

Other responses related that to the required learning outcome and the designed tasks for each lesson:

> *"Say, probably may be once every two weeks, if that would be a big block of it. But apart from that in every class there is always kind of a moment where they're researching something, or they have to give their opinion back or feedback. So, there is an element of it every class" (AQB-D)*
>
> *"I apply IBL once every two weeks as a structured planned activity. As a question that should be answered using scientific method steps, it is implemented every lesson" (AUHB-S).*

One of the participant teachers thinks that there is no limit to the use of IBL as it is applicable in all biology lessons:

> *"I would say every lesson ... I think [it] is very important" DXB-I.*

Two participants related the implementation of IBL instructions to the students' level and the curriculum requirements.

> *"I believe that inquiry-based learning is integrated fully into our curriculum. And so, because of that we see quite a lot of inquiry-based learning. The nature of the KPI performance indicators lend themselves to students who would benefit from*

an inquiry approach. So, there's at least some element of inquiry-based learning in my biology lessons at least once a week or so every week" (DXB-C).

One of the teachers argued that sometimes an IBL activity would not be useful for students to achieve the required understanding, which requires them to explain the lesson again.

> *"I don't want to say '[a] waste [of] time' because it shouldn't be wasting time. But the problem is when you ask the girls to do things, they do it, but they don't know what it's for. And at the end of that they don't gain anything. And the problem is I will then have to go and chase and try to go and squeeze everything else into it which is what I find like the hardest" AUHG-L.*

Another teacher added that she is using inquiry more frequently with students in the advanced science program, as they are academically better than students in other classes, therefore it is easier to ask them to work independently to investigate a concept in every session.

> *"The frequency of using the activity ... is varying according to the course time per week. So, for some advanced program classes like an [Advanced Science Program] ASP inquiry is applied at least one time per session. So, if we are having that [in], say two sessions per week in every session, there is an activity that is inquiry-based learning.*

However, for students in the regular classes, the use of IBL would be less frequent:

> *For regular track it's usually once a week and it is always implemented... in the first part of the lesson or after the introduction of the lesson. I sometimes use that inquiry-based learning to engage them into some kind of curiosity let's say stimulation for learning " AQB-G*

Type of IBL activities

There was an agreement among all biology teachers that guided or structured inquiry is mostly implemented in their classes. Such inquiry takes place when the teacher asks a question and provides a suggested procedure for students to follow. Open inquiry activities were rarely applied and were implemented only if they were related to laboratory investigations. One interviewee said that the level of inquiry can develop with students' academic level as he uses guided inquiry with grade 9 and open inquiry with higher grades like 11 or 12.

> *"Today I did; it was all three versions. It was structured. It was open and it was guided once more. But it's hard to have all the phases in one lesson. But sometimes you can get the material in a way that you want to link so you can do. But mostly for Grade 9 you can say it will be guided and structured but for grade eleven and twelve it can be open" AQB-M*

Whether students apply the stages of IBL activity

Three main perceptions emerged from teachers' responses to the questions about IBL stages and whether their students can apply the steps of the inquiry cycle independently. Five teachers think that students cannot ask investigative questions, and that they need support during IBL activities starting from forming a hypothesis, designing a procedure, collecting data and finally drawing conclusions.

> *"They need to ask themselves better questions than what they do, they need to be helped all through"* AUHG-NO.

The second group of teachers linked students' ability to apply steps of inquiry activities to their academic level and the nature of the topic.

> *" it varies ... according to the type of the topics that we're teaching. Some topics like interactive [have] to be work and some of them it's merely theoretical"* AUHB-H.

The last group of teachers emphasized the importance of previous training in addition to providing guidance during the activity. They explained that when students are exposed to inquiry-based learning instructions in prior grade levels, they will be able to ask questions and formulate hypotheses easily. In addition, some teachers emphasized the necessity of appropriate scaffolding for students, as they felt that once students were guided at the beginning of the inquiry and were given suitable support to identify the main variable required for their investigation, they can write correct hypotheses, collect data and draw conclusions easily in a collaborative environment. Another teacher highlighted the importance of appropriate guidance to students without providing direct answers to their questions, they stressed on the importance of supporting the students throughout the stages of the activity. One teacher mentioned her experience in introducing the IBL approach early in Grade 9 and how effective that was when she taught the same students in Grade 11:

> *"I think it depends on the training they have had throughout their study. I remember when I had the [grade] nine ASP three years [or] two years back, the basic understanding of it is really poor. But we actually had time during the [term] to go and do a few labs and then they came back [during] break and one group even came back on Saturday and go [went] through the entire procedure and they actually learned a lot. Now this year when I had them, I've got them back and I literally just opened for them, we're going to just do this just to drag their memory and they just took it so far. They asked each other and challenged each other* AUHG-L.

The teachers in Dubai also agreed that introducing the IBL approach at an early stage would help the students master the skills in their senior grades, the first teacher mentioned that:

> *"Grade 9 and 10 especially, they've been taught that the key principle of how to formulate a hypothesis statement and a lot of time it'll be a just a structured question saying, "what would be your hypothesis for this experiment?" [they] develop their own hypothesis when they're working in groups together" DXB-C.*

Another teacher in Dubai campus explained the idea of the requirement of scaffolding in her instructions to the students at the beginning of the activity to help them to proceed and find the correct results:

> *"Yes, the students determine which data to collect. I guide them when they have an investigation or in the classroom. When they have a particular topic, I'll guide them but then they will determine themselves what they need to collect, I may use what they've collected to indicate that maybe there's a bit more you need to do, but initially they do that". DXB-I*

The teacher in Al Ain had the same opinion about the importance of scaffolding, she said:

> *"The first step is always guided because writing a hypothesis for our student is still some challenging task for them, the rest of the work will just go with the flow and it is self-dependent." AQB-G.*

Discussions During IBL activities

When teachers were asked about the level of discussion among students in the collaborative work during IBL activities, some interviewees argued that group work was not useful, as the most able students dominate the discussion and less able students usually copy the answers. Although the teachers did not mention successful experiences of implementing IBL activities in collaborative work, they were aware of the importance of facilitation as an integral part of IBL activities.

One teacher said that if students were not supported, they will simply copy the work of the stronger students:

> *"In most of my classes. I don't feel that group work discussion is so efficient. Mostly one or two students are working, and the rest are just waiting for the answer. This is why I have to keep roaming between the groups asking them to work…I regroup them [to] change the culture, mix abilities… Putting the good students together and the [rest of the] students together, rearranging the groups. I'll end up doing most of the job with the weak students." AUHB-S*

Another teacher form Al Ain school explained that there is a need for collective efforts from the teachers of all subjects to train the students to apply IBL activities:

> *"It's mostly one able child. And the others are trying to obtain information from them, but then it's not the other way around. There's not a collective effort and it's hard to disperse that. I think that's the type of problems that we have". AQB-S*

Whilst a minority of teachers mentioned that students ask each other challenging questions, all other teachers agreed that the level of discussion during collaborative activities is limited to knowledge and comprehension on the cognitive domain based on blooms taxonomy and lack the "how" and "why" questions that help students to develop CT skills. Therefore, peer mentoring was also limited to answering comprehension questions.

“The discussion is at the level of knowledge” AUHB-M.

“I don't think that most of them understand the meaning of ‘Predict’. You have to evaluate” AUHB-H.

“The level of the questions between themselves was basic level and at the end of the day we need to guide them from where to find the data” AUHG-NI.

“Discussions are generally about how did they reach these results and what makes them accomplish this task correctly, and perfectly succeed [in making] the discussion become more in-depth. And more questions start to arise about what mistake came along the steps or along the process” DXB-C.

Critical Thinking

In the section about CT, the questions were divided into two main groups. The first group of questions clarifies teachers’ understanding of the meaning of CT and their pervious experiences with it. The teachers’ responses and further explanations were described and reflected upon. The second group of questions explored how teachers use CT in their teaching practices.

What is critical thinking?

According to the results, most of the teachers were not familiar with the educational meaning of CT. Five teachers described CT as a teaching strategy including questions that require higher order thinking skills.

” Critical thinking is a technique or strategy teachers use to enhance thinking skills of students”. AUHB-S.

" allowing the students to be able to think deeply about the question or the particular topic and thinking really deeply about what it is. 'Why is it like that?' or 'What does it mean?' It is an argument for and argument against, not just a straightforward answer" DXB-I

Four other teachers defined it as a thinking process that allows students to take basic information to a higher level, helps them apply the knowledge in different contexts and reflect on their points of view towards the idea, such as the following response:

"Thinking outside the box-which I keep stressing on the students. It's not just taking the information as is, it is thinking 'How I can apply this and how can I add my own input to it?' which we need to" AUHG-No.

Although most teachers did not provide an accurate definition of CT, three teachers identified CT as the ability to look at an issue from different perspectives, form an opinion, and be able to defend it and justify it. Their response included analyzing and evaluating components of CT as per the definition by Paul and Elder (2006).

"The ability to formulate an opinion of their own or use prior knowledge or acquired knowledge to justify their opinions" AQB-S.

One teacher identified CT as the classical logic and the ability to interpret prior knowledge to find a conclusion. When teachers were asked about their experience with CT when they were students, eight teachers responded that they did not experience CT at the high school level. The other five teachers had some teachers who helped them develop CT, especially in science laboratory and other subjects that required debating and formulating an opinion. An example response is as follows:

> *"I think I was in grade 11 GCSE and we had a subject called religious education and we had to justify whether assisted suicide was justifiable and not justifiable. So, we had to formulate an opinion based on religious texts, so that I think was the biggest critical thinking" AQB-S.*

Are there any components of critical thinking? If so, what are they?

As for the elements of CT, a common misconception amongst interviewees arises, as they were not familiar with the elements of thought and gave different responses, including motivation, communication and models of reasoning without specifying any of the elements of thought defined by Paul and Elder (2006). Only one interviewee was able to list some of the CT components as she mentioned in her response.

> *"[To] Analyze a problem to derive solutions, interpret results and problem solving" AUHG-R*

If you were asked to analyze thinking, how would you do so? What standards do you use when you evaluate someone's thinking?

When teachers were asked how they analyze thinking, the majority of responses were related to the use of discussion and questioning. This kind of response reflected a weak background regarding the elements of thought.

> *"It is very hard to answer this, I will use assessments like various questions, some of them subjective or objective questions, maybe images to reflect life" AUHG-Ni.*

Three interviewees had a response close to the elements of thought, as they referred to the ability of a person to have a point of view or relate knowledge to real life applications.

> *"[The] ability of a person to connect real life experience with prior knowledge to deduce reason about the world around them" AUHG-R.*
>
> *"I think I'm kind of looking to their objectivity and whether they have an open mind about things and whether they can see both sides of an argument" AQB-D.*

None of the responses referred to the importance of CT in improving thinking and building intellectual traits. Consequently, responses to the question about the standards used to evaluate thinking reflected the same level of information about intellectual traits. Most of the teachers related the evaluation of students' thinking skills to their ability to ask questions and respond to teachers' questions during classroom instructions. Only a few responses referred to items related to the elements of thought and the development of intellectual autonomy and intellectual integrity.

> *"Having different activities to express their understanding to show what they are actually thinking and express in different ways in the classroom and it gives all the students the opportunity to show what they're capable of, [and] allows them to be free thinkers so they can express whatever they have in the best way they can." DXB-I*

"You're looking at the steps of how they got to this final decision or conclusion. And you're looking at the depth at which they've looked at as well. And then you're looking at the evidence. So 'how did they get to this final conclusion?' " AQB-D

How does critical thinking apply to the study of science?

In this question, the interviewees shared four main perspectives about how CT is applied to the study of science. The first one related the students' understanding of scientific concepts to their ability to think critically. If students develop CT skills, they will be able to understand scientific concepts. CT was described as the essential backbone required to build scientific concepts.

"Science is a field of inference, predictions and reasoning which are the main elements of the critical thinking, so critical thinking plays a backbone role in all fields of science." AQB-M

"I think if you're not a critical thinker you can't actually grasp the [scientific] concept, which is why so many of our students fail. That is the underline of how you study it and see things" AUHG-L.

The second perspective related CT skills to scientific inquiry and the steps of the scientific method, reasoning that the completion of a scientific research following the classical scientific procedure would require students to analyze data, infer results and evaluate their conclusions.

"Science has the scientific method. So, the steps involved in the scientific method and being able to understand the science of something requires a lot of deep thinking and why something is the way it is. [It is] How I can back up evidence and explain that evidence concludes evaluation" DXB-I.

The third view was related to CT promoting curiosity and motivating students to learn.

"The easiest and quickest way to introduce critical thinking is in the beginning of the lesson … It's very easy to communicate a leading question to students. Give them a question and see where they go from that" DXB-C.

The fourth opinion by 2 teachers out of 12 reflected a limited view about CT, as the teachers mentioned that it should be used in questioning during assessment and class projects.

"We should implement it during exams, whether it is a full or somewhat difficult examination or assessment. Also, I think during the project if there is any project during the term" AUHB-M

"Science may be based on the scientific method in the way of inquiry and it has to be there all the time. The way of the question we are providing the student and also their work in any lab experiment it will be applied" AUHB-H

How do you foster critical thinking in the classroom (in general)?

Teachers' responses to the interview item were related to techniques followed to foster CT and can be categorized into three strategies. The main strategy was embedding CT in class discussions or conducting differentiated activities. Some interviewees referred to the importance of project-based learning and asking a challenging question that requires research. The third strategy was to develop a scenario or a real-life situation as a starting activity to motivate students and encourage them to think critically. An important point that should be considered during instructions was also highlighted, to allow students to make mistakes, guide them to think about their conclusions and not focus solely on the final correct answers. Below are some examples of the teachers' responses.

> *"Questioning is one of the main ones I use, and group discussions. So that allows the weaker students to work with another student and express the ideas they're thinking" DXB-I.*
>
> *"Problem solving*-so *if you give them tasks, they actually have to do -we don't do any here- but we had one project that was a problem you had to go and solve. You had this amount of resources, they have this amount of time, and you need to then produce this. Then they would actually come [up with] so many different ideas and what they learned in the past, and everything would come together in order to … fulfill this*

project within the criteria. I think things like that will help bring out project-based learning" AUHG-L

"Well I foster it by embedding my critical thinking questions through art worksheets throughout the general discussions. Guiding the students to think in a certain direction" AUHB-S.

Obstacle to bringing critical thinking more explicitly and more deeply into instruction

Finally, the teachers were asked about the obstacles they faced when integrating more CT into class instructions. One interviewee mentioned that integrating CT into instructions is important and can be always included, he said that there is no excuse for not integrating CT in daily teaching.

"There's always ways of creating it. If you're limited with certain resources, time, but you can always find ways for critical thinking. So, an obstacle in the sense [of a] permanent obstacle, I don't think there is an obstacle". DXB-I

However, nine teachers out of the thirteen interviewed argued that integrating CT comes with many obstacles such as students' readiness and their ability to become critical thinkers, the absence of a real implementation of project-based learning, lack of professional development for teachers, time constrains, the cultural context and finally, the density of the content knowledge in the curriculum, below some examples of teachers' responses about the students level and their ability to be critical thinkers.

"Critical thinking is hard. Kids are used to follow what they're told, or they have this particular perception about the role of

teacher. So, they believe that they are students therefore they're the recipients of information. It's challenging. That needs to be changed for them to be more confident with their opinions. Every child has an opinion but it's a matter of providing a safe space for them". AQB-S

"There are a lot of factors that contribute to why they're not giving good enough projects. One of them at this time is student capabilities". AUHG-No

Another participant referred to the lack of professional development for teachers:

"I think professional developments of the teachers is the key role to build connections between the latest methodologies and the needs of students. The disinclination by the students is often a barrier". AQB-M

One participant mentioned the teachers' workload and mentioned that the requirement to complete the knowledge part in the curriculum is a major obstacle that teachers face:

"I think a teacher is always under pressure. Even though we live in the 21st century, where we as educators we say to ourselves, we must have a student-centered lesson. We still are under pressure to move through knowledge and material, and sometimes because of that pressure we may be tempted to simply communicate and convey and deliver that material to

students to simply tick boxes and ensure we've moved through the material without taking a step back and saying 'how am I developing my students' thinking skills?'. The pressure is -as a *teacher- at the planning level to ensure that when you plan your lessons you're doing it for a lens of how I might develop critical thinking and so often even in people's professional backgrounds they've not been trained as a professional practitioner to think in that way about that some planning. So it is just making sure when you sit down to plan a lesson you're saying to yourself 'How am I developing critical thinking in this lesson?' 'Which bits of the material lend itself to an activity that I could develop critical thinking?'". DXB-C*

Two teachers from AUH G referred to the method by which teachers treat mistakes in the classroom, and how the students think that they must not make mistakes:

> *"I think we have to allow them time to think and allow them to be wrong, it doesn't matter. And this is our problem. ...Allow them to think that 'it doesn't matter if you [students] think like this',' why did you [students] think like this?' This is what we need to do about the attitude towards it. To allow them to reflect and it's OK to get it wrong. It's OK to think differently" AUHG-L*

The effect of Inquiry-based learning on CT

Two main questions in the interview were asked to identify teachers' perceptions about the use of IBL to build students' CT skills.

Do you think that the activities students perform during IBL will help them to develop CT? can you provide an example?

The first question targeted the activities that students perform during IBL and whether they helped students develop CT. A common theme existed, where IBL was said to encourage students to develop CT skills, as it involves a series of steps that are logically organized and lead to a conclusion. Below are some examples of the teachers' responses.

> *"An inquiry-based learning activity is an activity based on the critical thinking level, and it's guiding the student to think in a critical way". AUHB-S*
>
> *"I believe the activities students perform during Inquiry based learning will help them develop Critical thinking. The reason for this is the Inquiry based approach in a classroom is student-centered, promotes depth of knowledge, requires students to be engaged and enables them to think deeply". DXB-C*

One interviewee argued that students should change their mindset first, by accepting to research ideas and not expecting ready answers form their teachers.

> *"If the students are convinced to accept the idea that they need to search and find answers about new ideas and not to receive the information from the teacher. I had seen some students who*

> *finally accept the IBL and now they are developing more critical thinking [skills]". AUHG-Ni*

What hinders the IBL to be effective in students' learning?

The second question was about hindrances in the way of an effective implementation of IBL instructions. Interviewees had mentioned several causes that can be summarized in three main points: the time constraints accompanying a dense curriculum, students' readiness and ability to apply IBL activities and teachers' readiness and ability to design IBL activities.

> *"Time and tight pacing, [through] IBL, the students must be given enough time to search for the answer, to think about possible solutions. Unfortunately, with the time frame that I work with, I cannot say that I can implement IBL in its full meaning. (I saw videos about IBL and a simple concept was given a time frame of 2 or 3 weeks)*
>
> *- Materials: students lack the foundation level or basis in most of the topics that we teach, so they find it is easier for them to wait for the teacher to explain instead of searching by themselves.*
>
> *- Students' willingness and readiness: [for] most of our students, this is an alternative way for her [the student's] laziness and she wants only to impress the administration. As I just said, they are trained to receive information only, even if the teacher at the end of each activity wrapped up and*

summarized the idea, still the students think that the teacher did not explain that concept.

- Not all teachers are mastering the IBL and do not know how to apply it." AUHG-Ni

Table 4.25 summarizes the key findings in teachers' responses to the interview questions.

Table 4.25 Summary of teachers' responses to the interview items

Interview Question	Summary of the results
How frequently do you implement IBL activities in the classroom?	Biology teachers agreed that inquiry in the form of questions that should be investigated as part of a lesson, is done nearly every biology lesson. However, as open-inquiry, it is rarely done in most cases. The teachers related the frequency of implementing inquiry to: - Students' academic level - Curriculum requirements
What level of IBL do you mostly apply?	Biology teachers agreed that they use guided or structured inquiry for grades 9 and 10 and they move to open inquiry with students in grades 11 and 12
Whether: - Students formulate questions which can be answered through investigations - Students develop their own hypothesis - Students design their own procedures for investigations - Students determine which data to collect - Students develop their own conclusions for investigations	The interviewed teachers mostly agreed that students need guidance in order to ask investigative questions and identify variables in open inquiry investigations. Some teachers expressed that students need guidance all through the activity, and others argued that students can work independently if they were guided at the beginning of the activity. Two teachers highlighted the importance of training students to practice inquiry skills early in school years.

What level of discussion do students apply in their groups?	Most of the biology teachers agreed that the level of discussion during collaborative IBL activities is basic and limited to the level of content knowledge. Two teachers argued that the level of discussion is related to the students' understanding of the concepts and their performance in the activity.
What is critical thinking?	Biology teachers shared five different perspectives on the meaning of critical thinking as: - A teaching strategy that depends on questioning techniques - A thinking process that helps students use basic information and apply it in different real-life situations at a higher level - Classical reasoning and logic - The ability to form of an opinion and defend it
When you were in school, did your teachers in school encourage you to think critically?	Most biology teachers were not exposed to CT at a high school level, except for three teachers who studied in a British high school curriculum, the IGCSE.
Are there any components of critical thinking? If so, what are they?	Most of the interviewees reflected poor understanding of the elements of CT, as they were not able to identify the components of thinking and referred to items such as: - Types of questions - Communication - Motivation and curiosity - Models of reasoning
If you were asked to analyze thinking, how would you do so? What standards do you use when you evaluate someone's thinking?	Most of the teachers related the evaluation of someone's thinking to: - Involvement in discussions - Forming a point of view - Ability to relate concepts to real-life situations Few responses included some elements of thoughts including: - Analysing a problem to derive solutions - Interpreting results

	- Problem solving
How does critical thinking apply to the study of science?	The biology teachers emphasized the importance of the relation between CT and science education, they mentioned four main points: - when students develop CT skills they will be able to understand scientific concepts, CT is the backbone of science - scientific inquiry and the scientific method are related to CT skills - CT can be used to motivate students and encourage their curiosity - CT is used to assess scientific concepts
How do you foster critical thinking in the classroom (in general)?	The teachers shared some ideas about how they apply CT in their teaching practices including: - Project-based learning through challenging questions - Questioning during class discussions - Using introductory case studies or scenario questions
What is the most significant obstacle to bringing critical thinking more explicitly and more deeply into instruction?	The interviewed teachers mentioned several causes for not using CT in instruction. - Students' academic level and readiness - Time constrains - Condensed curriculum - Teachers' experience
Do you think that the activities students perform during IBL will help them to develop CT? Can you provide an example?	The interviewed teachers agreed that the application of IBL instructions would help students develop CT skills
What hinders the IBL in being effective in students' learning?	The interviewed teachers suggested that some causes that hinder effective IBL application are: - Students' academic level - Condensed curriculum - Teachers' skills in designing and implementing IBL activities

4.4.3 Document analysis

Artefacts collected from students included two types of documents through which students reflected their understanding of the explained concepts. The formative assessment documents included class worksheets, laboratory reports, classroom notes and videos that were created by the students. The summative assessment documents included samples of a standardized exam that was conducted in the middle of the second term for all of the students in the school system.

4.4.3.1 Formative assessment samples

The formative assessment samples collected included in-class quizzes, lab reports, class worksheets, students' notes and students' responses via interactive applications such as interactive online walls (Padlet wall) or making videos. A sample of raw data on how each type of the formative assessment samples collected included IBL or CT attribute is enclosed in appendix 4.7.

Table 4.26 shows number of samples collected from each document type and number of the samples that showed IBL or CT attributes. The table shows that IBL items were identified in the lab reports, class worksheets, interactive applications and students' notes. However, CT items were merely found in the submitted documents.

Table 4.26 Formative assessment documents showing IBL or CT attributes

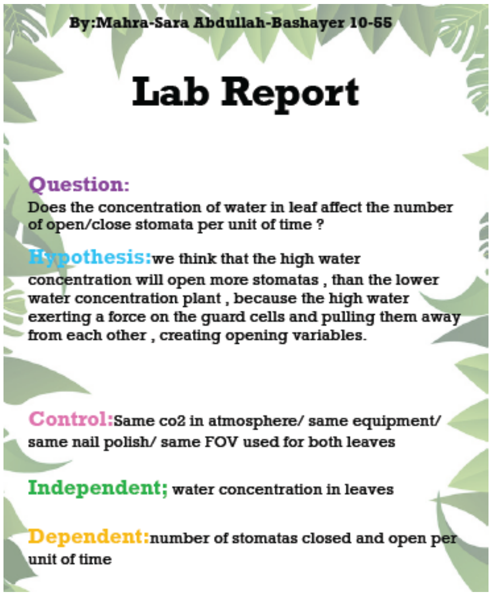
Document type	Number of Samples collected	IBL1	IBL2	CT1	CT2	CT3	CT4	CT5	CT6
In class Quiz	6	0	0	1	0	2	0	3	0
Lab reports	3	3	3	2	0	2	2	1	1
Class worksheet	5	4	2	0	0	0	0	1	4
Interactive applications	5	3	2	1	0	0	1	0	0
Students notes	4	2	1	2	0	0	0	0	0

It can be seen from the results that the IBL attributes are only applied when students are given the opportunity to perform scientific investigation and write a scientific laboratory report. However, the application of CT attributes is limited in the in-class quizzes, discussions and worksheets. Table 4.27 summarized the overall percentage of the documents that included attributes of IBL and CT.

Table 4.27 CT percentage in the formative assessment documents

IBL and Critical Thinking Attributes		Percentage of documents with IBL or CT attributes
IBL1	Preparing for investigation	%52
IBL2	Application of the inquiry activity	%35
CT1	Express the new question in several ways to clarify its meaning	%26
CT2	Think independently and develop intellectual courage activities that encourage independent thinking and speak out opinion	%0
CT3	Analysis (Accuracy and precision) Argument analysis	%17
CT4	Evaluation (Relevance) use valid criteria to evaluate claims	%13
CT5	Inference (depth and breadth)	%22
CT6	Explanation (significance) self-regulation (Fairness)	%22

Results show that IBL instructions were detected in 52% of the collected samples. While CT2 attributes related to thinking independently and developing intellectual courage were not evident in any of the students' samples collected. The best implementation of IBL instructions was recorded when students had a complete inquiry lesson that depended on performing a scientific investigation. Figure 4.8 shows two sample of students' lab reports on the open inquiry laboratory investigation. The notes reflect students' ability to ask question, state a hypothesis and record their steps.



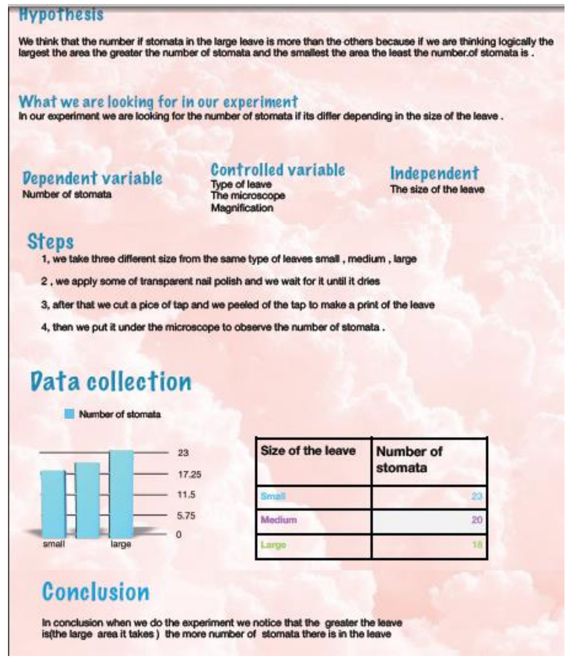
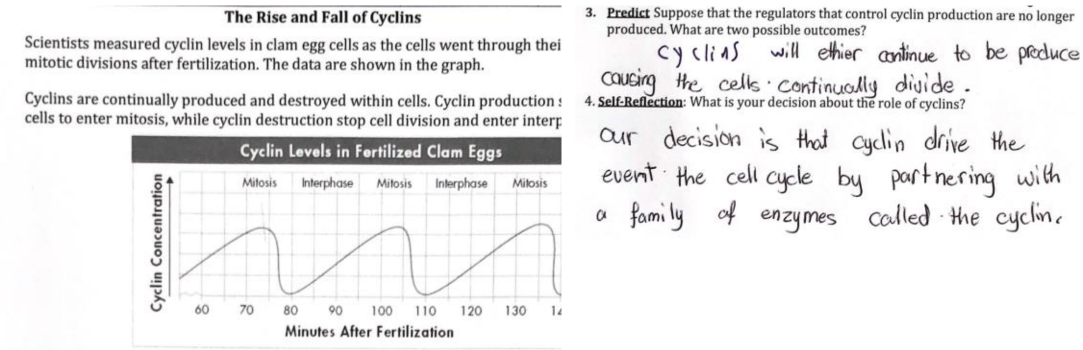


Figure 4.8Students' lab reports

Another example of IBL activity in a class worksheet is shown in Figure 4.9. In this example, the students were given a data related to cyclin concentration. In the first part of the question, they were asked to predict what could happen if cyclin was no longer produced. During the discussion, students practiced inference as a CT core skill. The second part of the question was guiding the students to evaluate their answers and make a decision.


The Rise and Fall of Cyclins

Scientists measured cyclin levels in clam egg cells as the cells went through thei mitotic divisions after fertilization. The data are shown in the graph.

Cyclins are continually produced and destroyed within cells. Cyclin production s cells to enter mitosis, while cyclin destruction stop cell division and enter interp

3. **Predict** Suppose that the regulators that control cyclin production are no longer produced. What are two possible outcomes?

cyclins will ethier continue to be produce causing the cells continually divide.

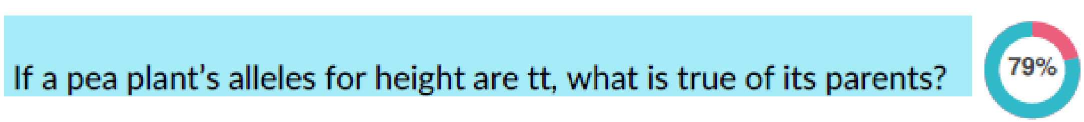
4. **Self-Reflection**: What is your decision about the role of cyclins?

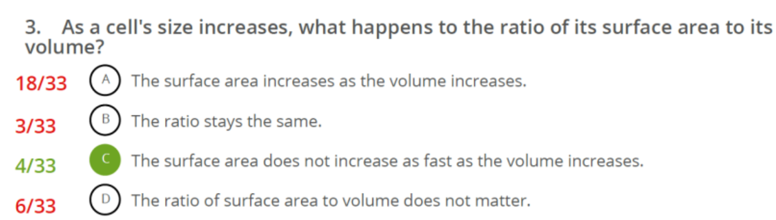
our decision is that cyclin drive the event the cell cycle by partnering with a family of enzymes called the cyclin.

Figure 4.9Example question on Inference from a class worksheet

Inference in the classroom was also evident in some of the quizzes. Thus, the number of students who were able to answer such questions in the classroom differed depending on the classroom. The first screenshot in Figure 4.10 was from a report for ASP students and the second one was for the same report from another section in the regular track. It is apparent from the examples that 79% of the ASP students were able to answer the inference question correctly. While only 33% of the regular class students provided a correct response for the inference question.

Screenshot 1

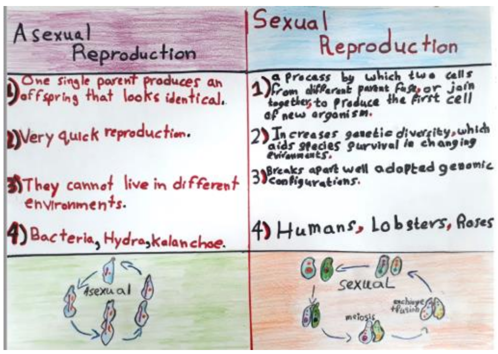




Screenshot 2

Figure 4.10 Students' responses to inference questions

The interpretation skill to clarify meanings was also found in 22% of the collected samples. It was mainly evident in students' notes. Figure 4.11 shows some examples of notes that indicate mind mapping to compare and categorize information, in addition to the use of drawings to clarify the structure of the studied parts and procedures. One of the samples shows how students illustrated the difference between sexual and asexual reproduction. The other sample shows the difference between primary and secondary growth in the stem.



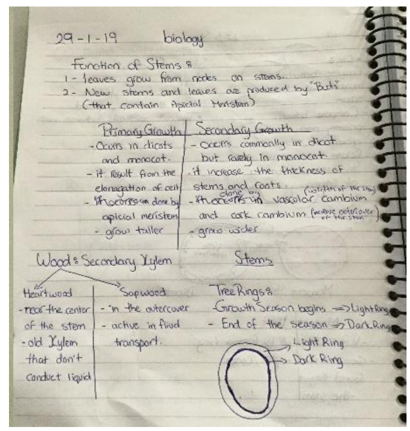


Figure4.11Samples of students' notes showing interpretation

When students were asked to produce a poster and a video to explain cell division, they were required to practice CT skills such as evaluation, analysis and self-regulation. Figure 4.6 shows a sample of one of the posters created by the students during the lesson. The researcher was also given samples of the final videos produced by the students.

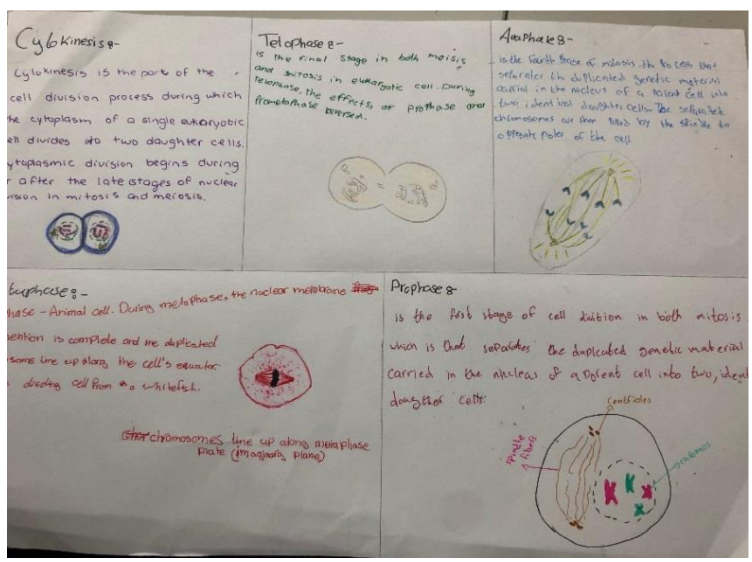


Figure 4.12 A poster produced during one of the observed lessons

4.4.3.2 Summative assessment samples

An analysis of the summative assessment samples collected from the students was done to identify the types of CT questions that were included in the exam papers. The questions were then categorized into interpretation, analysis, inference, evaluation and explanation questions based on Facione's (2015) categorization. Table 4.28 summarizes the distribution of CT questions in each of the collected examination papers.

Table 4.28 CT distribution in the summative assessment papers

Summative assessment samples	Interpretation	Analysis	Inference	Evaluation	Explanation	CT Q	Total number of exam questions	Percentage of CT Questions
9 Non-ASP	5	1	3	1	2	12	25	%48
9 Non-Asp V2	4	0	3	1	1	9	23	%39
9 ASP	5	1	3	1	2	12	22	%55
10 Non-ASP	4		1		1	6	25	%24
10 ASP	3		2	1	1	7	23	%30
Total	21	2	12	4	7	46	118	%39
Percentage of questions appeared	18	2	10	10	18			

Further analysis of the correct responses in the summative assessment was done using an Excel sheet to color-coded correct and incorrect responses to CT questions in all samples. Two samples of the raw data for grades 9 and 10 are enclosed in appendix 8. A summary of the results for all grade levels is shown in Table 4.29. The results revealed that in general, the performance of the students enrolled in the Advanced Science Program (ASP) is better than the performance of the students in other sections. The results show that more than 50% of the responses to the interpretation and inference questions were answered correctly in both grades 9 and 10 ASP samples.

Whereas the percentage of the correct responses in the Non-ASP classes was generally less than 40% which reflected weak CT skills.

Table 4.29 Percentage of correct responses to CT questions

Summative assessment samples	Number of samples	Percentage of correct responses				
		Interpretati on	Analysis	Inference	Evaluation	Explanation
9 Non-ASP	9	38	11	48	33	28
9 Non-Asp V2	1	25		67	0	100
9 ASP	3	60	0	78	67	33
10 Non-ASP	12	31		33		17
10 ASP	3	56		67	33	67

Table 4.30 summarizes the percentage of correct responses based on the type of the CT question. The results show that %53 of the students were able to answer inference questions. Interpretation and evaluation questions were answered nearly in the same percentage, while students reflected poor practice in the analysis questions as only 8% of the total number of inference questions in all the examination papers was answered correctly.

Table4. 30 Percentage of the correct responses based on the type of the CT question

Type of Question	Total number of questions in the summative assessments	Percentage of Correct Responses
Interpretation	21	%39
Analysis	2	%8
Inference	12	%53
Evaluation	4	%38
Explanation	7	%30

One example of explanation questions for grade 9 students who are not enrolled in the Advanced Science Program (ASP) is shown in Figure 4.13. The students were asked to read a paragraph about cancer treatment, then they had to answer two parts of the question. First, they were asked to explain how chromatography causes low blood count. Then, students were required to explain how cancer can lead to death and show their reasoning in two points. The assessment rubrics for this question along with two samples of student' responses are shown in the figure. Sample 1 is for a high achieving student who was able to provide the explanation at the depth required and provided the evidence needed for the answer to be complete. However, sample 2 is for an average student who was able to relate chemotherapy to the death of healthy cells, however, the student failed to think deeper and relate the death of healthy cells to the division required for the repair process.

Question 13.a and b

13. Read the paragraph below and answer questions **a** and **b**. [8 marks]

Cancer is treated by radiation, which interferes with the copying of DNA in multiplying cancer cells, and chemotherapy, which is the use of chemicals to kill cancer cells. It is noticed that chemotherapy has side effects on the body that includes hair loss and anemia (low blood cell count). After chemotherapy stops blood cell count increase and hair grows.

a. Explain how chemotherapy cause low blood count? (4 marks)

b. Explain how cancer can lead to death, show your reasoning in **two** points. (4 marks)

Marking scheme

a. Explain how chemotherapy cause low blood count? (4 marks)

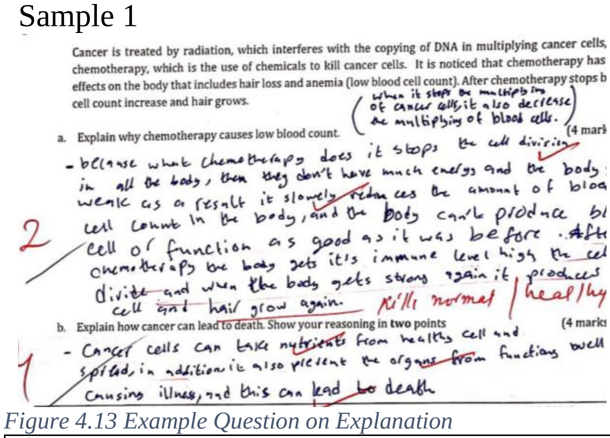
The chemicals **stop cell division** in both cancer cells and healthy cells such as the ones that produce blood cells No **new cells are replacing dead cells** in the blood/ **result low blood count.**

4 marks	Student referred to healthy cells affected by chemotherapy, also referred to cell division and related that to replacing dead blood cells
2 marks	Student only referred to cell division that is stopped without relating it to the blood formation process
1 mark	Student only mentioned that healthy cells are affected by chemotherapy

b. Explain how cancer can lead to death, show your reasoning in **two** points. (4 marks)

Rapidly dividing cancer cells take nutrients away from healthy tissues (2 marks). This leads to a disruption of the proper functioning of body organs that causes illness and may lead to death (2 mark).

Sample 1


Cancer is treated by radiation, which interferes with the copying of DNA in multiplying cancer cells, chemotherapy, which is the use of chemicals to kill cancer cells. It is noticed that chemotherapy has side effects on the body that includes hair loss and anemia (low blood cell count). After chemotherapy stops b[lood] cell count increase and hair grows.

a. Explain why chemotherapy causes low blood count. (4 mark[s])

(when it stops the multiplying of cancer cells, it also decrease the multiplying of blood cells.)

- because what chemotherapy does it stops the cell division in all the body, then they don't have much energy and the body weak as a result it slowly reduces the amount of blood cell count in the body, and the body can't produce bl[ood] cell of function as good as it was before. After chemotherapy the body gets it's immune level high the cell divide and when the body gets strong again it produces cell and hair grow again. kills normal healthy

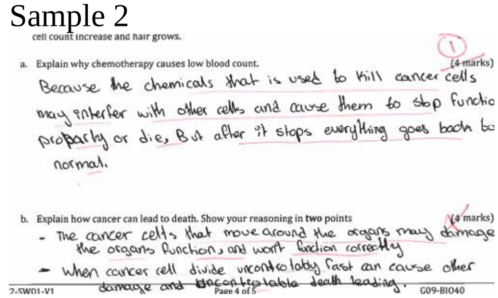
2

b. Explain how cancer can lead to death. Show your reasoning in two points (4 marks)

- Cancer cells can take nutrients from healthy cell and spread, in addition it also prevent the organs from functions well causing illness, and this can lead to death

1

Sample 2


cell count increase and hair grows.

a. Explain why chemotherapy causes low blood count. (4 marks)

1

Because the chemicals that is used to kill cancer cells may interfer with other cells and cause them to stop functio[n] proparly or die, But after it stops everything goes back to normal.

b. Explain how cancer can lead to death. Show your reasoning in two points (4 marks)

- The cancer cells that move around the organs may damage the organs function, and won't function correctly
- When cancer cell divide uncontrolably fast can cause other damage and uncontrolable death leading.

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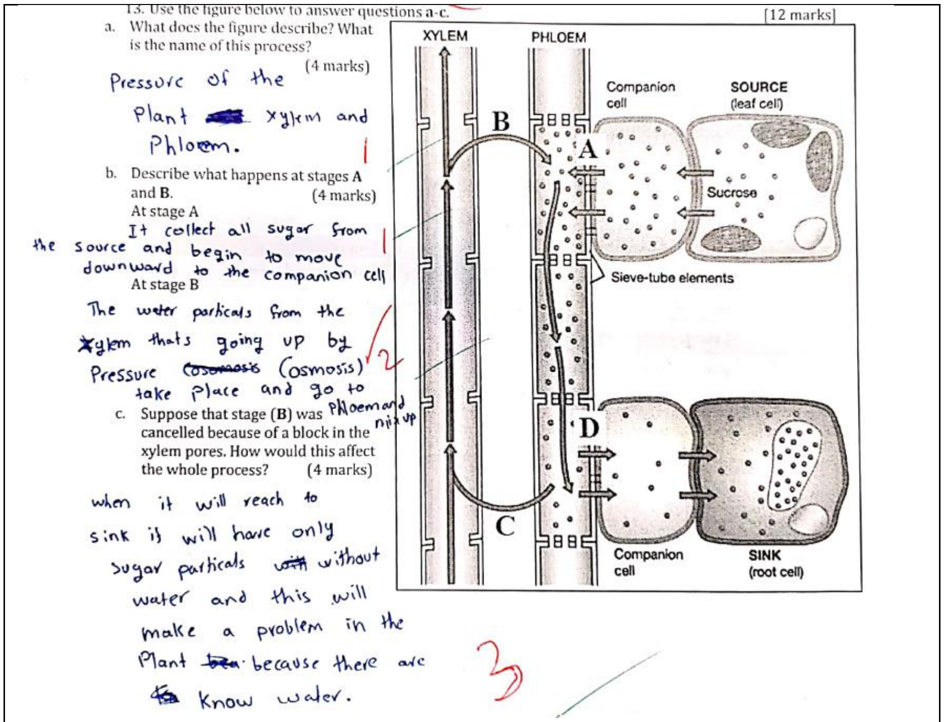
Figure 4.13 Example Question on Explanation

Sample 1: student who was able to infer the consequences correctly



Sample 2: student who was not able to provide correct response.

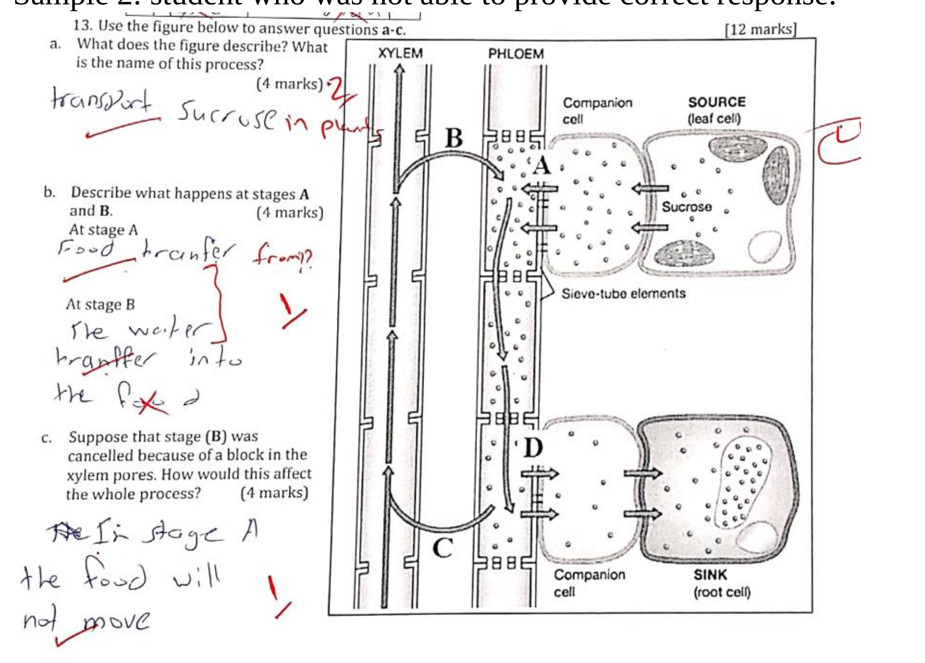


Figure 4.14 Example Question on Inference

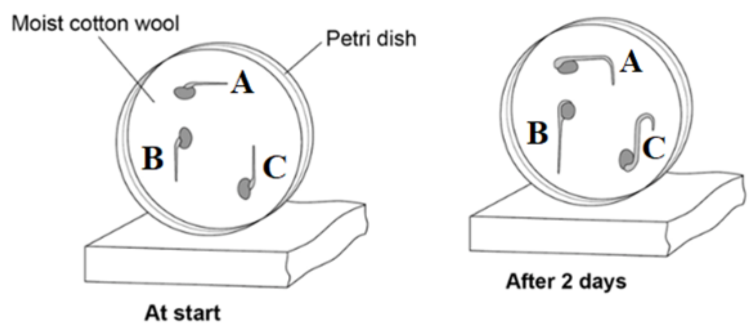
An additional example for grade 10 assessment is shown in Figure 4.14. Question 13 section c was classified as an inference question. The students were given a diagram that shows the movement of water and nutrients in the xylem and phloem. Questions a and b were targeting the basic knowledge required to understand the concept. Part c of the question was asking the students to infer what will happen if xylem pores were blocked.

Only 4 samples of the 12 collected exam papers reflected a correct response to this question. Two students failed to answer the question completely and six students could infer that it will stop the movement of the food, yet, they were not able to relate the block on xylem pores to the osmosis pressure that is needed to move food.

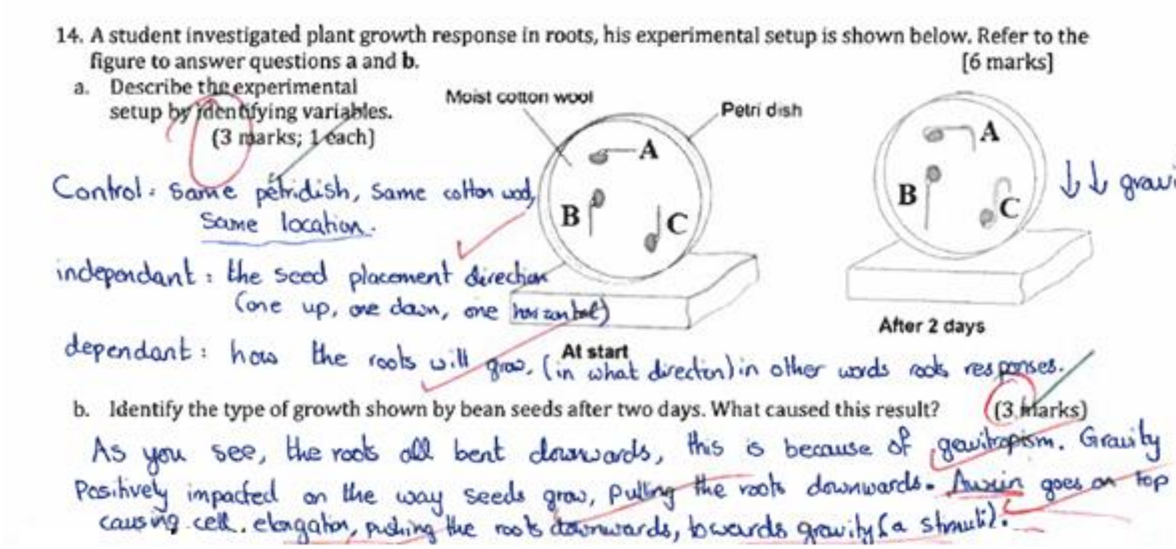
An additional example to show students' performance in questions related to scientific investigations and inquiry process is shown in Figure 4.15. The question shows an experimental setup and the students were asked to describe the design and identify the cause of the growth shown in the results based on their knowledge of plant tropism. From the 12 samples collected, only two students were able to answer this question, one of them is sample 1 in Figure 4.9 and the students in the other 10 samples were not able to provide correct responses.

14. A student investigating plant growth response in roots, his experimental setup is described below. Use the setup to answer questions **a** and **b**. [6 marks]

a. Describe the experimental setup in the petri dish for the seeds A, B and C. (3 marks; 1 each)
A: the seed is positioned on the side
B: the seed is positioned upright
C: the seed is positioned upside down



b. Identify the type of growth shown by bean seeds after two days? What caused this result? (3 marks)
Garavitropism, roots grew downwards (1.5 marks)
The Auxin prohibits cell elongation in the roots which causes the roots to bend down into the soil (1.5 marks).


14. A student investigated plant growth response in roots, his experimental setup is shown below. Refer to the figure to answer questions a and b. [6 marks]

a. Describe the experimental setup by identifying variables. (3 marks; 1 each)

Control: same petridish, same cotton wool, same location.

independant: the seed placement direction (one up, one down, one horizontal)

dependant: how the roots will grow. (in what direction) in other words roots responses.

b. Identify the type of growth shown by bean seeds after two days. What caused this result? (3 marks)

As you see, the roots all bent downwards, this is because of gravitropism. Gravity positively impacted on the way seeds grow, pulling the roots downwards. Auxin goes on top causing cell. elongation, pushing the roots downwards, towards gravity (a stimuli).

Figure 4.15 Example Question on Scientific Investigation

Table 4.31 below shows a summary of the utilization of core CT skills in the formative assessment and summative assessment samples.

Table 4.31 Summary of the utilization of the core CT skills in the collected documents

Core CT skill	Formative assessment	Summative assessment
Interpretation	Was mostly evident in lab reports and students' notes indicating mind mapping to compare and categorize information.	Was recorded in 21 items in the collected samples. The percentage of recorded correct responses was 39%.
Analysis	Was found only in two of the in-class quizzes and in two lab reports. The students' responses to the in-class questions varied as 50% of the students were able to answer the analysis question in one of the sections and 75% in the other section.	Only two items in the summative assessment were categorized as analysis questions. Only one response out of 12 samples was correct.
Inference	Was recorded in three in class quizzes, one lab report and one class worksheet. Correct students'	Was found in 12 items in the collected samples. The percentage

	responses in the in-class questions was 79% in the first section, 37% in the second and 12% in the last section.	of recorded correct responses was 53%.
Evaluation	Was evident in the lab reports and one submitted class worksheet.	Was found in 4 items in the collected samples. The percentage of recorded correct responses was 38%.
Explanation	Was evident in one of the lab reports and four students' worksheets in which the students were asked to reflect on their learning experience	Was found in 7 items in the collected samples. The percentage of recorded correct responses was 30%.

4.4.3.3 Summary of results from the collected documents

IBL implementation: In the formative assessment samples, the steps of inquiry were evident in seven of the collected samples. Clear implementation of all the inquiry steps was evident in the scientific investigations. Yet, limited application of inquiry activities was recorded when the inquiry was part of the lesson. Whereby in the summative assessment samples, the results reflected few correct responses to the questions related to scientific investigation.

Core CT skill application: The in-class formative assessment strategies lacked questions that help students practice core CT skills. Even though only a few questions were recorded, the correct responses to these questions were minimal. While, the summative assessment samples included a higher percentage of CT questions. Similarly, the percentage of correct responses to these questions was less than 50% in all core skills detected.

4.5 Summary of the Results

The quantitative results indicated that IBL instructions are regularly implemented as guided or structured IBL activities. In addition, students' responses reflected different practices with regards to the training on core CT skills. For example, they were trained on CT skills related to interpretation more than those that support in evaluating and assessing claims. In addition, the practices related to CT development were different in different campuses. The results also reflected that there is a statistically significant difference between Grade 9 and Grade 10 students' responses to IBL activities.

The lesson observations and interview results indicated the implementation of a short guided inquiry activity as a part of the lesson, and a long open inquiry activity as a practical scientific investigation in classrooms. In the case of the short-guided inquiry activity, students were not given an opportunity to complete the inquiry stages such as data analysis and self-reflection. However, when the lesson is planned as open inquiry, the students were required to do a practical activity, which allowed for more opportunities to implement data analysis and self-reflection. There was an identifies gap in the assessment practices related to the IBL activity. The frequency of using CT questions in the observed lessons was limited.

The interview results revealed some obstacles that hindered the implementation of IBL for the development of students' CT skills, including students' academic level, time constraints and curriculum requirements. Teachers agreed that scaffolding and introducing IBL activities gradually as structured then guided and open inquiry will enhance IBL implementation in their classrooms. In addition, the interview revealed some gaps in teachers' conceptualization of CT and how they could integrate it within instructions. The document analysis revealed that applying scientific investigations would provide the maximum opportunity for students to practice core CT skills.

Chapter 5

Discussion, Conclusion, Recommendations and Limitations

The previous chapter reported the quantitative and qualitative results that emerged from the reviewed data and explained how they contributed to answering the research questions. This chapter presents the discussion and conclusion of the research study. The results were compiled and interpreted in relation to the four research questions. The answers provided were then used to draw the conclusion of the study. The discussion combined the findings from the qualitative and quantitative tools used in the study. Results were then interpreted to provide a clearer outlook on the effectiveness of IBL instructions on the development of students' CT skills consequently, providing detailed answers to the four research questions. The first question was related to students' experiences with IBL activities in a high school biology course, including the levels of complexity of IBL activities implemented, application of the inquiry cycles, and assessment of IBL activities. The answer to the second question identified the extent to which students developed CT skills through the use of IBL activities in their biology course, thus clarifying the current practices related to core CT skills and the relation between IBL instructions and CT skill development. The third question was meant to describe the influence of high school biology teachers on students' development of CT skills, including an explanation regarding teachers' perceptions of IBL activities, the effect of their knowledge and CT skills on their teaching practices and the impact of their teaching practices on the development of their students' CT skills. Finally, the fourth question aimed to explain the effect of demographic factors including gender, grade level and the location of the students' campuses on the research results. Based on the findings of this research, the recommendation included a suggestion of conducting a series of professional development workshops through which the teachers are trained to utilize IBL instructions effectively and create learning experiences that ensure the appropriate practice of IBL instructions and develop core CT skills in students. The last part of this chapter explains the limitations of this study, practical and field implications and recommendations, in addition to recommendations for further research and the conclusion of the study.

5.1 Discussion

The aim of this study was to investigate the effectiveness of incorporating inquiry-based learning in biology classes on the development of high school students' critical thinking abilities. The research study followed the mixed method complex design, specifically "equal status, concurrent design" of mixed research (Johnson and Christensen 2008). The findings of this research study are based on the nonexperimental questionnaire, lesson observations, interviews with teachers and document analysis of students' artefacts.

The study was based on four major questions, each of which was answered using the data collected and analysed from a combination of the qualitative and quantitative tools described in the methodology. Data collection from both tools took place concurrently, and the results were combined and interpreted in this section to support the findings of the study. The following sections will discuss how the data extracted from the tools were used to answer the four research questions. Then, a concluding section will present a suggested plan for professional development that addresses the problems identified in this study and is meant to train teachers to effectively utilize IBL instructions to develop students' CT skills.

5.1.1 What are students' experiences with IBL implementation in a high school biology course in UAE?

The first research question required direct input from students reflecting on their own learning. To obtain sufficient data to address it, answers to the quantitative non-experimental questionnaire collected from students were analysed. The questions related to IBL implementation in biology course were designed to prompt students to describe their experiences with IBL implementation in their high school biology courses. To support the findings associated with the responses collected from the questionnaire, the qualitative data was used to provide evidence extracted from lesson observations, teachers' interviews and documents collected from the students after each lesson observation. The main findings related to this question are described in three main subsections: the first subsection is related to the levels of complexity observed and students' independence during IBL activities. The second subsection discusses the application of the inquiry cycles, including questioning and forming a hypothesis, planning and investigating, analysing data and evidence, formulating conclusions and communicating knowledge. The last subsection is related to the assessment of IBL activities conducted by teachers in regards to how effective they are in developing students' learning and CT skills.

5.1.1.1 Levels of complexity of IBL activities

According to Banchi and Bell (2008), IBL activities can be categorized into four different levels of complexity, which are confirmation inquiry, structured inquiry, guided inquiry, and finally open inquiry, ordered from least complex to most complex. In this study, results pointed towards a limited level of complexity in terms of the IBL activities implemented in biology classrooms. According to the results of the questionnaire collected from the students, the majority of students' responses reflected that IBL instructions were implemented approximately once every two weeks. However, there were high responses to items related to receiving step-by-step instructions and observing demonstrations by the teacher, indicating that structured and guided IBL activities were the dominant types of instruction. Students were therefore not given the opportunity to work independently through open-inquiry activities, which was supported by the fact that their responses to items related to planning and implementing an investigation were relatively low. All through structured inquiry, questionnaire responses reflected that students were less autonomous and more dependent on the teacher to ask them a question first, follow a procedure to collect data and draw a conclusion from a given activity (Llewellyn, 2011). During the lesson observations, the qualitative data describing classroom interactions also indicated the dependence on instructions and guidelines as a general theme during IBL activities. Students were undoubtedly given opportunities to participate in IBL activities in nine of the observed lessons. However, seven out of nine of the activities that took place were structured and guided, where students were provided with a question and were guided throughout the activity. Moreover, students were given an opportunity to apply an open-inquiry scientific investigation only in one class observation out of twelve. Theoretically, applying open inquiry activities would help students gain autonomous skills and become self-independent learners (Llewellyn, 2011). From the teachers' perspective, the use of guided inquiry was considered to be more convenient, as most teachers expressed in the interviews conducted during qualitative data collection. They agreed that students' academic level and the nature of specific topic discussed, presented a challenge when preparing for other types of IBL activities and incorporating them within classroom instructions. For example, as per the teachers' interviews, the topics that requires investigating the effect of environmental factors on biological processes could have several IBL applications. However, topics related to plant anatomy would have less applications. This is supported by the study by Schramm et al., (2017) which proved that IBL supported students to overcome all their misconceptions related to photosynthesis and cellular respiration topics. Teachers also mentioned that students should be trained on the application of IBL activities during their study in Grades 9 and 10, so that they can implement more open inquiry activities in higher grade levels. In all, the findings of this study confirmed that students' experiences in IBL activities were limited to structured and guided types of inquiry. Though the curriculum resources shared with the teachers in the schools in which the current study was done included open inquiry activities, the students reflected in their responses to the questionnaire that they experienced activities in which they follow step by step instructions to complete them. In addition, the high percentage of observed lessons in which guided and structured IBL activities were done It is necessary that all types of inquiry are integrated into classroom activities, especially moving towards more open inquiry activities, as its importance has been demonstrated by Artayasa et al, (2017) who proved that despite the fact that three types of inquiry (structured, guided and open) would all improve students' integrated science process skills and are considered better teaching strategies compared with the traditional teaching method, the open IBL activities always had the highest effect on the improvement of students' scientific process skills, including working scientific procedures, data collection, presentation and discussion in addition to drawing conclusions.

The finding of this study also confirmed that training is required to implement IBL activities. However, scaffolding must be utilized to lead students to gain the skills required to implement more open-inquiry IBL activities, this means that open inquiry lessons must be integrated in classroom instructions gradually, and students' progress should be observed in terms of their improved independence within the academic year in each grade level. This was also emphasized by Caswell and LaBrie (2017) who indicated in their study recommendations that students need to be trained and prepared to receive new types of instructions, and they should be exposed to more independent inquiry activities during school time. In addition, the finding of Scott et al, (2018) emphasised that when students are exposed more frequently to IBL activities, they develop a better understanding of the nature of science and are encouraged to join STEM careers in future. Hence, limiting IBL activities to structured and guided in classrooms will not help students gain the experimental scientific skills needed to become independent learners. The results of this study indicated that the students who were exposed to full inquiry activities were given opportunities to analyse and interpret data, which was evident in their submitted laboratory reports. On another note, Van Uum, Verhoeff and Peeters, (2017) emphasised the importance of professional development for teachers that would enable them to implement open inquiry. The conclusion of their study was that when teachers were trained on implementing scaffolding, they were able to create open inquiry activities and allowed students more independence in their learning. An earlier supportive empirical study by Hughes and Ellefson (2013) proved that providing IBL instructions training to a graduate teacher assistant had a significant effect on the students' performance in standardized examinations. This supports the recommendation of this study, which is to design specific professional development workshops to support teachers to design and apply open IBL activities in the biology high school curriculum.

5.1.1.2 Application of the inquiry cycles

In their class time, students were successfully guided to perform the questioning, hypothesizing, experimenting and concluding stages of the inquiry cycle. Nonetheless, results did not provide any evidence for appropriate data analysis performed by students during IBL activities, which mostly affects the quality of conclusions drawn. Students' competence in four of the five inquiry cycle stages was reflected in the quantitative data, where questionnaire responses showed that students were able to ask questions, perform a procedure, collect data and draw conclusions. In addition, students' responses to questions related to their ability to connect the conclusion with the scientific concept being studied were at an acceptable level (average 3.7), which meant that the students mostly agreed that they can connect the IBL activity to the topic of the lesson. However, analysis of students' responses to items related to designing and implementing a procedure in an investigation reflected a relatively low implementation of such activities. Thus, it was apparent that students were not sufficiently exposed to the kind of learning experiences that train them to perform the complete inquiry cycle throughout a scientific investigation.

An Inquiry Cycle typically begins with questioning a certain phenomenon, then hypothesising a solution, followed by creating an experimental design with an identified variable, collecting and analysing data, interpreting evidence and drawing conclusions. Findings from lesson observations also identified the same gaps in the inquiry cycle when IBL activities were implemented in the observed classrooms. These gaps were particularly present in the steps related to designing a proper scientific investigation and performing an in-depth data analysis by collecting and interpreting evidence to draw conclusions. From the teacher interviews, two distinct views related to the implementation of the inquiry cycle were expressed by the participating teachers. The first view was that students needed support and guidance all through the inquiry process, where they related the benefit of IBL instructions to the effective guidance of the students in order to direct their thinking and support them with connecting their findings to the main topic. The second view was that if students were guided at the beginning of the inquiry activity to develop a hypothesis and identify variables, they will be able to complete the task successfully. Both views were aligned with the lesson observation findings. Yet, most of the observed lessons reflected full guidance by the teacher, while students' autonomy in performing the IBL activity was only observed in limited situations, as students were given the opportunity to perform open inquiry activities only when they were required to complete a scientific investigation in the laboratory. This is supported by Nybo and May (2015) who confirmed that when students apply IBL instructions through scientific investigations, they develop better understanding to the scientific concepts.

The findings of this study imply that the implementation of the data analysis and result interpretation phase was limited, as the lesson observations reflected lack of data analysis practice during classroom instructions. This would negatively affect students' understanding of the discussed concepts. Pedaste et al., (2015) defined the IBL phases including orientation, questioning and hypothesis, experimentation and exploration, data interpretation and finally the conclusion. If students missed the data interpretation stage, their conclusions would end up being unauthentic. As per Llewelyn (2011), analysing data should lead the students to determine if the data was biased or accurate, then they can seek relationships between different types of data and find evidences that supports the new connections. After finding the evidences based on the collected data, they will be able to draw accurate conclusions. The need to practice all of the phases of scientific inquiry was supported by Arnold, Kremer and Mayer, (2014) who clarified that students need to follow the scientific procedure during school time to fill any gaps in their learning, as they need to develop their experimental knowledge and skills such as finding and interpreting valid data to draw reliable conclusions. The results of this study revealed that scaffolding and guidance are essential elements in implementing IBL instructions, as they are required to train the students to master the required skills to complete IBL activities. This finding is in line with the finding of Kang and Keinonen, (2017) and Lazonder, A. and Harmsen, R. (2016) who emphasized that guidance is an important component in implementing scientific inquiry, and that scaffolding in inquiry design is required in order to train students to write a hypothesis and identify the experimental variables, which is crucial if students were to gain the skills required to perform scientific experiments. Another supportive metanalysis study by Lazonder and Harmsen (2016) and Sun, Looi and Xie, (2016) also concluded that guidance is an essential requirement to implementing IBL instructions, whether it was for a short-term activity or a long-term open-inquiry activity and had a similar recommendation to the previous study. They recommended implementing scaffolding practices as an essential requirement to successfully apply IBL activities. A similar recommendation from an earlier study by Chen and She, (2014) entails that to integrate the implementation of IBL within scientific reasoning, it is important to prepare a framework of scaffolding techniques to support students throughout the given activities. All the results related to the importance of scaffolding and the practice of core CT skills are aligned with Vygotsky's theory of social constructivism and the zone of proximal development model, which are part of the theoretical framework supporting this study (Slavin, 2011; Long et al, 2011).

5.1.1.3 Assessment of IBL activities

The answers related to this subtopic emerged from interpreting and analysing the data collected from lesson observations and document analysis. The lesson observation tool included two items related to assessment practices: "Inquiry cycles are assessed frequently after each step" and "Develop and use valid criteria for evaluation (i.e. rubrics) that are clearly communicated and understood by students". Out of the twelve lessons observed, only five lessons included the use of clear assessment tools to evaluate students' performance after each inquiry stage. Hence, most of the students were not assessed after each inquiry stage in the observed activities. Besides, students were not sufficiently trained to use rubrics for self-evaluation, since this item was seen in only one of the observed lessons. The findings of the lesson observations indicated poor assessment of IBL activities. To support the findings of the lesson observations, the artefacts and assessment samples submitted by the students after each observed lesson were also reviewed. With the exception of the laboratory reports submitted after scientific investigation, the documents reflected poor responses by students to the questions related to scientific investigation, which indicated a prevalence of weak analysis skills. It can be concluded that when students are not assessed after each inquiry stage, they will not develop the essential CT core skills that would prepare them to become critical thinkers. This is indicated by the poor implementation of the data analysis stage in the observed IBL activities, which leads to poor practice of sorting data and finding relationships between various facts collected (Llewelyn 2011). When this stage is missing from the IBL activity or it is not assessed by the teacher to ensure that students discussed their collected data and were able to identify evidences for their findings, then the teachers cannot confirm that their students had practiced inferring or explanation CT core skills. As per Facione (2015) if students were exposed to learning situations where they can practice inferring, interpretation, explanation and evaluation, they can develop CT skills.

This finding is in line with the results of several research studies that linked assessing students' performance after each inquiry stage to their ability to develop critical thinking skills and reflect the required impact of IBL activities on their learning experiences (Pedaste et al., 2015; Grob, Holmeier and Labudde 2017; Sabri and Forawi 2019). The findings of this study revealed the lack of rubric utilization to encourage self-regulatory learning skills, which was also contributing to their poor results in the summative assessment samples. This result is in line with the study of Grob, Holmeier and Labudde (2017) who referred to the importance of sharing rubrics with students and described that as one of the best practices that support the formative assessment of IBL activities. In addition, the results related to the use of laboratory reports were aligned with the results of the research by (Aydın, 2016) who emphasized the importance of writing scientific laboratory reports to improve students' communication skills and avoiding bias when making decisions.

Overall, the results of this study suggest that students were not receiving effective IBL instructions that allowed for the implementation and assessment of all the steps of the inquiry cycle. This result is supported by the results of several empirical studies mentioned in the literature review emphasizing the importance of formative assessment and observing students' interactions and behaviour throughout the IBL stages to enable teachers to evaluate their students' performance and provide the required guidance to support their learning (Pedaste et al., 2015; Grob, Holmeier and Labudde 2017; Sabri and Forawi 2019). The research by Pedaste et al., (2015) emphasized on the importance of teacher-student and student-student interactions throughout the IBL phases, they suggested that teachers must follow up class discussions and ensure that all their students are communicating their understanding and reflecting upon it. In addition, Sabri and Forawi (2019) highlighted the importance of formative assessment in implementing effective IBL activities. Their research indicated that when students are provided with effective feedback after each inquiry phase, they develop a better understanding of the discussed scientific concepts. This is also supported by the study of Kim et al., (2015) which recommended structuring classroom instructions into short time intervals to guide students through several learning cycles, rather than having one long learning cycle that includes less assessment activities. If IBL instructions were implemented through distinct stages followed by clear assessment activities, the teacher will be able to track individual student progress throughout the lesson. Additionally, the importance of the use of rubrics in training students to assess their own performance has been highlighted by Grob, Holmeier and Labudde (2017) who suggested supportive practices that could help teachers to better evaluate their students' performance during IBL activities using formative assessment. Their suggested practices included explaining assessment rubrics to the students, ensuring the application of the element of assessment after each inquiry stage and proper time management.

To sum up the answer of the first research question, students were given a fair opportunity to implement guided and structured IBL activities, yet lacked sufficient implementation of open-inquiry, which is at a higher level of complexity. They have practiced the questioning and hypothesis, experimentation and exploration phases of the inquiry learning cycle. However, their experiences with the implementation of data interpretation to draw authentic conclusions were limited. The assessment of their IBL practices during implemented lessons was also limited, which relatively narrowed their experiences with IBL implementation in high school biology classes, as students did not receive sufficient feedback to reflect on their own learning appropriately.

5.1.2 To what extent do students develop critical thinking skills through the use of high school biology IBL activities?

The second research question was answered by compiling data from both the quantitative non-experimental questionnaire and the three qualitative tools, including lesson observations, teachers' interviews and document analysis. The main findings related to this question are described in two main subsections, the first subsection describes how students practice the five core CT skills including clarity, analysis, evaluation, inference and self-regulation based on their responses to the nonexperimental questionnaire, data collected from lesson observations and the submitted artefacts. The second subsection discusses the relationship between the implementation of IBL activities and students' development of CT skills.

5.1.2.1 The practice of core CT skills

The core CT skills as described by Facione (2015) and Paul and Elder (2014) include the ability to interpret concepts and get more clarification about the subject, analysing the data to build an understanding to evaluate any situation then being able to make informed decisions to improve thinking. Data collected from the non-experimental questionnaire, lesson observations and document analysis was analysed to determine the extent to which the core CT skills were practiced by the students when the observed IBL activities took place. The core CT skills investigated include clarity, analysis, evaluation, inference, explanation and self-regulation (Facione 2015).

In terms of clarity, the results of the quantitative questionnaire indicated that students agreed with a relatively high average (between 3.8 and 4; significance between 0.028 and 0.001) that they practice skills related to seeking clarity in stating questions. This was supported by the results obtained from the qualitative tools. During lesson observations, it was evident that teachers mostly used interpretation questions in classroom discussions. Hence, the questions used during classroom discussions required students to categorize ideas and clarify meanings before answering them. In addition, findings from document analysis revealed that the majority of the identified CT questions used in the worksheets, classwork tasks and summative assessment samples were also classified as interpretation questions. As per Facione (2015) stating clear questions is one of the characteristics of strong critical thinkers. Considering the results collected from all the research tools, it can be concluded that when students are given the opportunity to practice interpretation to clarify meanings within classroom instructions, and the same type of questions appears in the formative and summative assessments, the students will develop the skill and start using it in their daily practices. This finding confirms Dewey's theory regarding the role of education and practice in the development of mind habits (Dewey 2010), and is also in agreement with Cargas, Williams and Rosenberg's, (2017) conclusions, which showed that integrating CT skills within the contents of any subject would lead to improving CT skills. Additionally, the finding supports the ideas of Nisa, Jatmiko and Koestiari, (2018) who suggested that the use of developed materials that integrate CT skills in a physics classroom had a positive effect on the improvement of students' CT skills. Furthermore,

As for analysis, students' responses showed an agreement averaging between 3.6 and 3.7; and a significance between 0.030 and 0.002, that they practiced skills that improve their analytical skills. Yet, a relatively high average for item number CTA7 "I passively accept claims being made in classroom discussions" indicated poor implementation of analysing and seeking relevant information. Thus, as per Facione (2015) students lacked one of the important characteristics of strong critical thinkers. Reviewing lesson observation results revealed that students were not given an opportunity to practice data analysis during the implemented IBL activities. Consequently, analysis questions comprised a mere 16% of the identified CT questions recorded during all lesson observations. This meant that current classroom instructions lacked this type of questioning, and students were not able to adequately practice analysis. As a result, students' responses in the collected samples of the summative and formative assessments lacked meaningful evidence related to students' abilities to analyse and interpret data. This finding is supported by Forawi (2016) who proved that CT skills such as analysis skills are developed through IBL. The document analysis review also supported this finding, as analysis questions constituted only 17% of the questions that appeared in the formative assessment, and 2% of the questions that appeared in the summative assessment samples. As a result, students' performance in the summative assessment samples revealed that 92% of students were not able to respond to analysis questions correctly. This indicates that lack of appropriate exposure to CT skills in the classroom can negatively impact the development of those skills. This is consistent with the findings of Saputro, Rohaeti and Prodjosantoso, (2019) which revealed that when students were given a chance to practice scientific process skills they developed CT skills, while students who were not exposed to the same scientific experience did not show a development in their CT skills.

In the case of evaluation, students' responses showed an average agreement between 3.7 and 3.8 and significance values ranging from 0.003 to 0.009 that students practice evaluation skills in biology lessons. This included assessing the credibility of information and learning how to identify their learning gaps. However, one item in that category did not show indicate a significant implementation (CTE9) which stated: "I draw conclusions about a problem based on the evidence at hand". This result was compared with the findings from lesson observations, as the item addressing discussion and making an argument was observed in eight lessons out of twelve and the item related to finding conclusions or generating and assessing solutions was observed in nine lessons. However, the item related to analysing arguments was realized in 50% of the observed lessons. This meant that students were not given the same opportunities to practice questions that support the development of their evaluation skills. In addition, the percentage of evaluation questions recorded in the observed lessons was only 1.3%. The document review showed that questions that can be classified as evaluation questions were only 13% of the formative assessment questions. 10% of the questions in the samples from laboratory reports appeared in the summative assessment. During the summative assessment, 38% of the students were able to provide correct answers to the evaluation questions that appeared in it. Further analysis of the results indicated that all of the students who were able to provide correct answers in the summative assessment for evaluation questions were present in lessons where the teachers utilized various processes to resolve, re-address, and re-analyse complex situations to gain new insights. Considering the results from both the qualitative and quantitative tools, it can be concluded that students' development of evaluation skills depends on the type of practice provided in the class. This finding is supported by the study of Kong (2015) which revealed that when students were given more opportunities to practice evaluation skills through instructions, they were able to improve their CT skills significantly across the three years of the study.

With respect to inference, students' responses reflected an agreement with an average of 3.8 in two items, with significant values of 0.001 and 0.006 respectively, for CTI15 and CTI16 which are "I learn how to think within the point of view of those whom I disagree with their opinion" and "I consider how my assumptions are shaping my point of view". This means that from the students' point of view, they were given opportunities to practice skills that would help them to identify the elements that they need to draw conclusions Facione (2015). Throughout the lesson observations, the items related to students' encouragement to think independently and suspend judgment or prior conceptions were observed in ten lessons out of the twelve, and the students in these lessons were allowed to give their opinion in a safe environment, without being blamed for their wrong choices, and they were guided through discussions to think deeper and adjust their decisions. However, the percentage of inference questions recorded in all lesson observations was only 8% of the identified CT questions. This means that while the teachers were supporting students to gain inference skills during the flow of class discussions, they were not assessing this skill through their verbal questioning. In document analysis, the percentage of inference questions that appeared in the formative assessment tools was only 22% and comprised 10% of the summative assessment samples. The summative assessment results showed that 53% of the students' responses to inference questions were correct. Linking the teaching practices observed to the summative assessment results leads to the same conclusion as other core CT skills, which was that provided students were trained to use CT skills in daily instructions, they will develop CT skills. This finding is also supported by the study of Kong (2015) which revealed that students develop inductive skills and inference when they are provided with instructional materials that require them to infer information from a given scenario. This finding is supported by Paul and Elder's model (2006) that explains the relationships between intellectual standards including clarity, accuracy, precision, relevance, depth, breadth, logic ,significance and fairness with the application of core critical thinking skills such as interpretation, inference and point of view as an element of thought that leads to the development of intellectual traits such as humanity, autonomy, integrity, courage, perseverance, confidence in reason, empathy and fairmindedness.

For the CT skill of explanation, student responses reflected significant agreement with a high average of 3.8 and a significance of 0.002 that they practice skills that allow them to justify reasons and analyse arguments. Similarly, the reviewed data from lesson observations showed that in eleven lessons out of twelve, teachers were providing constructive feedback and asking students to explain their choices to identify their strength and weakness points. Yet, the percentage of verbal explanation questions recorded in the observed lessons was only 4%, indicating a lack of follow-up to assess the development of this skill during classroom instructions. As for document analysis, the formative assessment samples collected included only one explanation question that was identified in one of the submitted laboratory reports. In the summative assessment samples, 18% of the questions that appeared were classified as explanation questions. The results of the analysis of the summative assessment revealed that only 30% of students' responses to explanation questions were correct. This also leads to the conclusion that using verbal constructive feedback in classroom instructions is not enough for students to be able to exhibit explanation skills clearly in their final assessment. This finding is also in line with Paul and Elder's model (2006) and it is supported by the study of Michaluk et al. (2016) who used Paul and Elder's CT model to design assignments for students in the first year of an Engineering program. Their study confirmed that teachers must use structured rubrics along with constructive written feedback to help students to improve their explanation skills. The development of the skill of explanation with the practice of IBL activities was confirmed by the study of Duran (2016) which showed a significant difference between students' CT development in the group of students who were given an opportunity to practice IBL activities, which allowed interactive discussion and questioning that improved students' skills in explanation.

Finally, in items related to the self-regulation CT skill, students' responses reflected a significant (0.003) agreement with an average of 3.8 that students were conscious about their own performance. They were correcting their assumptions and revisiting their views before making a decision and thinking precisely about their thinking process. This finding gave an indication that students were trained to evaluate their work and adjust their learning accordingly. However, this was not consistent with the data collected from lesson observations, as the item related to the use of valid criteria for evaluation was observed only in one lesson out of twelve, which meant that students were not given opportunities to assess their own performance based on specific rubrics. In addition, the percentage of questions that can be classified as self-regulation questions was only 9.3% out of all the questions asked in the classroom. These findings provided clear evidence that students were not trained to evaluate their own performance during the classroom instructions. To follow up on the development of this skill, the revision of document analysis revealed that students were required to reflect upon their learning experiences only in four worksheets collected from the same lesson. This skill was not present in any of the summative assessment samples utilized in the current study. This finding is in line with the findings of Trauth-Nare and Buck (2011) who linked the importance of the use of reflective practices within daily formative assessment techniques to develop students' abilities to evaluate their own work and provide explanations about their thinking processes.

To sum up, the current study revealed that students develop the core CT skills at different levels based on the nature of classroom instructions and the amount of practice provided for each core skill. Students were able to showcase significant development in their interpretation and inference skills. However, the development of analysis, evaluation, explanation and self-regulation skills was not evident. These core skills needed better implementation and further practice to be evident in the students' final assessment. This finding is in line with Dewey's theory regarding training of thoughts, in which he explains the importance of improving the teaching and learning process in accommodating the requirements of transforming thinking habits. These requirements include training through inference, critical examination and continuous inquiry (Dewey 2010). This was also supported by Zapalska et al., (2018), as their research study demonstrated the importance of the consecutive development of thoughts through aligning thinking processes with the six stages of bloom's taxonomy. Their research study provided an empirical evidence about the development of CT skills by guiding students through a series of thinking processes starting from remembering and gradually develop to reach creating and evaluating. The current study also confirms what was explained by Paul and Elder (2014) about the importance of practice in order to develop core CT skills. They clarified that critical thinkers must practice the analysis of their thoughts and the evaluation of their choices with the intention of improving their decisions. The findings of the current study are similar to the findings of Haridza and Irving, (2017) who suggested that learning resources in the middle school science classroom must be directed to help students to improve their CT skills. The instructional methodology adopted in their study helped the students to develop their interpretation and decision-making skills. On the other hand, the students did not reflect their ability to provide a scientific explanation nor logical reasoning behind their decisions.

In addition, the findings of this study are in line with the findings of Darabi and Arrington (2017) which revealed that the adoption of instructional methods that integrate theoretical models to develop CT skills along with intensive scaffolding techniques would support the students to develop their CT skills. This is supported by Dwyer Hogan and Stewart (2014) who emphasized the importance of integrating basic comprehension and application skills with higher cognitive skills such as analysis, evaluation and inference to build the ability to make reflective judgments. When students develop core CT skills discussed in this section, they are also expected to gain intellectual traits such as autonomy, when they become independent thinkers able to look at each concept from different perspectives, intellectual humility, when they become aware of the human nature of egocentrism and the existence of bias due to prejudice, intellectual courage and the confidence in evidence (Paul and Elder 2007a).

5.1.2.2 The relation between IBL instructions and CT skill development

The students' responses to the questionnaire indicated that they practiced CT skills frequently during biology lessons. However, a moderate positive correlation between the responses to IBL instructions and responses to the practice of CT was found. The relation was evident only when students were given opportunity to develop conclusions and connect between the scientific investigation conducted and the scientific concept being explained.

Considering this finding from the questionnaire, the qualitative data collected from lesson observations showed that the discussions among students during IBL instructions were limited and, in most cases discussed questions only at the knowledge and comprehension cognitive level; they did not relate the answers to main scientific concepts related to the IBL activity done. The evidence from the lesson observation led to the assumption that the implementation of the IBL activities at this level was not enough to lead to the development of CT skills. This assumption was also supported by the results collected from teachers' interviews, as some teachers expressed that during the current implementation of IBL in classes, students do not build the required understanding of the lesson, and teachers would need to re-explain the concept to students again if they were to develop CT skills during the lessons. As per the results collected from document analysis, IBL instructions were clearly present only in the laboratory reports and in four samples of class worksheets. The worksheets samples lacked questions that require students to analyse data and evaluate information, but the laboratory reports included questions that improve students' ability to interpret, analyse data, evaluate, infer results and explain ideas. This meant that when students are required to perform practical experiments following appropriate scientific research procedures, they will be offered several opportunities to develop core CT skills. This finding is in line with the findings of Hardianti and Kuswanto, (2017) who concluded that improving students' procedural skills related to scientific investigations leads to their ability to develop core CT skills. Another supportive study by Nisa, Jatmiko and Koestiari, (2018) confirmed that there is a need to develop inquiry-based learning materials to help students to improve their CT skills.

The results from the questionnaire also indicated that students' responses to the analysis and evaluation constructs were the same across all schools. This indicated that the opportunities given to the students to analyse arguments and use valid criteria to evaluate claims were the same across all schools. However, students' responses showed that the application of clarity, inference and self-regulation skills varied between the campuses, which may have been due to the influence of various teaching practices and pedagogies that normally vary in different school locations. This finding is supported by the study of Hacisalihoglu et al. (2018) that provided an empirical evidence on the effect of changing teaching practices on the development of students' CT skills.

Evidence from lesson observations indicated two common issue related to the IBL instructional practices, the first one was related to training students to analyse data and take the information to a higher level. The second one was related to training students to use specific rubrics and evaluate the IBL activity outcome for themselves as well as for their colleagues. This finding is in agreement with the study of Grob, Holmeier and Labudde (2017) with regards to the importance of sharing assessment rubrics with the students and training them to evaluate their own work and improve it. When students practice evaluation and improve their work, they develop the self-regulatory learning skill, which is a core CT skill. A similar study by Boleng et al, (2017) proved that the use of project-based learning as an instructional method supported students' development of CT skills. Applying scientific investigations and the project-based learning model share common skills that students need to practice, such as developing hypotheses, deductive reasoning and drawing conclusions.

5.1.3 How do high school biology teachers influence the development of students' critical thinking skills?

The answer to this question was extracted from the teachers' interviews, then the teachers' point of view was compared with their actual practices through lesson observations and the samples of formative assessment shared by their students after the observed lessons. This section is divided into three subsections, the first one analyses teachers' perceptions regarding IBL and the integration of CT skills in classroom instructions. The second subsection describes the effect of teachers' knowledge and their CT skills on their actual teaching practices. The third section presents the impact of the teachers' practices on the development of their students' CT skills.

5.1.3.1 Teachers' perceptions regarding IBL and the integration of CT in teaching instructions

Teachers' responses to the interview questions reflected their familiarity with IBL instruction and the importance of implementing this type of instruction to increase students' understanding of the scientific concepts. They also stated that the use of structured inquiry is beneficial with lower grade levels as it provides a good opportunity for them to be master the required skills to implement open inquiry.

However, most of the teachers clarified that they do not use open inquiry frequently due to time constrains and the students' poor readiness to apply this type of inquiry. The findings are in line with a recent study performed in the UAE by Eltanahy and Forawi (2019) which concluded that middle school teachers' science teachers reflected good knowledge of IBL instructions, yet they were unable to implement different types of inquiry, particularly open inquiry activities. These findings are also consistent with Karunanayaka et al (2017) which emphasized that despite the time constraints, the use of IBL instructions builds up CT skills, and Glackin and Harrison (2017) who found that teachers are concerned about implementing IBL instructions due to the inability to ensure that students learned all the learning outcomes through open inquiry activities. In addition, the findings are consistent with the study of Kang and Keinonen, (2017) who reported that guided inquiry-based activities and selecting topics that are relevant to students' real life had a positive effect on students' performance. While open inquiry-based instructions and class discussions had a negative influence on students' performance. However, the results of this study do not follow the recommendation of Hardianti and Kuswanto (2017) who explained that the effectiveness of IBL instructions increases with the higher levels of inquiry, and students' experience with IBL activities develop with practice. The results of their study indicated that students who were exposed only to structured inquiry did not show improvement in their process skills as compared to the students who were given the opportunity to implement guided and open inquiry activities. Local studies in the UAE support the results regarding science teaching practices. Dickson, Kadbey and McMinn (2016) proved that the beliefs of science teachers are not aligned with their actual practices in the classroom, as the teachers in their study demonstrated an understanding of the importance of open inquiry activities to develop students' process skills. Yet, their actual practices in the classroom were teacher centred and lacked hands-on activities. On the other hand, the result of the study by Sabri and Forawi (2019b) indicated that physics and chemistry teachers reflected better application of the IBL and formative assessment teaching skills compared to biology teachers. Both studies recommended professional development for science teachers to help them overcome the challenges that hinder the implementation of IBL instructions in their classrooms

The findings from the interviews also revealed that teachers had limited perceptions of CT, as they provided five main ideas with respect to the meaning of CT, including that it is a questioning teaching strategy, thinking process that links information to real-life situations using logic and reasoning and forming an opinion and defending it. None of the ideas discussed with the teachers reflected a proper understanding of CT based on Paul and Elder's (2014) definition of CT, that it is the analysis of one's thoughts and their evaluation in an attempt to improve decisions. In addition, they were not able to identify the elements of CT, which means that they would not be able to apply instructional methods to integrate the elements of thought within instructional materials for their classes. Teachers agreed that integrating CT in instructional activities is important. However, they were unsure about the way in which this integration must be done and what the most effective method to help the students become critical thinkers was. This finding aligned with the findings of Forawi (2016) that teachers lack proper awareness of the concept of CT and how it can be integrated within teaching and the learning processes. The findings from the interview revealed that biology teachers were mostly aware of the relation between teaching science and the development of CT skills; they referred to the stages of scientific procedures and the importance of having a deep understanding of science in order to improve students' performance in all science subjects. This finding is also supported by the study of Akgun, and Duruk (2016) which confirmed that preservice teachers' CT dispositions are relatively low and that they require academic guidance in order to grasp the concept of CT and its elements, which would enable them to plan and implement classroom instructions that allow for opportunities for students to develop CT skills. This finding is also in agreement with the findings of Saputro, Rohaeti and Prodjosantoso, (2019) as they confirmed that when students practice scientific inquiry through practical laboratory activities, they exhibit a better development of their CT skills.

The teachers in this study suggested several methodologies to integrate CT within their instructions, such as project-based learning, open discussions through questioning and the use of scenario or case studies to practice problem solving. This finding seems to be consistent with previous studies that proved the effectiveness of the same methodologies which were suggested by the teachers in this study, such as Boleng et al, (2017) who proved that utilizing the project-based learning model improves students CT skills. Additionally, Karunanayaka et al, (2017) who suggested that the use of the scenario-based approach with appropriate formative assessment tools would improve students' reflective and CT practices.

5.1.3.2 The effect of teachers' knowledge and CT skills on their teaching practices

The findings of the interviews in relation to the findings of lesson observations indicated that when teachers had a shallow understanding of the concept of CT and its components, their observed lesson reflected a lack of CT questioning techniques, constructive feedback provided to students and self or peer assessment strategies. On the other hand, teachers that had a good background on CT and its elements demonstrated better questioning techniques that enhanced students' contribution and provided opportunities for students to adjust their thoughts and provide better answers. In addition, the majority of interviewed teachers expressed their concerns about the condensed curriculum and related that to their inability to integrate CT skills in their instructional practices, as they may not be able to complete all the required learning outcomes and prepare the students for the standardized testing. On the other hand, a teacher with a good background about the concept of CT expressed that it could be applied in any situation and that there are no limitations to integrating it within daily instructions. This means that teachers should be made aware of the concept of CT and its components, and then trained to design instructional activities that support students and allow them to practice core CT skills. This finding is consistent with the study of Forawi (2016) which recommended training pre-service science teachers to recognize CT attributes and designing suitable instructional activities to improve students' CT skills. Another supportive study by Mok and Yuen (2016) revealed that teachers' background knowledge about CT was limited to describing CT as a generic reasoning skill that should be developed in their students. The Hon Kong teachers' understanding of CT lacked the requirement of analysing, evaluating and readjusting thinking as a constructive procedure. With respect to standardized testing, the study of Fong et al. (2017) indicated that if students could develop the required skills to think independently, it will positively affect their performance in standardized examinations.

Though most of the teachers agreed that the use of IBL instructions would help students to develop CT skills, their actual applications observed in the lessons lacked practices that would help students to develop essential CT skills such as analysis, evaluation, explanation and self-regulation. This means that teachers needed professional development to design guided inquiry activities that would promote students to practice CT skills. This finding is in line with the findings of the study of Almuntasheri, Gillies and Wright (2016) which revealed that when students were exposed to guided inquiry instructions led by trained teachers, they reflected scientific explanation skills at a significantly higher level than the students who were exposed to teacher-centred instructions.

5.1.3.3 The impact of teaching practices on the development of students' CT skills

The variation in teachers' feedback related to the opportunities given to students to develop CT through IBL activities were supported by the quantitative results of the questionnaire. It was evident that students' responses to their experiences regarding interpretation, inference and self-regulation were not consistent in different school locations. This led to the assumption that if teachers were trained enough to design IBL activities and support students during the instructions, the students will be able to practice and develop the core CT skills.

In addition, the collected samples of formative assessment documents reflected poor integration of core CT skills in the given assignments and worksheets, as the level of students' responses in most of the documents was at the knowledge and comprehension level of Blooms taxonomy.

Students' responses to the summative assessment questions revealed low percentages of correct answers for almost all the questions that can be categorized as CT questions. The previous analysis of IBL practices in the observed biology classroom revealed the need to emphasize data analysis, evaluation of evidence, scientific explanation and self-reflection skills in the implemented IBL activities. Therefore, it can be concluded that the current practices in biology classrooms do not support students to develop their CT. This finding is supported by literature that linked between appropriate implementation of IBL instructions and the development of students' core CT skills (Saputro, Rohaeti and Prodjosantoso, 2019; Nisa, Jatmiko and Koestiari, 2018; Caswell and LaBrie 2017; Fuad et al., 2017; Duran 2016; Pedaste et al., 2015; Arnold, Kremer and Mayer, 2014). The recommendations of this study will include a plan for teachers' professional development that will enable them to implement effective IBL instructions and provide opportunities for students to practice core CT skills.

5.1.4 How do demographic factors affect the development of students' critical thinking skills when applying IBL activities in the biology curriculum?

The demographic factors considered in this study included the gender of the students, grade level and the location of the school. Data analysis for the results from the non-experimental questionnaire was performed to investigate the effect of each of the demographic factors on the development of students' CT skills. The answer for this question is divided into three main subsections: the first one discusses the effect of students' gender on the utilization of IBL activities and students' development of CT skills. The second subsection presents the discussion related to the effect of grade level, which will consider the nature of the topics and the level of inquiry in each grade level.

The third subsection presents the effect of the location of the campus, which is affected by the teachers' background and experiences in utilizing IBL instructions to develop students' CT skills.

5.1.4.1 The effect of gender on the research results

The analysis of the non-experimental questionnaire results revealed that male students had responded with slightly less averages than female students for all the items related to their experiences with the implementation of IBL instructions and the practice of CT skills. With respect to IBL instructions, this difference was significant only in the items related to data collection and drawing conclusion from a set of data. However, the difference between male and female responses to all other items related to IBL instructions was not significant, which means that male and female students were given the same opportunities to implement IBL activities and had approximately the same feedback about their experiences after the application of IBL activities. This finding is not in agreement with the findings of Kekule et al (2017) who investigated the effect of gender when assessing IBL in science education. The sample of the study was the pre-service science teachers. The results of their study revealed that IBL instructions had a higher impact on female students than male students. On the other hand, this finding is consistent with the findings of the study of Nunaki et al., (2019) about IBL instructions in a senior high school in Indonesia, the study revealed that both male and female students demonstrated the same level of improvement in their metacognitive skills after the implementation of IBL activities. There are several possible explanations for this result, as male and female students are exposed to the same conditions with respect to IBL activities in biology lessons. Nunaki et al., (2019) explained that the similarity of effect of IBL on male and female students was due to having the students in the same classroom and creating collaborative groups that consist of male and female members. However, this is not the case in the schools in which this study was implemented, as male and female students are segregated in different classes. A possible explanation for the similarity in this school system could be related to the distribution of a unified curriculum plan that identifies specific IBL activities that must be delivered in the same period of time. The curriculum provides a suggested list of IBL activities that teachers can implement based on their preference; they can design the activity to be open inquiry or they can provide the students with the question and guide them through the activity. All teachers follow the same pace, have the same resources and implement the same activities. This reduces the amount of variation with respect to the implementation of IBL activities. In addition, as per the results of the teachers' interviews, most of the teachers' experiences and perceptions towards IBL lead them to apply approximately the same instructional methods in both male and female schools.

The development of students' CT skills was shown to have more of an association with students' gender, seeing how the results of this study revealed that female students responded at slightly higher means than male students to all items related to CT, except for the item related to readdressing complex situations to gain new insights, which didn't show a significant difference between male and female students. The findings reflected a significant moderate association between gender and practicing CT skills. This finding is consistent with the finding of the studies by Devika and Soumya (2016) and Fuad et al., (2017) which revealed a significant difference between female and male students with regards to the ability to develop CT skills. Similar to the current study, female students in their studies presented higher CT abilities than male students. The difference in female and male responses can be explained to be due to the difference in the anatomy of the human brain and the ability of females to use both sides of the brain simultaneously. However, the difference between female and male responses in the research results is too small. Therefore, it can be concluded that gender has a minimal contribution to the research results, even though the difference is considered significant. The same result was also provided by Fuad et al., (2017) in which the sample included Grade 7 in a school in Indonesia. Consequently, the findings of this study may support the studies of Bećirović et al, (2019) and Piraksa, Srisawasdi and Koul, (2014) which proved that CT development is not affected by the gender of the students.

5.1.4.2 The effect of students' Grade level on the development of CT skills

The analysis of the non-experimental questionnaire to find the relation between students' grade level and their responses to IBL and CT items proved that grade 9 students responded with higher means to the items related to IBL activities. This can be related directly to the topics discussed in the curriculum that allow for more IBL activities, such as cellular biology, photosynthesis and cellular respiration in the ninth-grade curriculum, while the topics in the tenth Grade are focused on plants, evolution and body systems. This is supported by the study of Forawi (2016) which emphasised the importance of the curriculum plan in integrating IBL activities that promote the development of students' CT skills.

In addition, students in grade 9 are introduced to the system for the first time, which may cause them to have a higher motivation due to the implementation of IBL activities. The relation between the implementation of IBL instructions and motivation was proved by the study of Hadjichambis et al., (2015) which proved that students' motivation towards learning increases in classroom environments which utilize IBL instructions.

Grade 9 students responded with slightly higher means than Grade 10 students in items related to CT development. However, the difference was significant only in five items, each of which is related to one core CT skill, including interpretation, analysis, inference and self-regulation skills. This finding can be related to the nature of the curriculum required in both grade levels including the topics covered and the suggested laboratory activities. The importance of integrating CT core skills in the curriculum was proved by the study of Cone et al., (2016) as they concluded that CT skills can be integrated into the curriculum, taught in the classroom and assessed using special tools. This can be applied to develop the current biology curriculum by including learning outcomes that require students to use the core CT skills. In addition, it would be required to add suggested IBL activities that are based on performing scientific investigations.

The findings of this study revealed that Grade 9 students presented better experiences in the practice of IBL activities and CT skills. This can be explained by two main factors, the topics required in Grade 9 curriculum and the students' curiosity as they join the school system and experience this type of learning for the first time. This finding was unexpected, as previous literature suggested that when students are trained to apply IBL activities at earlier stages, they will be able to develop their procedures and perform better in higher grade levels (Saputro, Rohaeti and Prodjosantoso, 2019; Fong et al. 2017; Hardianti and Kuswanto 2017). Although the finding is not consistent with the result of the research studies which confirmed the effectiveness of the sequential implementation of IBL activities, meaning that students experience structured then they move to guided and open IBL activities. This difference was explained to be due to the inclusion of biology topics that can be investigated through IBL activities such as cellular activities, photosynthesis, cellular respiration and cellular reproduction topics in the curriculum and the insertion of a higher percentage of IBL activities in the lower grade levels. For example, Bećirović et al, (2019) investigated students' CT levels in a high school in Turkey. Their study indicated that the students in the senior high school grade levels presented lower levels of CT compared to students in the first and second grades in the high school. They reasoned their findings by referring to the curriculum for each grade level, which may have included less opportunities to practice CT skills at senior high school grade levels. Another reason for this result could be related to students' motivation and their curiosity to apply new strategies when joining a new educational system in lower grads, this assumption is supported by Ellwood and Abrams (2017) who confirmed in their study that students with higher motivation towards their learning are more committed to their learning responsibilities and achieve higher academic scores.

5.1.4.3 The effect of school location on the development of students' CT skills

The findings of this study proved that there is no significant difference in implementing IBL instructions between the eleven campuses across the UAE. This can be related to the centralized curriculum and the implementation of the same IBL activities across the schools, as one curriculum document with identified learning outcomes is distributed to schools. In addition, the same learning resources are shared with the students in all the schools. However, there was a significant difference in the students' development of CT skills. This finding leads to an assumption that instructional methodologies in different campuses vary and cause the significant difference in the practice of CT skills. Consequently, students' ability to develop CT skills also differs. These results are better explained when they are aligned with the findings from lesson observations and teachers' responses in the interviews. Hence, the findings reflected a variation in the conceptual understanding of CT between biology teachers, which led to the variation in their instructional strategies to integrate the practice of core CT skills. As a result, these findings indicated a clear variance in the application of CT skills in different school locations. This can be related to teachers' experiences and their ability to integrate the application of CT in their instructional practices. For example, when teacher reflected strong background knowledge and skills about the concept of CT, their lesson observation revealed the proper use of questioning strategies in the classroom. This was also reflected in the responses of their students in the formative and summative assessment samples submitted by their students. These findings are supported by the previous literature which related between the teachers' background and their experience with CT and their ability to develop suitable instructions to help the students develop CT skills (Forawi 2016; Mok and Yuen 2016; Fong et al. 2017)

5.1.5 Suggested professional development for teachers

Science teacher professional development is essential for allowing teachers to develop their skills in utilizing IBL to improve students' CT skills. The results of the current study revealed that professional development is needed for science teachers to become familiar with utilizing IBL instructions to develop students' CT skills. This finding is supported by Forawi (2015) who explained in detail the requirements needed for science teachers' professional development in the UAE. The main aspects of professional development needs that were discussed in Forawi's (2015) study were teaching pedagogies including guided inquiry, CT development and assessment methodologies. In addition, the ministry of education in the UAE has initiated the teacher licencing project to ensure that all teachers have the foundational scientific knowledge and the pedagogical experience that would qualify them to teach in the UAE. By 2020, the teacher licence will be a mandatory requirement for teaching in UAE (Tls.moe.gov.ae, 2018). In case the teacher did not meet the criteria for licensing, they will be directed to enrol in specific professional development workshops based on their needs.

The result of this research study indicated that most biology teachers were aware of the types of IBL instructions. However, they avoided using open inquiry activities due concerns related to time management, the fear of losing control on students' learning and the condensed curriculum that needs to be completed before standardized testing. The results also reflected poor conceptual knowledge regarding the meaning of CT and how it can be integrated into daily instructions. This is supported by the study of Almuntasheri, Gillies and Wright (2016) who proved that trained teachers were able to deliver IBL instructions effectively, as their students achieve higher results than the students who were taught through traditional strategies.

The findings of the current research study necessitate a plan that would help the teachers to change their mind-set regarding the control on students' learning and begin to implement IBL activities with appropriate assessment methods that would ensure students' learning, core CT skill development and their readiness to enrol in higher education institutions upon the completion of their high school education.

Professional development of teachers is a powerful engine that stimulates student performance. Following the Interstate Teacher Assessment and Support Consortium (InTASC) 2013, teachers' professional development is a continuous cycle as illustrated in figure 5.1. Designing a comprehensive teacher-training program based on the guidelines in the cycle entails a range of aspects, including the identification of specific teachers' needs, peer mentoring and coaching programs, self-reflection, evaluation and continuous professional development procedures.

Figure 5.1 Continuous Professional Development Cycle -adopted from InTASC Model Core Teaching Standards and Learning Progressions for Teachers (2013)

5.1.5.1 Identification of the areas of improvements

The first step in any planned professional development begins with the identification of the areas where teachers need support in. The results of this research study exposed two main areas of improvements in science education. The first one was the need of guidance, support and training for science teachers to enable them to utilize IBL instructions to support high school students in developing their critical thinking skills. The second one was the need to introduce CT as a concept and higher order thinking skill, and explain its elements and evaluation methods, in addition to the various methods of integrating it in daily classroom instructions (Vieira, Tenreiro-Vieira & Martins 2011; Forawi 2012; Forawi 2016). The suggested series of workshops aim at training teachers to:

- Develop IBL activities that clearly progress from structured and guided to open inquiry and allow more space for students' autonomy.
- Prepare IBL activities that require students to perform all the inquiry phases without skipping the analysis and interpretation parts.
- Prepare assessment tools to ensure students' mastery of the concepts discussed after each inquiry stage.
- Allow peer discussions and collaboration between students at different academic levels to ensure variation within students' groups.
- Evoke students' thinking by asking how and why questions.
- Provide constructive feedback that would help students to adjust their learning and develop a correct conceptual understanding of the discussed topics.
- Provide students with rubrics for each given task and allow them to evaluate their own work and suggest various mechanisms to improve it.
- Provide opportunities for students to present their findings and reflect upon their thinking processes.
- Identify students' learning gaps and methods to bridge them.

- Practice class management skills that promote student-centred learning activities.

The implementation of the mentioned methods will provide several opportunities for students to practice interpretation, analysis, evaluation, explanation and self-regulatory learning skills, which have been identified by Facione (2015) as the main core CT skills. When students are trained to practice these skills within daily classroom instructions, they will be able to use them frequently in their life and develop CT and problem-solving skills. This suggestion is in line with the framework provided by Vieira, Tenreiro-Vieira & Martins (2011) that guides science teachers to utilize CT to develop students' scientific literacy. Their framework demonstrates the relation between scientific literacy, competency and CT development. In addition to the study of Forawi, (2012) which identified the science standards that would guide students to develop critical thinking skills in the curriculum, these standards are used to help teachers to recognize CT requirements when interpreting the science curriculum. Guidance from the study of Nisa, Jatmiko and Koestiari, (2018) was used to provid some examples of guided IBL activities that were successfully used to help teachers integrate IBL instructions within their classes.

5.1.5.2 Peer mentoring and coaching programs

Following the identification of the areas of improvement, a series of ten professional development workshops will be designed to focus on the development of one method at a time. The workshops can be delivered by selected teachers who proved their mastery of one or more areas of improvement identified by this research. The selected teachers will play the role of a teacher coach or a mentor to support other teachers in specific areas of improvement. Each workshop must be followed by classroom visits to ensure precise implementation of the skills gained after the professional development sessions. To implement this plan, it is important to:

- Ensure that mentor teachers in schools provide guidance and supervision to all science teachers in close collaboration with the each other, and with the academic advisors or principal in each school.
- Ensure that trainee teachers receive constructive feedback after ongoing lesson observations that would help them to improve their teaching practices.
- Ensure that mentor teachers guide specific case studies in the classroom, facilitate group planning and implement lessons tailored according to students' abilities.

Literature proved that peer mentoring programs always had a positive influence on the participants' skills (Mayer et al., 2013). More specifically, in teacher education, Geeraerts et al., (2014) developed a model that can benefit new teachers and experienced teachers alike, by guiding them to develop their teaching skills through a peer-group mentoring model which necessitates that teachers should work in constructive social collaboration and transfer knowledge and experience between each other. In this model, the teaching practices are discussed between a group of teachers including new and experienced teachers to ensure reaching effective outcomes that will be shared with all teachers to adjust their teaching practices to the benefit of their students.

5.1.5.3 Self-reflecting and continuous professional development

When science teachers are trained to identify strength and weakness areas in their instructional practices, they will be able to adjust their practices and create better learning opportunities for their students. The suggested professional development focused on training teachers to evaluate their instructional practices in relation to the use of IBL instructions to develop students' CT skills. This would be facilitated through utilizing established international teacher standards related to teaching IBL and developing students' CT skills. In addition, teachers are encouraged to undertake collaborative action research to evaluate their own teaching practices, where action research is a research in which the teacher is the researcher who will collect data and use it to improve his/her educational practices. Teachers are encouraged to use the feedback they get form their peers, mentor, head teacher or principal to improve their teaching practices. They can also use the feedback from their students regarding their level of engagement and understanding of the science concepts discussed in the classroom using IBL instructions.

An important act is to keep teachers up to date in their educational practices. Hence, they need to keep learning through continuous professional development. The most important point in continuous professional development is to view teachers' development as a lifelong learning experience in order to cater for the rapid changes in schools, the potentially long careers of many science teachers and the need for updating skills related to science teaching. One of the effective strategies is to maintain professional learning communities and ongoing professional learning plans developed in individual schools based on the staff capacity and their experiences. To promote continuous professional development within the schools, policy makers may consider the following:

- Adjusting the performance evaluation system to include a professional development module. This includes an individual professional development plan.
- Adding action research to other characteristics and requirements of the teaching profession, based on the consistent implementation of action research as a part of the teaching experience.

This is supported be several research studies that agreed on the importance of self-evaluation and action research in developing teaching practices (Volk, 2010; Mitchener, and Jackson, 2011; McCullagh, 2012; Campbell, 2013; Forawi; 2015). In addition, it was also supported by studies that showed the importance of using psychological research to adjust teaching practices in the classroom, as was clarified by Long et al, (2011) and Mitchener, and Jackson, (2011)

5.2 Limitations of the study

The current research considered several procedures to perform data collection procedures accurately and produce a proper academic study. However, several limitations emerged during and after the implementation of the study, were out of the researcher control. For example, the current research study was performed with only two high school grade levels (Grade 9 and Grade 10), the data collected reflected only the experiences of these particular students, other students in higher grade levels who are provided with more specialized biology courses could have different views about the course. Additionally, the research study investigated the high school biology curriculum only, and results were limited to the biology curriculum and did not include students' experiences in other science subjects such as chemistry and physics, which may have led to different experiences regarding IBL implementation and the development of CT skills.

The results if this study helped to identify whether the students were able to develop CT skills or not, it did not measure the actual critical thinking level that students gained after utilizing IBL instructions in their biology lessons. Similarly, the questionnaire and CT attributes used in this study measured the opportunities provided for students to develop critical thinking skills, and not the actual levels of CT skills that the students would develop.

This study was limited in time, as it was implemented between September 2018 and January 2019. Therefore, the data collected from the classroom observations, questionnaire, document analysis and teachers' interviews reflected the practices that were implemented in that limited period of time. Other inquiry practices and students' skills may have been developed after the completion of data collection for the current study. Additionally, responses to the non-experimental questionnaire only included students who volunteered to participate from different campuses; other students from the target group who did not participate in the questionnaire could have different opinions that may have affected the results of this study.

Furthermore, the recommendations developed from the results of this study included a series of suggested professional development workshops based on the observations and areas of improvement recorded during this study, considering a certain time interval and the context of the research. Other areas of improvements may be identified in a different time or context.

5.3 Implications and Future Research

The findings of this research study have implications on both academic research and teaching and learning practices. The subsections below summarize main implications on future academic research, including investigating students' CT skills after applying a professional development model for teachers or change in the curriculum or applying IBL models. In addition to the implications on teaching and learning practices including the curriculum change, teachers' professional development and adopting IBL as a pedagogical approach.

5.3.1 Implications on Academic research

This study contributed to current academic research by analysing Grades 9 and 10 biology students' and teachers' perceptions regarding the implementation of IBL and CT practices. Four main areas of consideration can promote future academic research related to this study.

The first area of consideration is related to addressing the measurement of the actual development of CT skills after implementing the suggested professional development program for teachers. CT skills can be measured before and after conducting CT professional development for teachers to identify its impact on students' CT skills.

The second area of focus would be addressing the topics discussed in biology curricula and relating the topics tackled to the ability to develop IBL activities related to each topic. Academic research studies may compare between two different topics utilizing

IBL activities and investigate if the concepts discussed would influence the effectiveness of IBL activities to develop students' CT skills.

The third area of focus for future studies may also address the improvement of students' critical thinking abilities after receiving a specific IBL instructional model. This can be done by utilizing the results of this research further and developing an assessment tool that would measure the level of students' critical thinking skills before and after the implementation of IBL instructions.

The fourth area of focus would be to overcome the limitations of the current study that accompany the restricted number of lesson observations and teacher and student participation, the same study can be repeated with other teachers on a larger scale, and data could be collected from a larger amount of lesson observations. In addition to replicating the study about different science subjects. Since this study was conducted exclusively in biology classrooms for grades 9 and 10, future research may include other sciences (physics and chemistry) and for different grade levels such as Grade 11 and 12, in order to observe CT and IBL implications irrespective of curriculum and grade level.

5.3.2 The implications on teaching and learning practices

Teaching and learning practices would be affected by the results of this study in three main areas: the curriculum and content, teachers continuous professional development and adopting IBL as pedagogical approach.

5.3.2.1 Curriculum and content

The results of this study indicated that some topics in Grade 9 biology curriculum such as cellular biology including the functions of the cell, cellular energy and cellular production had more IBL applications in the curriculum than other topics included in Grade 10 curriculum such as human biology, plant physiology and evolution. This indicates that the Biology curriculum should be reviewed to ensure the inclusion of IBL activities for all the topics covered in the curriculum and distribute them equally between Grade 9 and Grade 10 Biology curricula.

5.3.2.2 Teachers' professional development

The first area is related to the identification of areas of improvement in science educational practices, which entails the identification of the strengths and weakness of science teacher in each school. Then organize the implantation of the suggested professional development plan to adjust the instructional practices accordingly utilizing peer and group mentoring practices. The second area of implications includes guiding the teachers to develop more positive mind-sets and introducing them to the ways in which they can alter their instructional practices through following up on appropriate implementation of IBL activities and measuring the impact and effectiveness of the professional development provided for science teachers.

The third area of the practical implications is related to the identification of specific gaps in the teachers' conceptions of CT attributes that must be addressed to enable teachers to identify the main critical thinking attributes in biology courses and translate them into actual teaching strategies in the classroom.

The fourth implication of the results of this research promoted self-evaluation practices, including the utilization of action research, which would have several implications on science educational practices, including the validation of the teaching profession and the valuable improvement of individual teaching practices, as they would then be based on informed research

5.3.2.3 Changing pedagogical practices

The results of this study emphasized the importance of changing the teachers' mindset and encouraging them to apply IBL instructions and assess students' performance after each inquiry stage. In particular, applying data analysis stage that promotes students to verify data to find relationships between the collected facts or variables and identify evidences to support their claims. In addition, the study supports the importance of assessing students' skills and gained knowledge after each inquiry stage implemented to ensure that students had the opportunity to practice core CT skills during each IBL stage.

5.4 Conclusion

The UAE vision of 2071 considered excelling in education as one of the top priorities in the county, which highlights developing the ability to innovate in sciences as one of its points of focus, as it is stated: "Certain areas of focus in education include advanced science and technology, space science, engineering, innovation and health sciences" (Mocaf.gov.ae, 2017). The UAE's leadership initiated educational reform to emphasise on the importance of developing students' skills to become life-long learners and succeed in their future. Reform in science education would contribute to this effort and help students to gain the required core CT skills and achieve the leadership's goals.

The results of this study contribute to science education reform efforts in the UAE. The results revealed that IBL activities implemented in the high school biology courses observed enabled students to practice the questioning and hypothesis, experimentation and exploration phases of the inquiry learning cycle. However, their experiences in the implementation of data interpretation to find authentic conclusions were limited. Therefore, this study recommended helping teachers to apply more open IBL activities that allow students autonomy and develop methods to assess each inquiry stage in the learning cycle with emphasis on data analysis and reflection skills.

With respect to CT development, the current study revealed that students develop the core CT skills at different levels, based on the nature of classroom instructions and the amount of practice provided for each core skill. Students were able to show development in their interpretation and inference skills. However, the development of analysis, evaluation, explanation and self-regulation skills was not evident. Therefore, the recommendations of this study included a plan to support teachers to create classroom activities that allow student to interact together and with their teacher to provide opportunities to practice core CT skills, and become critical thinkers.

The study revealed that teachers have an essential role in supporting their students to develop CT skills. The teaching strategies and questioning skills implemented in the science classroom directly affect students' learning and their skill development. The teachers in the current study did not show consistency in their practices, experiences and backgrounds related to the development of CT skills, which was apparent in the variability of the results related to practices that would help students to develop analysis, evaluation, explanation and self-regulation skills. Therefore, the recommendations of this study suggested that teachers undergo professional development to help them design guided inquiry activities that would allow students to practice CT skills.

Finally, the effect of demographic factors on students' development of CT after experiencing IBL instructions was studied. This study discussed the effect of gender, grade level and the location of the campus. The effect of gender was concluded to have a statistically significant but minimal contribution to the research results, while different grade levels showed a small difference in students' experiences as this study revealed that Grade 9 students reported better experiences in the practice of IBL activities and CT skills. This finding was unexpected, as previous literature suggested that when students are trained to apply IBL activities at earlier stages, they will be able to develop their procedures and perform better in higher grade levels. With respect to the location of the campus, the findings of this study proved that due to the centralized curriculum, there was no significant difference in implementing IBL instructions between the eleven campuses across the UAE. However, there was a significant difference in the students' development of CT skills. This finding leads to an assumption that instructional methodologies in different campuses vary and cause the significant difference in the practice of CT skills. Consequently, students' ability to develop CT skills also differs.

In conclusion, it is essential to empower science teachers and develop their teaching skills to enable them to implement effective IBL activities that would provide several opportunities for students to develop their CT skills, review the curriculum content and ensure the inclusion of learning outcomes that explicitly require teachers to apply IBL activities to explain a certain topic and increase the number of suggested IBL activities related to each topic. In addition to the importance of enforcing assessment strategies throughout IBL phases that ensure students' mastery of the concepts along with their ability to communicate their learning experiences and reflect upon their learning process.

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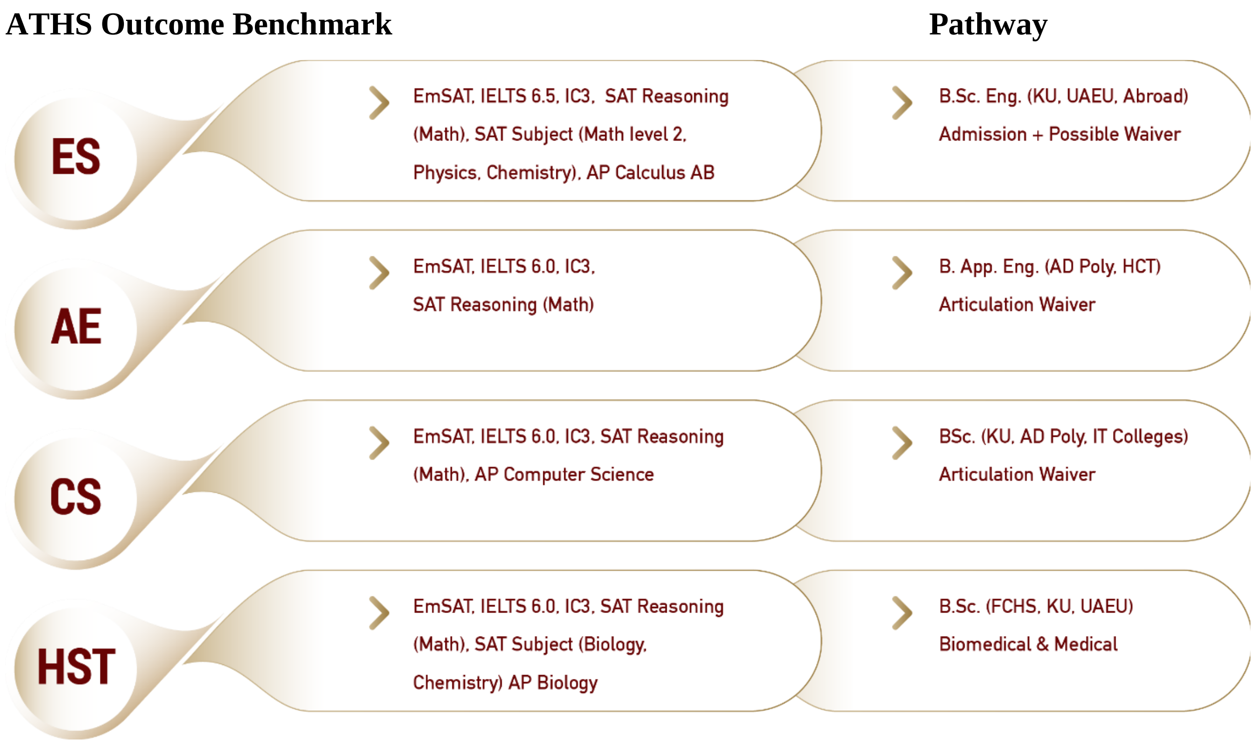
Appendices

Appendix 1.1



Appendix 3.1: The structure of the questionnaire

Dear students
This questionnaire will be used in an educational research to improve science instructions, it will take 10-15 minutes. Your participation will help in data collection regarding actual effect of IBL on students' critical thinking development. There are no risks from this participation, data collected will serve only the research purposes and will be kept confidential and anonymous.

The questionnaire includes three main sections:

1- **Your demographic information**
2- **Items asking about inquiry-based learning activities in biology classroom.**
3- **Items asking about the use of critical thinking skills in biology classroom.**

Part I Demographic

1- Grade Level

9	**19**	**9ASP**	**10ASP**

2- Gender

Male **Female**

3- Campus

AUH B AUH G DXB WR AAN-AQB

AAN-TBMEC SHI AJM B AJM G UAQ

FUJ RAK

Part II: Inquiry-based learning

How frequent the following is implemented in your biology class?

5 Every Lesson	4 Once biweekly	3 Once per month	2 Once per term	1 Never

		Student	**الطالب**
		Principles of Inquiry	**مبادىء الاستقصاء**
Preparation for an investigation	1	I formulate questions to be answered in investigation	أقوم بصياغة الأسئلة التي يتعين عليّ الإجابة عليها من خلال التحقيق
	2	I receive step by step instructions before I investigate	أتلقى التعليمات خطوة بخطوة قبل أن أجري تحقيقاً
	3	I design my procedure for the investigation	أقوم بتصميم الخطوات الخاصة بي للتحقيق
	4	My teacher conducts the experiment and I observe	يقوم معلمي بإجراء التجربة وأنا أراقب
Performing investigation and drawing conclusions	5	I conduct the procedure for an investigation	أقوم بتطبيق الإجراءات المعطاة للقيام بالتحقيق
	6	I decide which data to collect	أقرر ما البيانات التي ينبغي عليّ جمعها
	7	I develop conclusions for the investigation	أكوّن استنتاجاتي للتحقيق
	8	I can connect the conclusion with the scientific concept	أستطيع ربط استنتاجاتي بالمفهوم العلمي

Part III: Critical thinking attributes

How would you rate the implementation of the following skills when studying biology course (consider classroom activities, discussions and homework assignments)?

LIKERT Scale

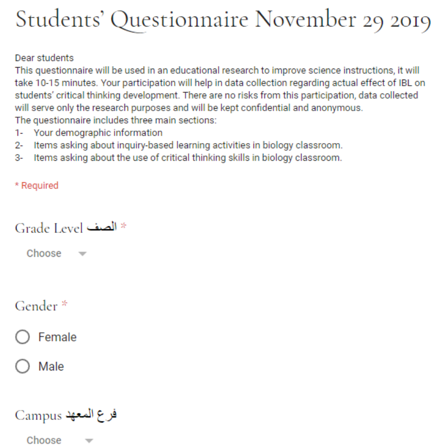
1	2	3	4	5
Completely disagree	Disagree	I don’t know	Agree	Completely agree
لا أوافق على الإطلاق	لا أوافق	لا أعرف	أوافق	أوافق تماماً

CT skill		**CT Items**	

Interpretation (Clarity)	9.	Before giving an answer, I always focus on the question first.	أحاول فهم السؤال جيداً قبل الإجابة
	10.	I clarify meaning and define terms that are not familiar	أعرف المصطلحات الجديدة و فهم معانيها
	11.	I express the new question in several ways to clarify its meaning and scope	أعيد صياغة السؤال بعدة طرق لأوَضّح المعنى و النطاق
	12.	I raise significant questions for more clarification	أطرح أسئلة معبّرة لتوضيح أفكاري
Analysis (Accuracy and precision)	13.	I perform activities that encourage me to think independently and speak out my opinion	أقوم بأنشطة تحفزني على التفكير المستقل و التعبير عن رأيي
	14.	I assess claims being made in classroom discussions.	أقيّم الإدّعاءات التي تُسرد خلال النقاشات الصفيّة
	15.	I passively accept claims being made in classroom discussions	أتقبل الإدعاءات التي تُسرد خلال النقاشات الصفيّة كحقائق
	16.	I analyse arguments being made and their consequences.	أحلل الحجج المطروحة و تبعاتها
Evaluation (Relevance)	17.	I draw conclusions about a problem based on the evidence at hand	أستنتج خصائص المشكلة المطروحة بناءً على الأدلة الموجودة
	18.	I use various processes to resolve, re-address, and re-analyze complex situations to gain new vision	أستعمل العديد من الطرق لإعادة حل، معالجة، وتحليل الحالات المعقدة لاكتساب وجهة نظرة جديدة
	19.	I develop and use valid criteria to evaluate claims being made in class discussions	أطور وأستخدم معايير مناسبة لتقييم الإدعائات التي تُسرد خلال النقاشات الصفية
	20.	I learn how to distinguish what I know from what I don't know in any new concept	أتعلّم كيف أُحدد المعطيات المعروفة والمعطيات التي يجب عليّ تعلّمها عند البدء بفهم كل موضوع جديد
Inference (depth and breadth)	21.	I restrict my claims only to those supported by the evidence	أقدّم الإدّعائات فقط عند وجود دليل واضح على صحتها
	22.	I search for information that opposes my position as well as information that supports it.	أبحث عن معلومات تناقض الموقف الذي اتخذته، بالإضافة إلى معلومات تدعم موقفي
	23.	I learn how to think within the point of view of those with whom I disagree their opinion	أتعلّم كيف أضع نفسي في موقف من أخالف رأيهم و أفكّر من خلال نطاق تفكيرهم
	24.	I consider how my assumptions are shaping my point of view.	أعتبر دور افتراضاتي الشخصية في تشكيل وجهة نظري
Explanation (significance) self-regulation (Fairness)	25	I can justify the strategies that I used to solve a problem or create an argument.	أستطيع أن أثبت صلاحية الاستراتيجيات التي اتخذتها لحل مشكلة أو طرح حجة
	26	I can present my argument to others in a way that they will understand.	أستطيع أن أعرض حجتي للآخرين بطريقة واضحة ومفهومة
	27	I correct my assumptions and revisit what I mean by certain things before making any final decisions	أصحح افتراضاتي و أسترجع المفاهيم المتعلقة بها قبل اتخاذ قرار حاسم
	28	I think precisely about thinking- using critical thinking vocabulary such as analysis and evaluation.	أفكّر -تحديدا- بطريقة تفكيري، مع استخدام مفردات متعلقة بالتفكير النقدي مثل التحليل والتقييم

Appendix 3.2 The Online final form

Section 1



Students' Questionnaire November 29 2019

Dear students
This questionnaire will be used in an educational research to improve science instructions, it will take 10-15 minutes. Your participation will help in data collection regarding actual effect of IBL on students' critical thinking development. There are no risks from this participation, data collected will serve only the research purposes and will be kept confidential and anonymous.
The questionnaire includes three main sections:

1- Your demographic information
2- Items asking about inquiry-based learning activities in biology classroom.
3- Items asking about the use of critical thinking skills in biology classroom.

* Required

Grade Level الصف *

Choose

Gender *

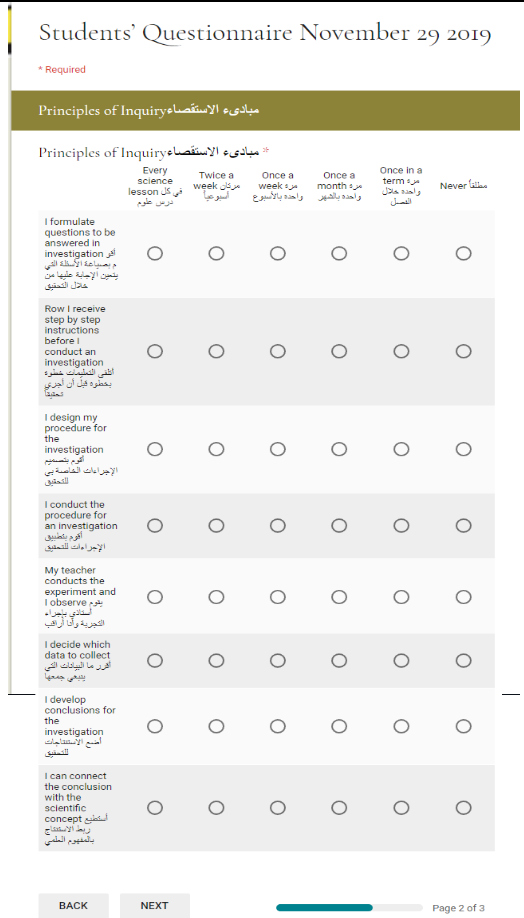
○ Female

○ Male

Campus فرع المعهد

Choose

Section 2



Students' Questionnaire November 29 2019

* Required

Principles of Inquiryمبادىء الاستقصاء

Principles of Inquiryمبادىء الاستقصاء *

	Every science lesson في كل درس علوم	Twice a week مرتان أسبوعياً	Once a week مره واحده بالأسبوع	Once a month مره واحده بالشهر	Once in a term مره واحده خلال الفصل	Never مطلقاً
I formulate questions to be answered in investigation أقوم بصياغة الأسئلة التي يتعين الإجابة عليها من خلال التحقيق	○	○	○	○	○	○
Row I receive step by step instructions before I conduct an investigation أتلقى التعليمات خطوه بخطوه قبل أن أجري تحقيقاً	○	○	○	○	○	○
I design my procedure for the investigation أقوم بتصميم الإجراءات الخاصة بي للتحقيق	○	○	○	○	○	○
I conduct the procedure for an investigation أقوم بتطبيق الإجراءات للتحقيق	○	○	○	○	○	○
My teacher conducts the experiment and I observe يقوم أستاذي بإجراء التجربة وأنا أراقب	○	○	○	○	○	○
I decide which data to collect أقرر ما البيانات التي ينبغي جمعها	○	○	○	○	○	○
I develop conclusions for the investigation أضع الاستنتاجات للتحقيق	○	○	○	○	○	○
I can connect the conclusion with the scientific concept أستطيع ربط الاستنتاج بالمفهوم العلمي	○	○	○	○	○	○

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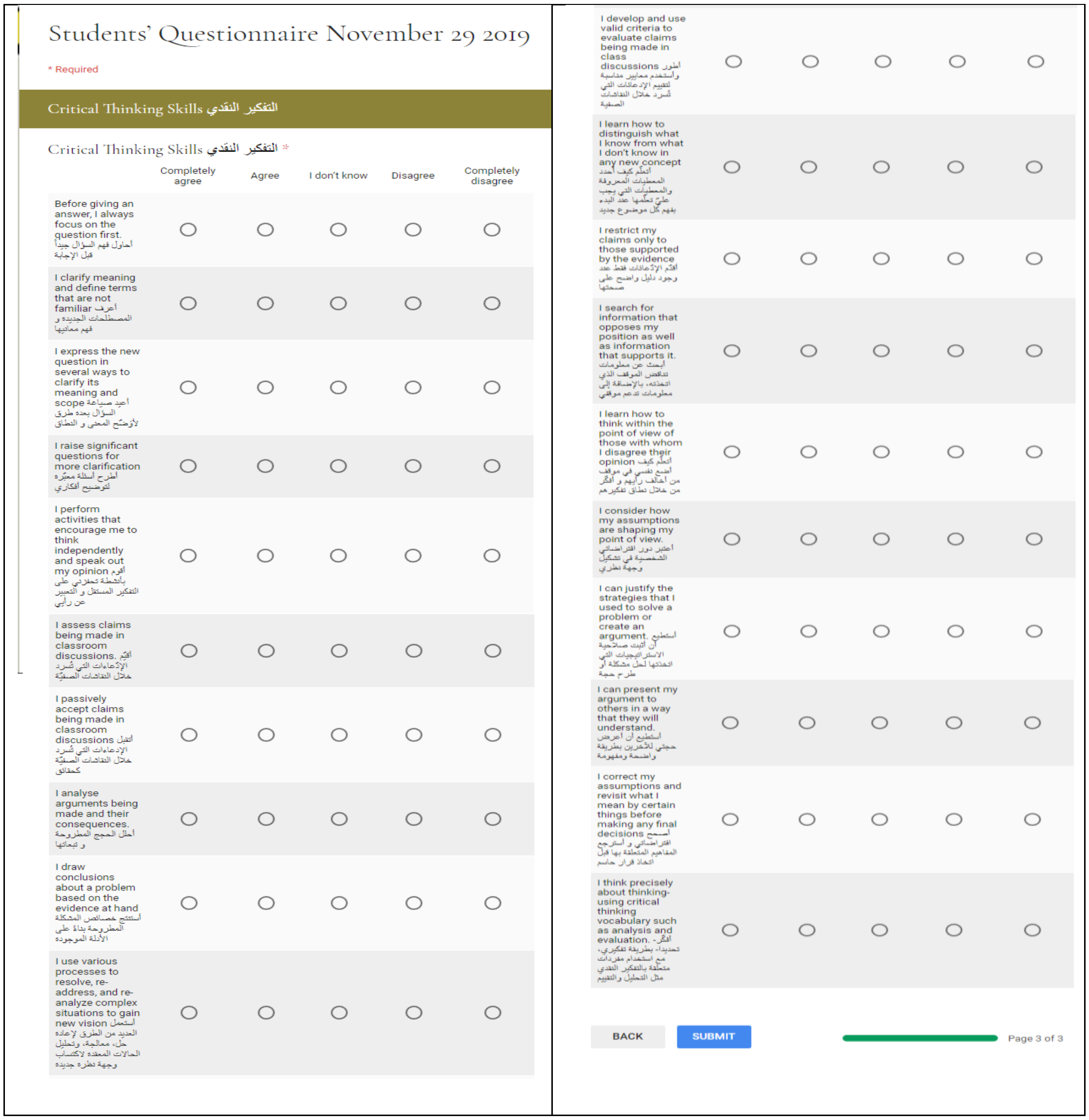
Section 3



Students' Questionnaire November 29 2019

* Required

Critical Thinking Skills التفكير النقدي

Critical Thinking Skills التفكير النقدي *

	Completely agree	Agree	I don't know	Disagree	Completely disagree
Before giving an answer, I always focus on the question first. أحاول فهم السؤال جيداً قبل الإجابة	○	○	○	○	○
I clarify meaning and define terms that are not familiar أعرف المصطلحات الجديده و فهم معانيها	○	○	○	○	○
I express the new question in several ways to clarify its meaning and scope أعيد صياغة السؤال بعده طرق لأوضّح المعنى و النطاق	○	○	○	○	○
I raise significant questions for more clarification أطرح أسئلة معبّره لتوضيح أفكاري	○	○	○	○	○
I perform activities that encourage me to think independently and speak out my opinion أقوم بأنشطة تحفزني على التفكير المستقل و التعبير عن رأيي	○	○	○	○	○
I assess claims being made in classroom discussions. أقيّم الإدّعاءات التي تُسرد خلال النقاشات الصفيّة	○	○	○	○	○
I passively accept claims being made in classroom discussions أتقبل الإدعاءات التي تُسرد خلال النقاشات الصفيّة كحقائق	○	○	○	○	○
I analyse arguments being made and their consequences. أحلل الحجج المطروحة و تبعاتها	○	○	○	○	○
I draw conclusions about a problem based on the evidence at hand أستنتج خصائص المشكلة المطروحة بناءً على الأدلة الموجوده	○	○	○	○	○
I use various processes to resolve, re-address, and re-analyze complex situations to gain new vision أستعمل العديد من الطرق لإعاده حل، معالجة، وتحليل الحالات المعقده لاكتساب وجهة نظره جديده	○	○	○	○	○
I develop and use valid criteria to evaluate claims being made in class discussions اطور وأستخدم معايير مناسبة لتقييم الإدعاءات التي تُسرد خلال النقاشات الصفية	○	○	○	○	○
I learn how to distinguish what I know from what I don't know in any new concept أتعلّم كيف أحدد المعطيات المعروفة والمعطيات التي يجب عليّ تعلّمها عند البدء بفهم كل موضوع جديد	○	○	○	○	○
I restrict my claims only to those supported by the evidence أقدّم الإدّعاءات فقط عند وجود دليل واضح على صحتها	○	○	○	○	○
I search for information that opposes my position as well as information that supports it. أبحث عن معلومات تناقض الموقف الذي اتخذته، بالإضافة إلى معلومات تدعم موقفي	○	○	○	○	○
I learn how to think within the point of view of those with whom I disagree their opinion أتعلّم كيف أضع نفسي في موقف من أخالف رأيهم و أفكر من خلال نطاق تفكيرهم	○	○	○	○	○
I consider how my assumptions are shaping my point of view. أعتبر دور افتراضاتي الشخصية في تشكيل وجهة نظري	○	○	○	○	○
I can justify the strategies that I used to solve a problem or create an argument. أستطيع أن أثبت صلاحية الاستراتيجيات التي اتخذتها لحل مشكلة أو طرح حجة	○	○	○	○	○
I can present my argument to others in a way that they will understand. أستطيع أن أعرض حجتي للآخرين بطريقة واضحة ومفهومة	○	○	○	○	○
I correct my assumptions and revisit what I mean by certain things before making any final decisions أصحح افتراضاتي و أسترجع المفاهيم المتعلقة بها قبل اتخاذ قرار حاسم	○	○	○	○	○
I think precisely about thinking- using critical thinking vocabulary such as analysis and evaluation. أفكّر -تحديدا- بطريقة تفكيري، مع استخدام مفردات متعلقة بالتفكير النقدي مثل التحليل والتقييم	○	○	○	○	○

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Appendix 3.3: Preliminary results of the pilot study

			Item	Mean	std. Dev
Principles of Inquiry مبادئ	Preparing for investigation	1	I formulate questions to be answered in investigation أقوم بصياغة الأسئلة التي يتعين الإجابة عليها من خلال التحقيق	3.9	1.83
		2	Row I receive step by step instructions before I conduct an investigation أتلقى التعليمات خطوة بخطوة قبل أن أجري تحقيقاً	4.7	1.65
		3	I design my procedure for the investigation أقوم بتصميم الإجراءات الخاصة بي للتحقيق	3.7	1.62
		4	I conduct the procedure for an investigation أقوم بتطبيق الإجراءات للتحقيق	3.9	1.52
		5	My teacher conducts the experiment and I observe يقوم أستاذي بإجراء التجربة وأنا أراقب	2.5	1.75

	Application of the inquiry activity	6	I decide which data to collect أقرر ما البيانات التي ينبغي جمعها	3.8	1.79
		7	I develop conclusions for the investigation أضع الاستنتاجات للتحقيق	3.8	1.75
		8	I can connect the conclusion with the scientific concept أستطيع ربط الاستنتاج بالمفهوم العلمي	3.8	1.77
Critical Thinking Skills التفكير النقدي	Interpretation (Clarity)	9	Before giving an answer, I always focus on the question first. أحاول فهم السؤال جيداً قبل الإجابة	4.4	0.66
		10	I clarify meaning and define terms that are not familiar أعرف المصطلحات الجديدة و فهم معانيها	3.9	0.88
		11	I express the new question in several ways to clarify its meaning and scope أعيد صياغة السؤال بعدة طرق لأوَضّح المعنى و النطاق	3.8	0.83
		12	I raise significant questions for more clarification أطرح أسئلة معبّرة لتوضيح أفكاري	3.6	1.03
	Analysis (Accuracy and precision)	13	I perform activities that encourage me to think independently and speak out my opinion أقوم بأنشطة تحفزني على التفكير المستقل و التعبير عن رأيي	3.2	1.07
		14	I assess claims being made in classroom discussions. أقيّم الإدّعاءات التي تُسرد خلال النقاشات الصفيّة	3.1	1.21
		15	I passively accept claims being made in classroom discussions أتقبل الإدعاءات التي تُسرد خلال النقاشات الصفيّة كحقائق	2.5	1.14
		16	I analyse arguments being made and their consequences. أحلل الحجج المطروحة و تبعاتها	3.5	0.94
	Evaluation (Relevance)	17	I draw conclusions about a problem based on the evidence at hand أستنتج خصائص المشكلة المطروحة بناءً على الأدلة الموجودة	3.6	0.89
		18	I use various processes to resolve, re-address, and re-analyze complex situations to gain new vision أستعمل العديد من الطرق لإعادة حل، معالجة، وتحليل الحالات المعقدة لاكتساب وجهة نظرة جديدة	3.5	0.97
		19	I develop and use valid criteria to evaluate claims being made in class discussions أطور وأستخدم معايير مناسبة لتقييم الإدعائات التي تُسرد خلال النقاشات الصفية	3.5	0.87
		20	I learn how to distinguish what I know from what 3 in any new concept أتعلّم كيف أُحدد المعطيات المعروفة والمعطيات التي يجب عليّ تعلّمها عند البدء بفهم كل موضوع جديد	3.7	0.99
	Inference (depth and breadth)	21	I restrict my claims only to those supported by the evidence أقدّم الإدّعائات فقط عند وجود دليل واضح على صحتها	3.6	1.03
		22	I search for information that opposes my position as well as information that supports it. أبحث عن معلومات تناقض الموقف الذي اتخذته، بالإضافة إلى معلومات تدعم موقفي	3.5	1.08
		23	I learn how to think within the point of view of those with whom I 2 their opinion أتعلّم كيف أضع نفسي في موقف من أخالف رأيهم و أفكّر من خلال نطاق تفكيرهم	3.7	0.89
		24	I consider how my assumptions are shaping my point of view. أعتبر دور افتراضاتي الشخصية في تشكيل وجهة نظري	3.5	0.92

	Explanation (significance) self-regulation (Fairness)	25	I can justify the strategies that I used to solve a problem or create an argument. أستطيع أن أثبت صلاحية الاستراتيجيات التي اتخذتها لحل مشكلة أو طرح حجة	3.6	1.01
		26	I can present my argument to others in a way that they will understand. أستطيع أن أعرض حجتي للآخرين بطريقة واضحة ومفهومة	3.4	1.19
		27	I correct my assumptions and revisit what I mean by certain things before making any final decisions أصحح افتراضاتي و أسترجع المفاهيم المتعلقة بها قبل اتخاذ قرار حاسم	3.5	1.08
		28	I think precisely about thinking- using critical thinking vocabulary such as analysis and evaluation. أفكّر-تحديدا- بطريقة تفكيري، مع استخدام مفردات متعلقة بالتفكير النقدي مثل التحليل والتقييم	3.6	1.01

Appendix 3.4: Example of a filled Lesson observation form

Observation Form

Subject	**Biology**	**Campus**	AUH G
Grade	**9 ASP 17 students**	**Room/Lab**	Z238
Class duration	**90 minutes**	**Lesson title**	Mitosis

Part I

	Inquiry implementation	**Yes**	**No**	**Comments**
Utilization of critical thinking skills in IBL	Orientation	√		The teacher introduced the idea of having 46 chromosomes that should be organized and split
	Conceptualization (Raise and pursue significant questions, hypothesis,)	√		One question raised by the teacher to identify the phases of cell division and explain what is happening in each phase
	Investigation (Exploration, experimentation)	√		Students were asked to explore the topic and research for data to use them in their presentations
	Data collection and organization	√		Students were required to organize the information
	Data analysis		√	
	Conclusion (Generate and assess solutions)	√		Final product is a video explain the cell division process
	Discussion (Make arguments, interpretations, beliefs, or theories, and their implications)	√		Students had some discussions about the number of chromosomes and why would it duplicate then split
	Reflection (Think precisely about thinking, using critical thinking vocabulary)	√		Was demonstrated through group discussions, when students questioned their procedure to implement the task

	Assessment of Inquiry Cycles			
	Questioning strategies allow students time to process information and formulate appropriate responses	√		The teacher used questioning per group and addressed the whole class by some discussion questions
	Note-taking supports understanding of objectives and represents synthesis of learning	√		Different groups used different approaches for notetaking
	Inquiry cycles are assessed frequently after each step		√	The students were given long time to achieve the task, checking per step wad not clearly observed
	Develop and use valid criteria for evaluation (i.e. rubrics) are clearly communicated and understood by students		√	The teacher discussed evaluation criteria, clear rubrics were not shared

Interactions in the classroom	**Students' Interactions**			
	Classroom routines are established and facilitate cooperative learning	√		Students are trained to work in collaborative groups
	Students are encouraged to think independently and develop intellectual courage	√		Independent learning items were observed. Teacher's role was to observe students' interactions, during the first activity, students did not ask for her help as they write their own notes.
	Students are encouraged to suspend judgment or prior conceptions	√		The teacher was asking them about the consequences of their selections and how they would help them to complete the activity, her questions were guiding students to correct their thinking process and adjust their design
	Teacher's students' Interactions			
	Teachers utilize various processes to resolve, re-address, and re-analyse complex situations to gain new insight	√		During group work the teacher was able to identify gaps in learning, addressed the students with more clarification, and explained why they had the misunderstanding.
	Teachers lead discussions to analyse arguments, interpretations, beliefs, or theories, and their implications	√		
	Teachers lead discussions to help students to explore how egocentricity and sociocentric affect feeling, thought and behaviour		√	
	Feedback is constructive and specific, help students to identify strengths and weakness points	√		The teacher's feedback helped students to adjust their plant to complete the task

Part II

Place a tick mark whenever one of the following questions is mentioned in the class to indicate the number of times in which questions that promotes CT are repeated during the lesson either through addressing all students or during mentoring students' groups.

<u>1st 45 minutes</u>

CT skill promoted		Time in the lesson / minute							Total
	Example questions	**1-5**	**5-10**	**15-20**	**20-25**	**25-30**	**35-40**	**40-45**	
Interpretation	• What does this mean? • What's happening? • How should we understand that (e.g., what he or she just said)? • What is the best way to characterize / categorize / classify? • In this context, what was intended by saying/doing that? • How can we make sense out of this experience/feeling/ statement?	**1**	**1** **1**	**1**					**5**
Analysis	• Please tell us again your reasons for making that claim. • What is your conclusion/what is it you are claiming? • Why do you think that? • What are your arguments pro and con? • What assumptions must we make to accept that conclusion? • What is your basis for saying that?								

Inference	• Given what we know so far, what conclusions can we draw? • Given what we know so far, what can we rule out? • What does this evidence imply? • If we abandoned/accepted that assumption, how would things change? • What additional information do we need to resolve this question? • If we believed these things, what would they imply going forward? • What are the consequences of doing things that way? • What are some alternatives we haven't yet explored? • Let's consider each option and see where it takes us. • Are there any undesirable consequences that we can and should foresee?								
Evaluation	• How credible is that claim? • Why do we think we can trust what this person claims? • How strong are those arguments? • Do we have our facts right? • How confident can we be in our conclusion, given what we know now?					**1**			**1**

Explanation	• What were the specific findings/results of the investigation? • Please let us know how you conducted that analysis. • How did you come to that interpretation? • Please take us through your reasoning one more time. • What do you think that was the right answer/the right solution? • How would you explain why this decision was made?		**1**	**1**					**2**
Self-regulation	• Our decision on this issue is still too vague; can we be more precise? • How good was our methodology, and how well did we follow it? • Is there a way we reconcile these two apparently conflicting conclusions? How good is our evidence? • OK, before we commit--what are we missing? • I am finding some of our definitions a little confusing; can we revisit what we mean by certain things before making any final decisions								

Second 45 minutes

Group work to complete the video task given by the teacher

CT skill promoted		**Time in the lesson / minute**							**Total**
	Example questions	**1-5**	**5-10**	**15-20**	**20-25**	**25-30**	**35-40**	**40-45**	

Interpretation	• What does this mean? • What's happening? • How should we understand that (e.g., what he or she just said)? • What is the best way to characterize / categorize / classify? • In this context, what was intended by saying/doing that? • How can we make sense out of this experience/feeling/ statement?	**1**	**1**	**1** **1**		**1**	**1** **1** **1** **1**	**1** **1**	**11**
Analysis	• Please tell us again your reasons for making that claim. • What is your conclusion/what is it you are claiming? • Why do you think that? • What are your arguments pro and con? • What assumptions must we make to accept that conclusion? • What is your basis for saying that?		**1**	**1**					**2**

Inference	• Given what we know so far, what conclusions can we draw? • Given what we know so far, what can we rule out? • What does this evidence imply? • If we abandoned/accepted that assumption, how would things change? • What additional information do we need to resolve this question? • If we believed these things, what would they imply going forward? • What are the consequences of doing things that way? • What are some alternatives we haven't yet explored? • Let's consider each option and see where it takes us. • Are there any undesirable consequences that we can and should foresee?								
Evaluation	• How credible is that claim? • Why do we think we can trust what this person claims? • How strong are those arguments? • Do we have our facts right? • How confident can we be in our conclusion, given what we know now?			**1**	**1**				**2**

Explanation	• What were the specific findings/results of the investigation? • Please let us know how you conducted that analysis. • How did you come to that interpretation? • Please take us through your reasoning one more time. • What do you think that was the right answer/the right solution? • How would you explain why this decision was made?				**1**				**1**
Self-regulation	• Our decision on this issue is still too vague; can we be more precise? • How good was our methodology, and how well did we follow it? • Is there a way we reconcile these two apparently conflicting conclusions? How good is our evidence? • OK, before we commit--what are we missing? • I am finding some of our definitions a little confusing; can we revisit what we mean by certain things before making any final decisions					**1**	**1** **1** **1**		**4**

Part III
Best Practices observed

Students' discussions to apply the task provided good learning experience, as they questioned their practices and researched a better solution, all videos produced reflected good understanding of the topic

Items to be considered

Time management, follow up to evaluate students after each stage and sharing rubrics to help students to evaluate their progress

Direct Notes during the class observation

Discussion questions to recap previous lesson concepts about why cells cannot grow very large and they should divide
Introduction by the teacher to introduce the idea of having 46 chromosomes that should be organized and split

What do we do with DNA
How the cell will separate it
How bacteria
Why do we need asexual reproduction?
To grow, replace old cells.

Identify the phases and explain what is happening in each phase

Students were given 15 minutes to see a video about mitosis and answer the question a

Explain by using science facts why interphase is not a resting phase in the cell
Describe what happens during the four phases of mitosis
Describe the outcome of mitosis regarding number and kind of cells

While the video was on students were asked to write facts and notes about mitosis
The video describes the cell cycle and the interphase a the first phase for the cell to carry out cell functions and replicate DNA
Teacher's role was to observe students interactions, during the first activity, students did not ask for her help as they write their own notes and the video is suitable for their language level.
They only clarified some points that they have already recorded

Some groups were progressing before others
All had to complete within 15 minutes.
Students had some discussions about the number of chromosomes and why would it duplicate then split

Comprehension normal note taking was observed during the activity.
The students repeated the video more than one time to ensure that they understood the whole process and took notes for all stages.
Five more minutes to wrap up their notes

Last 10 minutes of the first lesson
Students were instructed to listen to each other

Using an app using clips a demonstration was illustrated to show the students how to use the App to explain their work
Students were asked to produce a video about Mitosis
Producing posters to show their understanding of the cell cycle
The students listed the stages of mitosis and how they progress

And the cytokinesis
Students should decide which type of cells they will display and find out the difference between plant and animal cell division
Explain the process of Cytokinesis in both plant cells and animal cell
Show the division in motion and explain what is happening in each phase

Students were given stationary required to create the video to describe mitosis

20 minutes were given to do this activity.

During this time students were discussing the best approach to make the video
Arguments were made on what tools should be used and how to visualize the steps and the sequence of the stages

The teacher was asking them about the consequences of their selections and how they would help them to complete the activity, her questions were guiding students to correct their thinking process and adjust their design.

The students are taking more time than the required to complete their task

The teacher is expecting to see a video the students were guided to complete the task and go online for the quiz to make sure the have understood the concepts.

During group work the teacher was able to identify gaps in learning, addressed the students with more clarification, and explained why they had the misunderstanding.

The teacher also followed up the students' progress and asked them to go faster.
Students enjoyed the lesson and the students didn't finalize the projects

Revise the main points discussed about the concepts.

Next lesson the difference between plant cells and animal cells.

Appendix 3.5 Document Analysis Checklist summative assessment tool

Teacher	Summative assessment	Gender	Interpretation		Analysis	Evaluation	Inference		Explanation
			Q3	Q.9.e	Q.11.c	Q14.b	Q7	Q11.b	Q13.a
AQB-S	Sample 1	Female							
	Sample 2	Female							
	Sample 3	Female							
AQB-M	Sample 1	Male							
	Sample 2	Male							
	Sample 3	Male							

Appendix 3.6 Document Analysis Checklist Formative assessment tool

		Collected documents				
IBL and Critical Thinking Attributes		In class Quiz	Lab reports	Class worksheet	Students' responses via interactive applications	Students notes
IBL1	Preparing for investigation					
IBL2	Application of the inquiry activity					
CT1	Express the new question in several ways to clarify its meaning					
CT2	Think independently and develop intellectual courage activities that encourage independent thinking and speak out opinion					
CT3	Analysis (Accuracy and precision) Argument analysis					
CT4	Evaluation (Relevance) use valid criteria to evaluate claims					
CT5	Inference (depth and breadth)					
CT6	Explanation (significance) self-regulation (Fairness)					

Appendix 3.7 Interview protocol

Teachers' Interview

Thank you for agreeing to this interview. The purpose is to look into your views on the use of IBL and development of CT.

More particularly, the purpose is to determine the extent to which the IBL instructions affected the use of tools and language of critical thinking.

In addition, how using critical thinking tools have come to play an important role in the way you think about teaching and learning, and the way you structure your lessons.

Part I: Demographic Information

- Gender
- Years of experience
- Grade level taught

Part II: Inquiry-based learning

The definition of Inquiry based learning (IBL) applied in this study is the use of the inquiry process as an instructional pedagogy to explain scientific concepts an utilizing the scientific methods and processes to learn scientific content.

Different levels of inquiry: structured, guided and open ended.

- How frequent you implement IBL activity in the classroom?
- What level of IBL you mostly apply?
- Students formulate questions which can be answered by investigations
- Students develop their own hypothesis
- Students design their own procedures for investigations
- Each student has a role as investigations are conducted
- Students determine which data to collect
- Students develop their own conclusions for investigations
- What level of discussion do students apply in their groups
- How well students reflect their understanding after the IBL

Part III: Critical thinking attributes

- What is critical thinking?
- When you were in school, did your teachers in school encourage you to think critically?
- Could you give me an example or two of how you came to learn about critical thinking?
- Are there any components of critical thinking? If so, what are they?
- If you were asked to analyze thinking, how would you do so?
- What standards do you use when you evaluate someone's thinking?

- How does critical thinking apply to the study of science?
- How do you foster critical thinking in the classroom (in general)?
- What is the most significant obstacle to bringing critical thinking more explicitly and more deeply into instruction?

Part IV: Inquiry-based learning effect of CT.

- Do you think that the activities students perform during IBL will help them to develop CT. can you provide an example?
- What hinders the IBL to be effective in students' learning?

Appendix 3.8 Lesson observations data analysis

		1-AQB-S		2-AQB-D		3-AQB-G		4-AQB-M		5-AUHB-S		6-AUHB-H		7-AUHB-M		8-AUHG-L		9-AUHG-R		10-AUHG-NI		11-AUHG-NO		12-DXB-I	
Utilization of critical thinking skills in IBL	**Inquiry implementation**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
	Orientation	√		√		√		√		√		**X**		√		√		√		√		√		√	
	Conceptualization (Raise and pursue significant questions, hypothesis,)	√		√			√	√			√		X	√		√		√		√		√		√	
	Investigation (Exploration, experimentation)	√		√			√	√			√		X	√		√		√		√		√		√	
	Data collection and organization	√		√			√	√		√			X	√		√		√		√		√		√	
	Data analysis		√		√		√	√			√		X		√		√	√			√		√	√	
	Conclusion (Generate and assess solutions)	√		√			√	√			√		X	√		√		√		√		√		√	
	Discussion (Make arguments, interpretations, beliefs, or theories, and their implications)		√	√		√		√			√		X	√		√		√			√	√		√	

	Reflection (Think precisely about thinking, using critical thinking vocabulary)	√			√		√	√			√		X	√		√			√		√		√	√	
	Assessment of Inquiry Cycles																								
	Questioning strategies allow students time to process information and formulate appropriate responses	√		√		√		√		√			X	√		√		√		√		√		√	
	Note-taking supports understanding of objectives and represents synthesis of learning	√		√		√		√		√		X		√		√		√		√		√		√	
	Inquiry cycles are assessed frequently after each step		√	√			√	√			√		X	√			√	√			√	√			√
	Develop and use valid criteria for evaluation (i.e. rubrics) are clearly communicated and understood by students	√			√		√		√		√		X		√		√		√		√		√		√
Interactions in the classroom	**Students' Interactions**																								
	Classroom routines are established and facilitate cooperative learning	√		√			√	√		√		X		√		√		√		√		√		√	

	Students are encouraged to think independently and develop intellectual courage	√		√		√		√			√		X	√		√		√		√		√		√	
	Students are encouraged to suspend judgment or prior conceptions	√		√		√		√			√		X	√		√		√		√		√		√	
	Teacher's students' Interactions																								
	Teachers utilize various processes to resolve, re-address, and re-analyze complex situations to gain new insight	√		√		√		√		√			X	√		√		√		√		√		√	
	Teachers lead discussions to analyze arguments, interpretations, beliefs, or theories, and their implications		√	√			√	√			√		X	√		√		√			√	√			
	Teachers lead discussions to help students to explore how egocentricity and sociocentric affect feeling, thought and behavior		√		√		√		√		√		X		√		√		√		√		√		√

	Feedback is constructive and specific, help students to identify strengths and weakness points	√		√		√		√		√			X	√		√		√		√		√		√	
Number of CT Questions	**Interpretation**	1	3	9	10	3	6	9	21	8	10	7	8	7	14	5	11	6	16	0	3	9	11	16	20
	Analysis	1		1		1		6		1		0		1		0	2	5		2		2		3	
	Inference	1		0		2		1		1		1		2		0	0	3		1		0		0	
	Evaluation	0		0		0		0		0		0		0		1	1	0		0		0		0	
	Explanation	0		0		0		2		0		0		0		2	2	0		0		0		0	
	Self-regulation	0		0		0		3		0		0		4		0	4	2		0		0		1	

Appendix 3.9 Sample of item analysis in Formative assessment data

	Formative Assessment			IBL1	IBL2	CT1	**CT2**	**CT3**	**CT4**	**CT5**	**CT6**
	Participant	Document type	Lesson title	Preparing for investigation	Application of the inquiry activity	express the new question in several ways to clarify its meaning	Think independently and develop intellectual courage	Analysis (Accuracy and precision) Argument analysis	Evaluation (Relevance) use valid criteria to evaluate claims	Inference (depth and breadth)	Explanation (significance) self-regulation (Fairness)
9 Non ASP	AQB-M	Group worksheet4	cancer		students were asked to interpret a graph related to regulation of the cell cycle						Students had to reflect about their learning experience
10 Non Asp	AUHB-S	Students' notes	Stems			Notes were indicating mind mapping to compare and categorize information					

10 Non Asp	AUHB-S	Kahoot Quiz	Roots, Stems and leaves			Q8 related to categorization 76% of the students answered correctly					
9 Non ASP	AUHB-H	Socrative Quiz	Cell growth division and reproduction							Q3 answered correctly by 4/33	
9 Non ASP	AUHB-H	Students' notes	Cell growth division and reproduction			Notes included comparison					
9 Non ASP	AUHB-H	Students popplet samples	Cell growth division and reproduction						Students' examples included questions about students' predictions about cell division in different conditions		
10 Non Asp	AUHB-M	Students' notes	Roots, Stems and leaves	All worksheets included a hypothesis and questions to be answered	students mentioned several points as there results and conclusions						
9 ASP	AUHG-L	Video representations	Cell Division	Students were asked to create representations about cell division	the submitted product was a video in which students explain their understanding of the cell division						
9 Non ASP	AUHG-NI	Quiz	Mitosis					Q10. Why would it be important to replicate DNA before a cell divides in mitosis? 75% of the students responded correctly		Q. 14. Fruit fly body cells have 8 chromosomes. After mitosis, you would expect a resulting fruit fly daughter cell to have. 37.5% of the students responded correctly	
9 Non ASP	AUHG-NI	Video representations	Cell Division	Students were asked to create	The final product						

				representations about cell division	reflected a summary of the process. Yet the students didn't show their understanding in the video						
10 Non ASP	AUHG-R	Lab report - Sample 1	Relation between number of stomata and leaf size	clear hypotheses and experimental procedure	evident data collection and conclusion	evident		Evident	Evident		
10 Non ASP	AUHG-R	Lab report - Sample 2	concentration of water in leaf affect the number of open/close stomata per unit of time	clear hypotheses and experimental procedure	evident data collection and conclusion	evident		Evident	Evident	Evident	Evident

Appendix 3.10 Samples of item analysis for the summative assessment data

9 Non ASP	Summative assessment		Interpretation					Analysis	Evaluation	Inference			Explanation	
	SWQ1	Gender	Q3	Q.9.e	Q.10.b	12.b	Q15	Q.11.c	Q14.b	Q7	Q10.a	Q11.b	Q13.a	Q13.b
AQB-S	Sample 1	Female	correct	Correct	5.5/7	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct	Correct
	Sample 2	Female	correct	incorrect	answered part related to cancer 4.5/7	incorrect	incorrect	Correct	Partly answered	Correct	not answered	incorrect	Correct	Incorrect
	Sample 3	Female	incorrect	incorrect	not answered	not answered	not answered	not answered	Incorrect	Correct	not answered	incorrect	incorrect	Incorrect
AQB-M	Sample 1	Male	incorrect	incorrect	1.5/7	incorrect	incorrect	incorrect	Incorrect	correct	not answered	incorrect	incorrect	Incorrect
	Sample 2	Male	correct	incorrect	answered part related to cancer 4/7	incorrect	incorrect	incorrect	Incorrect	incorrect	Correct	incorrect	Correct	Incorrect
	Sample 3	Male	correct	incorrect	not answered	incorrect	incorrect	incorrect	Partly answered	incorrect	not answered	Correct	incorrect	Incorrect

AUHG-NI	Sample 1	Female	correct	Correct	5.5/7	incorrect	Correct	Correct	Correct	Correct	Correct	incorrect	Correct	Incorrect
	Sample 2	Female	correct	Correct	5.5/7	incorrect	incorrect	incorrect	Correct	Correct	Correct	incorrect	Partly answered	Partly answered
	Sample 3	Female	incorrect	incorrect	not answered	incorrect	not answered	incorrect	Incorrect	incorrect	Correct	incorrect	incorrect	Incorrect

10 -Non ASP			Interpretation				Inference	Explanation
AQB-D	SWQ1		Q7	Q.9.a	Q11	Q15	Q13.c	14.b
	Sample 1	Female	Incorrect	Incorrect	Incorrect	not answered	Partly answered	Incorrect
	Sample 2	Female	Correct	Incorrect	Correct	Correct	Partly answered	Correct
	Sample 3	Female	Correct	Incorrect	Partly answered	incorrect	Correct	Incorrect
AUHB-M	Sample 1	Male	Incorrect	Not available	Not available	Correct	Partly answered	Incorrect
	Sample 2	Male	Correct	Not available	Not available	Correct	Partly answered	Incorrect
	Sample 3	Male	Incorrect	Not available	Not available	incorrect	Partly answered	Incorrect
AUHG-R	Sample 1	Female	Incorrect	Correct	Correct	Correct	Correct	Correct
	Sample 2	Female	Incorrect	Correct	Partly answered	Partly answered	Correct	Incorrect
	Sample 3	Female	Incorrect	Incorrect	Correct	Partly answered	incorrect	Partly answered
DXB-I	Sample 1	Male	incorrect	Incorrect	Incorrect	Partly answered	incorrect	Incorrect
	Sample 2	Male	Incorrect	Incorrect	Incorrect	incorrect	Partly answered	Incorrect
	Sample 3	Male	Incorrect	Correct	Incorrect	Partly answered	Correct	Incorrect

Appendix 3.11 Sample of thematic analysis of the interview responses

How does critical thinking apply to the study of science?
I think it's everywhere in science biology physics chemistry because. If a student does not understand a fact or an idea or a concept he will not learn. I don't think that he understood it. He did not learn it. It's not just like a definition memorizing. I keep asking my students not to memorize not don't memorize definitions. They have to understand it and use their own words. So if they understand that it means that if they understand in a critical way this means that he got the concept. Otherwise it's not. He did not learn it.
We should implement it. During exams whether it is a full or somewhat difficult examination or assessment. Also I think during the project if there is any project during the term instead of giving their student the name of a project OK just give them a chance in order to create their own Project.
Science may be based on the scientific method in the way of inquiry and it has to be there all the time. The way of the question we are providing this isn't and also. Working any lab experiment it will be applied

because they will become more interested in the material. Curious to find that information alone and not only to receive it from a teacher or feeding it to from the the books
Me It's about succeeding in the future. It's not only about what I'm giving them because some students can be very good critical thinkers but not have the best grades. So it's about succeeding. Taking this information later on long term in the future and how can they apply it.
Critical thinking is an integral part since no scientific solutions can be arrived without critical thinking
I think if you're not a critical thinker you can't actually grasp the concept which is why so many of us students fail. is the underline of how you study it and see things
The science has the scientific method. So the steps involved in the scientific method and being able to understand the science of something requires a lot of thinking deep thinking and why something is the way it is. How can back up evidence and explain that evidence conclude evaluate. On all on all areas of science. So just so so this chemistry biology physics.
I think science is critical thinking applied to the universe around us. I think I think for me. You know you get into a certain groove after they've been teaching for so many years and you have a certain way and a certain. Style of structuring the lesson I think for me the easiest and quickest way to introduce critical thinking is in the starter that the beginning of the lesson in the way that you know it's very easy to. Communicate a leading question to students. Give them a question and see where they go from that.
The study of science without critical thinking there is no evolution of science. You have to I mean the essentials. The first step of the scientific inquiry is observations and observations are only made when people are triggered or stimulated to think about their environment and why things happen in the way they are. So it has to be authentic independent thinking that starts the process.
Science is a field of inference, predictions and reasoning which the main elements of the critical thinking, so critical thinking plays a backbone role in all fields of science.
With there with those critical thinking there is very you know you need for science and also I think in terms of the classroom and for kids it really helps them learn because they can put you know they can see the bigger picture and think about things in more depth. If you just delivering all this information to them you know plants or whatever. You don't make them think about whether it's in the way they remember
I usually emphasize it by drawing a case or a mystery for them. So I would ask a question but the question would require them to. Investigate. This information or to investigate this idea. So case study basically mystery solving. Would basically guide my students into a critical thinking level not just a direct thinking level.

Appendix 3.12 Official permission letter granted for data collection

الجامعة البريطانية في دبي
The British University in Dubai
www.buid.ac.ae

3/26/2018

Applied Technology High Schools
Dubai, UAE

This is to certify that Ms.Sura Sabri with Student ID number 2016152135 is a registered part-time student in the Doctor of Education offered by The British University in Dubai since September 2016.

Ms. Sabri is currently collecting data for her research (Evaluating reflective practices of Inquiry-based Learning in High School Biology course in the United Arab Emirates).

She is required to gather data through conducting interviews, document analysis of student' artefacts, lesson observations and questionnaires that will help her in writing the final research. Your permission to conduct her research in your organisation is hereby requested. Further support provided to her in this regard will be highly appreciated. Please note that the date for data collection will be between September 2018- January 2019

Any information given will be used solely for academic purposes.

This letter is issued on Ms.Sabri's request.

Approved

Yours sincerely,

28-03-2018

Dr. Amer Alaya
Head of Academic and Student Administration

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Appendix 3.13 Teachers' ***Consent Form***

Consent Form for Educational Research

Title of the research: Investigating the effect of Inquiry-based Learning on students' critical thinking skills development in High School Biology in the UAE: Case Study

Principal investigator: Sura Sabri

Curriculum Development Unit

You are invited to participate in a research study aims to evaluate the effectiveness of inquiry-based learning in Biology for enhancing high school students' reflective and critical thinking abilities.

If you volunteer in this research study, one of your biology lessons will be observed to evaluate how interactions in the classroom can lead to CT skill development and you will contribute in an interview to reflect your opinion regarding the effect of IBL activities on student's cognitive development.

Your participation will help in data collection regarding actual effect of IBL on students' critical thinking development. You can withdraw participation at any time and you will not be panelized in any way if you drop or withdraw participation.

There are no risks from this participation, data collected will serve only the research purposes and will be kept confidential and anonymous.

If you have any question, please feel free to ask before signing the consent from.

Agreement to participate in the research

I have read, the above study and have the opportunity to ask questions which have been answered to my satisfaction. I agree voluntarily to participate in the study as described.

Date	Participant’s name:
Date	Signature of Investigator

Appendix 4.1: Descriptive and ANOVA for gender effect of IBL and CT skills.

Descriptive

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
IBLPre1	male	814	3.7678	1.39456	.04888	3.6719	3.8638	1.00	5.00
	female	516	3.8314	1.37688	.06061	3.7123	3.9505	1.00	5.00
	Total	1330	3.7925	1.38755	.03805	3.7178	3.8671	1.00	5.00
IBLPre2	male	814	3.9545	1.34709	.04722	3.8619	4.0472	1.00	5.00
	female	516	3.9419	1.38666	.06104	3.8219	4.0618	1.00	5.00
	Total	1330	3.9496	1.36207	.03735	3.8764	4.0229	1.00	5.00
IBLPre3	male	814	3.5086	1.42610	.04998	3.4105	3.6067	1.00	5.00
	female	516	3.6066	1.43543	.06319	3.4824	3.7307	1.00	5.00
	Total	1330	3.5466	1.42998	.03921	3.4697	3.6235	1.00	5.00
IBLPre4	male	814	3.6658	1.42077	.04980	3.5681	3.7636	1.00	5.00
	female	516	3.7248	1.40659	.06192	3.6032	3.8465	1.00	5.00
	Total	1330	3.6887	1.41505	.03880	3.6126	3.7648	1.00	5.00
IBLPost5	male	814	3.5688	1.50098	.05261	3.4655	3.6721	1.00	5.00
	female	516	3.5271	1.52431	.06710	3.3953	3.6590	1.00	5.00
	Total	1330	3.5526	1.50964	.04140	3.4714	3.6338	1.00	5.00
IBLPost6	male	814	3.7273	1.40174	.04913	3.6308	3.8237	1.00	5.00
	female	516	3.8837	1.40113	.06168	3.7625	4.0049	1.00	5.00
	Total	1330	3.7880	1.40305	.03847	3.7125	3.8634	1.00	5.00
IBLPost7	male	814	3.6118	1.41826	.04971	3.5142	3.7094	1.00	5.00
	female	516	3.7907	1.41105	.06212	3.6687	3.9127	1.00	5.00
	Total	1330	3.6812	1.41762	.03887	3.6049	3.7575	1.00	5.00
IBLPost8	male	814	3.7371	1.41323	.04953	3.6399	3.8343	1.00	5.00
	female	516	3.8159	1.42209	.06260	3.6929	3.9389	1.00	5.00
	Total	1330	3.7677	1.41666	.03885	3.6915	3.8439	1.00	5.00
CTCla1	male	814	4.1708	1.21048	.04243	4.0875	4.2540	1.00	5.00
	female	516	4.3391	.96104	.04231	4.2560	4.4223	1.00	5.00
	Total	1330	4.2361	1.12294	.03079	4.1757	4.2965	1.00	5.00
CTCla2	male	814	3.8771	1.20256	.04215	3.7944	3.9599	1.00	5.00
	female	516	4.0213	1.11020	.04887	3.9253	4.1173	1.00	5.00
	Total	1330	3.9331	1.16928	.03206	3.8702	3.9960	1.00	5.00
CTcla3	male	814	3.8022	1.26897	.04448	3.7149	3.8895	1.00	5.00
	female	516	4.1260	1.08727	.04786	4.0319	4.2200	1.00	5.00
	Total	1330	3.9278	1.21164	.03322	3.8626	3.9930	1.00	5.00
CTCla4	male	814	3.7064	1.24335	.04358	3.6208	3.7919	1.00	5.00
	female	516	3.9535	1.13624	.05002	3.8552	4.0518	1.00	5.00
	Total	1330	3.8023	1.20851	.03314	3.7372	3.8673	1.00	5.00

CTA 5	male	814	3.6253	1.35411	.04746	3.5321	3.7185	1.00	5.00
	female	516	3.7849	1.26270	.05559	3.6757	3.8941	1.00	5.00
	Total	1330	3.6872	1.32121	.03623	3.6161	3.7583	1.00	5.00
CTA 6	male	814	3.5393	1.34751	.04723	3.4466	3.6320	1.00	5.00
	female	516	3.7093	1.22308	.05384	3.6035	3.8151	1.00	5.00
	Total	1330	3.6053	1.30282	.03572	3.5352	3.6753	1.00	5.00
CTA 7	male	814	3.6646	1.29691	.04546	3.5754	3.7538	1.00	5.00
	female	516	3.8837	1.17830	.05187	3.7818	3.9856	1.00	5.00
	Total	1330	3.7496	1.25632	.03445	3.6820	3.8172	1.00	5.00
CTA 8	male	814	3.7064	1.28135	.04491	3.6182	3.7945	1.00	5.00
	female	516	3.8527	1.15482	.05084	3.7528	3.9526	1.00	5.00
	Total	1330	3.7632	1.23542	.03388	3.6967	3.8296	1.00	5.00
CTE 9	male	814	3.7924	1.27224	.04459	3.7049	3.8799	1.00	5.00
	female	516	3.9225	1.15321	.05077	3.8227	4.0222	1.00	5.00
	Total	1330	3.8429	1.22863	.03369	3.7768	3.9089	1.00	5.00
CTE 10	male	814	3.7224	1.28251	.04495	3.6341	3.8106	1.00	5.00
	female	516	3.9128	1.15336	.05077	3.8130	4.0125	1.00	5.00
	Total	1330	3.7962	1.23706	.03392	3.7297	3.8628	1.00	5.00
CTE 11	male	814	3.6794	1.29210	.04529	3.5905	3.7683	1.00	5.00
	female	516	3.8624	1.15517	.05085	3.7625	3.9623	1.00	5.00
	Total	1330	3.7504	1.24353	.03410	3.6835	3.8173	1.00	5.00
CTE 12	male	814	3.7568	1.27317	.04462	3.6692	3.8443	1.00	5.00
	female	516	3.9632	1.13231	.04985	3.8652	4.0611	1.00	5.00
	Total	1330	3.8368	1.22416	.03357	3.7710	3.9027	1.00	5.00
CTI1 3	male	814	3.7273	1.31106	.04595	3.6371	3.8175	1.00	5.00
	female	516	3.9012	1.17742	.05183	3.7993	4.0030	1.00	5.00
	Total	1330	3.7947	1.26329	.03464	3.7268	3.8627	1.00	5.00
CTI1 4	male	814	3.8268	1.28219	.04494	3.7386	3.9150	1.00	5.00
	female	516	4.0000	1.11477	.04908	3.9036	4.0964	1.00	5.00
	Total	1330	3.8940	1.22245	.03352	3.8282	3.9597	1.00	5.00
CTI1 5	male	814	3.6916	1.35632	.04754	3.5983	3.7850	1.00	5.00
	female	516	3.9729	1.15214	.05072	3.8732	4.0725	1.00	5.00
	Total	1330	3.8008	1.28784	.03531	3.7315	3.8700	1.00	5.00
CTI1 6	male	814	3.7617	1.24875	.04377	3.6758	3.8476	1.00	5.00
	female	516	3.9399	1.12788	.04965	3.8424	4.0375	1.00	5.00
	Total	1330	3.8308	1.20600	.03307	3.7660	3.8957	1.00	5.00
CTS R17	male	814	3.7629	1.29301	.04532	3.6739	3.8519	1.00	5.00
	female	516	3.9070	1.13850	.05012	3.8085	4.0054	1.00	5.00
	Total	1330	3.8188	1.23692	.03392	3.7523	3.8853	1.00	5.00
CTS R18	male	814	3.7211	1.31118	.04596	3.6309	3.8113	1.00	5.00
	female	516	3.9457	1.20071	.05286	3.8419	4.0496	1.00	5.00
	Total	1330	3.8083	1.27372	.03493	3.7398	3.8768	1.00	5.00
	male	814	3.7752	1.28472	.04503	3.6868	3.8636	1.00	5.00

CTS R19	female	516	3.9767	1.09697	.04829	3.8819	4.0716	1.00	5.00
	Total	1330	3.8534	1.21887	.03342	3.7878	3.9189	1.00	5.00
CTS R20	male	814	3.7555	1.28782	.04514	3.6669	3.8441	1.00	5.00
	female	516	3.9632	1.16110	.05111	3.8628	4.0636	1.00	5.00
	Total	1330	3.8361	1.24388	.03411	3.7692	3.9030	1.00	5.00

ANOVA- Gender effect

		Sum of Squares	df	Mean Square	F	Sig.
IBLPre1	Between Groups	1.277	1	1.277	.663	.416
	Within Groups	2557.448	1328	1.926		
	Total	2558.725	1329			
IBLPre2	Between Groups	.051	1	.051	.027	.869
	Within Groups	2465.574	1328	1.857		
	Total	2465.625	1329			
IBLPre3	Between Groups	3.032	1	3.032	1.483	.223
	Within Groups	2714.577	1328	2.044		
	Total	2717.610	1329			
IBLPre4	Between Groups	1.098	1	1.098	.548	.459
	Within Groups	2660.033	1328	2.003		
	Total	2661.131	1329			
IBLPost5	Between Groups	.548	1	.548	.240	.624
	Within Groups	3028.268	1328	2.280		
	Total	3028.816	1329			
IBLPost6	Between Groups	7.730	1	7.730	3.935	.047
	Within Groups	2608.478	1328	1.964		
	Total	2616.208	1329			
IBLPost7	Between Groups	10.108	1	10.108	5.045	.025
	Within Groups	2660.722	1328	2.004		
	Total	2670.830	1329			
IBLPost8	Between Groups	1.961	1	1.961	.977	.323
	Within Groups	2665.249	1328	2.007		
	Total	2667.210	1329			
CTCla1	Between Groups	8.954	1	8.954	7.134	.008
	Within Groups	1666.913	1328	1.255		
	Total	1675.868	1329			
CTCla2	Between Groups	6.564	1	6.564	4.815	.028
	Within Groups	1810.480	1328	1.363		
	Total	1817.044	1329			
CTcla3	Between Groups	33.103	1	33.103	22.920	.000
	Within Groups	1917.968	1328	1.444		

	Total	1951.071	1329			
CTCla4	Between Groups	19.283	1	19.283	13.325	.000
	Within Groups	1921.711	1328	1.447		
	Total	1940.993	1329			
CTA5	Between Groups	8.042	1	8.042	4.620	.032
	Within Groups	2311.841	1328	1.741		
	Total	2319.883	1329			
CTA6	Between Groups	9.126	1	9.126	5.394	.020
	Within Groups	2246.637	1328	1.692		
	Total	2255.763	1329			
CTA7	Between Groups	15.161	1	15.161	9.668	.002
	Within Groups	2082.464	1328	1.568		
	Total	2097.625	1329			
CTA8	Between Groups	6.762	1	6.762	4.442	.035
	Within Groups	2021.633	1328	1.522		
	Total	2028.395	1329			
CTE9	Between Groups	5.345	1	5.345	3.548	.060
	Within Groups	2000.812	1328	1.507		
	Total	2006.157	1329			
CTE10	Between Groups	11.453	1	11.453	7.521	.006
	Within Groups	2022.329	1328	1.523		
	Total	2033.781	1329			
CTE11	Between Groups	10.581	1	10.581	6.873	.009
	Within Groups	2044.544	1328	1.540		
	Total	2055.125	1329			
CTE12	Between Groups	13.457	1	13.457	9.034	.003
	Within Groups	1978.138	1328	1.490		
	Total	1991.595	1329			
CTI13	Between Groups	9.549	1	9.549	6.006	.014
	Within Groups	2111.414	1328	1.590		
	Total	2120.963	1329			
CTI14	Between Groups	9.476	1	9.476	6.366	.012
	Within Groups	1976.576	1328	1.488		
	Total	1986.052	1329			
CTI15	Between Groups	24.976	1	24.976	15.220	.000
	Within Groups	2179.223	1328	1.641		
	Total	2204.199	1329			
CTI16	Between Groups	10.034	1	10.034	6.930	.009
	Within Groups	1922.902	1328	1.448		
	Total	1932.936	1329			
CTSR17	Between Groups	6.556	1	6.556	4.295	.038
	Within Groups	2026.774	1328	1.526		
	Total	2033.330	1329			

CTSR18	Between Groups	15.932	1	15.932	9.886	.002
	Within Groups	2140.177	1328	1.612		
	Total	2156.109	1329			
CTSR19	Between Groups	12.830	1	12.830	8.686	.003
	Within Groups	1961.580	1328	1.477		
	Total	1974.410	1329			
CTSR20	Between Groups	13.617	1	13.617	8.853	.003
	Within Groups	2042.651	1328	1.538		
	Total	2056.268	1329			

Appendix 4.2: effect of grade level on IBL activities implementation.

Descriptive

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
IBLPre1	9.00	715	3.9133	1.34759	.05040	3.8143	4.0122	1.00	5.00
	10.00	615	3.6520	1.42084	.05729	3.5395	3.7645	1.00	5.00
	Total	1330	3.7925	1.38755	.03805	3.7178	3.8671	1.00	5.00
IBLPre2	9.00	715	4.0224	1.34083	.05014	3.9239	4.1208	1.00	5.00
	10.00	615	3.8650	1.38265	.05575	3.7555	3.9745	1.00	5.00
	Total	1330	3.9496	1.36207	.03735	3.8764	4.0229	1.00	5.00
IBLPre3	9.00	715	3.6210	1.41534	.05293	3.5171	3.7249	1.00	5.00
	10.00	615	3.4602	1.44315	.05819	3.3459	3.5744	1.00	5.00
	Total	1330	3.5466	1.42998	.03921	3.4697	3.6235	1.00	5.00
IBLPre4	9.00	715	3.8238	1.35131	.05054	3.7246	3.9230	1.00	5.00
	10.00	615	3.5317	1.47130	.05933	3.4152	3.6482	1.00	5.00
	Total	1330	3.6887	1.41505	.03880	3.6126	3.7648	1.00	5.00
IBLPost5	9.00	715	3.6685	1.48873	.05568	3.5592	3.7778	1.00	5.00
	10.00	615	3.4179	1.52376	.06144	3.2972	3.5386	1.00	5.00
	Total	1330	3.5526	1.50964	.04140	3.4714	3.6338	1.00	5.00
IBLPost6	9.00	715	3.8867	1.35443	.05065	3.7873	3.9862	1.00	5.00
	10.00	615	3.6732	1.45021	.05848	3.5583	3.7880	1.00	5.00
	Total	1330	3.7880	1.40305	.03847	3.7125	3.8634	1.00	5.00
IBLPost7	9.00	715	3.7706	1.41044	.05275	3.6671	3.8742	1.00	5.00
	10.00	615	3.5772	1.42001	.05726	3.4648	3.6897	1.00	5.00
	Total	1330	3.6812	1.41762	.03887	3.6049	3.7575	1.00	5.00
IBLPost8	9.00	715	3.8378	1.41381	.05287	3.7340	3.9416	1.00	5.00
	10.00	615	3.6862	1.41676	.05713	3.5740	3.7984	1.00	5.00

Total	1330	3.7677	1.41666	.03885	3.6915	3.8439	1.00	5.00

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
IBLPre1	Between Groups	22.566	1	22.566	11.816	.001
	Within Groups	2536.159	1328	1.910		
	Total	2558.725	1329			
IBLPre2	Between Groups	8.184	1	8.184	4.423	.036
	Within Groups	2457.440	1328	1.850		
	Total	2465.625	1329			
IBLPre3	Between Groups	8.550	1	8.550	4.192	.041
	Within Groups	2709.059	1328	2.040		
	Total	2717.610	1329			
IBLPre4	Between Groups	28.203	1	28.203	14.225	.000
	Within Groups	2632.928	1328	1.983		
	Total	2661.131	1329			
IBLPost5	Between Groups	20.771	1	20.771	9.170	.003
	Within Groups	3008.045	1328	2.265		
	Total	3028.816	1329			
IBLPost6	Between Groups	15.076	1	15.076	7.697	.006
	Within Groups	2601.131	1328	1.959		
	Total	2616.208	1329			
IBLPost7	Between Groups	12.366	1	12.366	6.177	.013
	Within Groups	2658.465	1328	2.002		
	Total	2670.830	1329			
IBLPost8	Between Groups	7.597	1	7.597	3.793	.052
	Within Groups	2659.613	1328	2.003		
	Total	2667.210	1329			

Appendix 4.3: A comparison between mean scores and standard deviation of IBL and CT responses in different campuses

Campus		IBL	CT
AUH B	Mean	26.8202	71.5169
	N	89	89
	Std. Deviation	10.89679	22.17549
AUH G	Mean	29.7474	76.1684
	N	95	95
	Std. Deviation	9.16163	18.65057
TBMEC	Mean	28.8647	75.2030

	N	133	133
	Std. Deviation	11.65656	25.90594
AQB	Mean	30.7374	78.9293
	N	198	198
	Std. Deviation	8.48718	18.88692
WR G & B	Mean	29.6216	75.8378
	N	37	37
	Std. Deviation	7.02516	18.40367
DXB	Mean	30.0099	76.1773
	N	203	203
	Std. Deviation	8.58215	18.66161
SHJ	Mean	33.0714	80.9524
	N	42	42
	Std. Deviation	6.33378	15.97246
AJM	Mean	30.1441	79.0742
	N	229	229
	Std. Deviation	9.02439	16.20371
UAQ B & G	Mean	30.7241	81.5862
	N	29	29
	Std. Deviation	8.46377	12.98218
RAK	Mean	29.2778	75.4944
	N	180	180
	Std. Deviation	8.31842	19.56667
FUJ	Mean	29.5895	72.3263
	N	95	95
	Std. Deviation	8.94962	21.33394