INQUIRY-BASED LEARNING IN SCIENCE EDUCATION: ASSESSING ITS IMPACT ON CRITICAL THINKING OF THE FEMALE STUDENTS

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Dedication

Dedicated to my parents for their unconditional love, prayers and support throughout my life; my siblings, especially my brother whose support and help in everything makes life easier.

Certificate of Originality

I hereby declare that this submission titled "Inquiry-Based Learning in Science Education: Assessing its Impact on Critical Thinking of the Female Students" is my own work. To the best of my knowledge it contains no materials previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any degree or diploma at NUST SEECS or at any other educational institute, except where due acknowledgement has been made in the thesis. Any contribution made to the research by others, with whom I have worked at NUST SEECS or elsewhere, is explicitly acknowledged in the thesis. I also declare that the intellectual content of this thesis is the product of my own work, except for the assistance from others in the project's design and conception or in style, presentation and linguistics, which has been acknowledged. I also verified the originality of contents through plagiarism software.

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List of Abbreviations

IBL – Inquiry-Based Learning

CT – Critical Thinking

CCTT – Cornell Critical Thinking Skills

CG - Control Group

EG - Experimental Group

TA - Traditional Assessments

ASER – Annual Status of Education Report

NEMIS – National Education Management Information System

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Abstract

The rising research in education recommends that the prior instructional methods are not sufficient for the emerging industrial needs and the challenges and opportunities students facing in 21st century. The purpose of the study is to compare the effectiveness of Inquiry-Based Learning (IBL) and teaching with traditional teaching lecture method on student's critical thinking (CT) skills and academic achievement in science of grade 8. The research took place in one of the urban public school of Islamabad, Pakistan. The study is a quasi-experimental in nature conducted with a pre-test and post-test of control and experimental group. Students from two science classes were the participants of the study (N = 70). The experimental group received IBL instructions, while the control group received traditional instructions. Content-specific CT pretests and posttests of two chapters of science were used to measure students' content-specific CT skills, posttest of Cornell Critical Thinking Test (CCTT) was used to measure students' general CT skills and traditional assessments of two science chapters were used to measure students' academic achievement in science during the 4-weeks intervention. The scores of control and experimental group students were compared to find the impact of each instructional method. Findings suggest that the IBL is an effective approach in promoting content-specific and general CT skills of the students and academic achievement of experimental group students was greater than the control group students. This study will significantly contribute to the existing research and will help future researchers to further explore the avenues of IBL and CT skills.

Keywords: Critical thinking skills, Inquiry-based learning, academic achievement.

1. Introduction

1.1 Background

To be successful in 21st century, 21st century skills are essential to meet the challenges and opportunities people face in education and professional life (Muzanni et al., 2018; Rahmi et al., 2019). There have been genuine differences in the manner we live and work in 21st century when contrasted with the data we assess. In 21st century, students requires 4 C's that is: CT and problem solving, communication, creativity, and collaboration to compete in a global society (Pursitasari et al., 2020). CT is the most vital skill that have been identified by the educationalists long ago. It is the important learning outcome as it is one of the several learning and innovation skill that makes students eligible for higher level education and the workforce (Muzanni et al., 2018). As the speed of progress advances and the thickness of issues in the corporate world turns out to be difficult, we are continually looked in ordinarily of our lives to apply basic deduction to investigate, assess, and make derivations about what to accept and what to do in new circumstances. There is an interest for graduated students to procure CT skills to remain cutthroat in the worldwide market.

John Dewey (1859-1952) is one of the most influential educational philosopher, pragmatist, progressivist, and social reformer to impact education to date (Williams, 2017). The evidence found in Dewey's theories and practices of 21st century skills in classroom as he believes in active learning in classroom where learners constructs their own learning and develop skills of CT, decision making, problem solving and social and moral values, and teachers act as moderator or facilitator and not direct the conversation among students (Williams, 2017). He proposed the theory of "constructivism" which defined as the philosophy or idea that "each person construct knowledge rather than getting it from others" (Witt & Ulmer, 2015). The term constructivism indicates the possibility that every learner develops and construct meaning individually or socially (Hein, 1991).

Constructivism is a process of teaching that stresses on the significance of building on student's prior knowledge and allowing the student to construct their own knowledge (Witt & Ulmer, 2015). The constructivist approach built on the motivation activities for the students in order to develop their thinking skills (Serafín et al., 2015). Constructivism is the theoretical framework for IBL. Inquiry is a "technique that encourages students to uncover or build knowledge" rather than the instructor "direct disclosing the information" (Witt & Ulmer, 2015). According to John Dewey, IBL is a student-focused approach that builds CT skills in learners (Spencer & Walker, 2011; Witt & Ulmer, 2015).

Learning is a functioning cycle where the student builds significance out of it. It incorporates the expression of the active student (Dewey's term) emphasizing that the student needs to achieve something; that learning isn't the uninvolved affirmation of data that exists "out there" nonetheless that learning remembers the student's drawing in with the world (Hein, 1991). It is important for the teachers to consider the dynamic learning approach that can drive student's CT skills, when they think about what should be included in a lesson. The learning process should assist students to keenly think and participate in constructing their knowledge and thinking and not just absorbing the information from teachers.

According to Muzanni et al., (2018) IBL is the effective method that supports teachers in teaching CT skills as it provides great opportunities to learners to actively take part in the learning process. Duran & Dökme (2016) mentioned that IBL is the student-focused method in which they ask questions, seek information, and improve CT skills by means of exploration and investigation in realistic environment. Kitot et al., (2010) mentioned in his study that there is a significant difference in CT skills of the students who receive IBL as compared to the students who receive traditional lecture method.

Thus, the IBL can be characterized as a learning strategy making learners long lasting students who can think freely, improve their scientific abilities, and further developing their CT abilities through conversations and exercises.

1.2 Problem statement

The traditional teaching lecture method for learning science is still being used in most of the schools of Pakistan (Rehmani, 2006). In traditional teaching, teacher's role is to transfer the knowledge and students are expected to consume and memorize the knowledge and given concepts. It is teacher-centered approach and students are the passive learners in classroom with no choice but to adapt to their teacher's restricted methodology and pre-planned lesson plans for gaining knowledge. Teachers are unable to engage students in classroom and their methodology contributes to little or no in developing their critical thinking skills (Rehmani, 2006). The thinking of even well-educated graduates in the Pakistan is based on rote memorization, they are "what to think" instead of "how to think". In spite of the significance of CT, the investigations show that learners, as a feature of social conscience, do not have the capacity to think critically (Sadidi & Pospiech, 2019).

The existing pedagogies practiced in schools are not successful in developing essential 21st century skills amongst the students. One of the problem world is facing today in education is the weak learning process in which learners are less encouraged to develop their thinking skills and learning is only taking place to remember information directly without understanding what they remembered (Zaini, 2016). The teachers are focused on completing the curriculum, without focusing on the learning gain of the students. More importantly, in recent years, the need and demand of these skills have increased in the professional sector to cope with the field dynamics and to face the 21st century challenges. Educators need to shift the focus of their pedagogies from preparing students for rote learning to pass the exams to be life-long learners to acquire skills and who are able to think critically, analyze, collaborate, and communicate effectively.

Many developed countries have realized the importance of student-centered learning pedagogies through effective research and analyze the importance of newer approaches to teaching and implement 21st century skills in classroom with the help of digital technology. However, in Pakistan, the awareness and importance of these skills is still lacking. Traditional and standard methods have applied in the classroom, particularly in the public schools and have not changed much since the existence of the country. Even though some private schools are implementing newer and more relevant techniques in the classroom, the majority of the Pakistani children cannot afford to enroll in these schools or do not have the accessibility to even attend the school be it public or private. To create a larger and more withstanding impact, the current classroom scenario of the public schools needs to be altered to provide openness and greater opportunities of experiences for the students regardless of physical distance.

Learning in public schools is even worse as it is curriculum based and students are totally dependent on teachers. Exam questions and format is repeated, rote learning is extensively practiced, and it is difficult for the students to do basic comprehension and develop deep understanding of the content (Rehmani, 2003). As a consequence, the students stumble when they have to address new problem using the concepts, they should have learned during the education process. Teaching techniques used in Pakistan's educational institutions are failed to instill the critical thinking skills in students and results in poor academic performance and educational development. Discussion among teachers and students and group discussion of students are rarely employed to brainstorm questions. Traditional classroom instructions lack real life examples, relative comparisons and multiple aspects of what is being taught.

Our social culture being authoritative has its own implications on the lives of students, who once discouraged to ask questions never try again. Such environment of class is not helping to nurture the brain and answering the needed questions/concepts, which afterwards become ambiguities. This limits their thoughts, creativity and innovation skills, which otherwise can do wonders if cherished. Such classroom environment does not prompt in-depth learning and understanding of concepts.

Curriculum design is another factor that plays and imperious role in shaping the cognitive abilities of students. Students studying in public sector schools are mainly focused on the isolated facts and prepackaged material in the textbooks provided that lack real life examples, quizzes and group tasks, thus not cultivating the classroom culture of thought and collaboration. Due to this, students remain oblivious to life outside the classroom as there exists a complete disconnection between books and practical knowledge. Curriculum instead of being used as a guideline is perceived as sole content that can fulfill the diverse learning needs of students. Can we assume that we have prepared the students for present and the future practical skills after they have gone through such learning experience?

In Pakistan, teachers use lecture-based approach to teach, where students passively receive information and memorize the concepts without giving it a second thought. It is challenging to change traditional culture of chalk and talk in classroom. Teachers thinks that they have high workload and limited time, which does not allow them to put extra effort to improve quality of teaching and pedagogy. Rote learning does not take part in developing CT skills or any other important skill. Students do rote memorization without understanding the content, which discourage them to think and question it. Therefore, memorizing book text is the main goal of rote learning other than meaningful learning. Schools only evaluate the book knowledge of the students. The pedagogical content present in the book has been the same for decades. The book content only equips the students with knowledge. Students do not gain any CT skills, creative thinking and problem-solving skills along the way. Therefore, in their lives, they are unable to make any decision and follows the same old direction as their older generations.

1.3 Motivation of the study

In 2017/8 global education monitoring report by UNESCO mentioned SDG 4 target 4.1 primary and secondary education: In 2015, 264 million primary and secondary age children and youth were out of school. Target 4.5 equity: there is gender parity in participation at all education levels except tertiary, only 66% of countries have achieved gender parity in primary education, 45% in lower secondary and 25% in upper secondary education (UNESCO, 2017).

Pakistan faces a serious problem of education access and learning challenges. According to the latest available data from Government of Pakistan (Pakistan Education Statistics 2016-2017), about 22.8 million children are out of school and those that go to school often do not achieve even basic learning levels (ASER, 2019). There are 49,090 middle schools in Pakistan, where 34% are government schools and 66% are private schools (NEMIS, 2018). According to survey conducted by Annual Status Education Report (ASER) in 2019, on national level, 57% boys and 43% girls of age group 6-16 are enrolled in government schools. 6% students (3% boys and 3% girls) are reported to be out of school. In 2019 Islamabad (urban), 52% boys and 48% girls of age group 6-16 are enrolled in government school. Learning level of girls is low as compared to boys of age 5-16. Girls' level is 65% and boys 70%. One of the main reason of girls less learning level than boys is lack of interest and lack of relevance with their lives. In 2014 survey, of the 25.02 million OOSC, more than half are girls (AlifAilaan 2014). Moreover, it has been found out that almost 85% children are out of school by the time they reach higher-secondary schools (AlifAilaan, 2015). The education of girls, especially in Pakistan is essential since more than half i.e., 55% of all out of school children are females (AlifAilaan, 2015). Dropping out of school has remained the serious concern in Pakistan (AlifAilaan, 2015). One of the major reasons for both boys and girls dropping out, as reported by parents, is that children themselves are unwilling to continue schooling. It has become important to address the drop out issues in Pakistan and promote girls' education equality. Moreover, there is a need to provide quality education to the student in Pakistan especially girls, to boost their interest in education and help develop critical thinking skills.

An immense need has been felt to improve the quality of education in Pakistan public education sector especially in the field of science for girls. Women are underrepresented in our society and many others in the fields of science and technology (Brotman & Moore, 2008; Hill et al., 2010; Meyer et al., 2015). Lack of interest is the main reason; students are not happily willing to continue studies and learn in schools. IBL is the student-focused approach which gives students autonomy to learn. They are in-charge of their own learning. They act as scientists to carry out their own investigation and find answers to the questions, they raise themselves during the lesson. Explore on their own, construct meaning to the learning. Discuss among other peers, conclude the information after discussion and present the extracted knowledge and share with the class. This gives them sense of constructing their own knowledge with the facilitation of their teachers.

In education CT is not a new concept. There are many reports on incorporation of CT into teaching and learning. For example, researchers focused on instructional strategies for fostering students CT skills via IBL (Hakim & Talib, 2018). CT is a mental process, tactics, and descriptions people use to solve problems, judgments and learn new ideas. The rising research in education recommends that the prior instructional models are not sufficient for the emerging industrial needs and the challenges and opportunities facing 21st century demands (Scott & Friesen, 2013). Scott & Friesen (2013) mentioned that empirical studies found that there is a dire need to replace traditional teaching methods which emphasize on mere recalling the science facts by more effective teaching and learning which enables CT and transmission of skills and use of knowledge in new circumstances. The importance of CT in science education is increasingly present in last year studies but still needs implementations in classrooms.

To instill CT skills in students in science, student centered approach is required such as Inquiry-Based Learning. In this regard, IBL is implemented in classroom to help develop CT skills in learners. It facilitates students to construct knowledge and carry out the investigation of science processes on their own way and better prepare them for the complexities of the modern world.

Since last two decades, more attention has been paid to implement technology in education system. In recent years, a lot of educational content is developed for the teachers and students in science and technology. Science and technology cannot be ignored from everyday life. Education in science and technology is necessary to give student insight into the meaning in their own lives. Technology can create an impact that would be greater and long lasting than other methods. Keeping this importance of technology in mind, video lesson plans are implemented in this study to better know the concepts of science through IBL.

Therefore, 8th grade is considered as an essential and critical point for interest development and positive attitude of the students in science education (ERGÜL et al., 2011). Hence, we should not forget that there is a challenge to train our students with basic skills that they need to survive on their own in today’s world. And to meet this challenge, there is a critical need of transforming schools in such a way that they are able to promote CT skills, because it is needed to be successful in work and life.

1.4 Objectives of the study

The aim of this quasi-experimental study was to understand the impact of IBL in science on academic achievement, content-specific and general CT skills of the female students of grade 8. The objectives of the study are mentioned below:

a) To find the effectiveness of IBL in science on content-specific CT skills of the grade 8 students.
b) to find the effectiveness of traditional teaching lecture method in science on content-specific CT skills of the grade 8 students,
c) to find the effectiveness of IBL on general CT skills of the grade 8 students,
d) to find the effectiveness of traditional teaching lecture method on general CT skills of the grade 8 students,
e) to find the effectiveness of IBL in science on academic achievement of grade 8 students,
f) to find the effectiveness of traditional teaching lecture method in science on academic achievement of grade 8 students,
g) to find comparative effectiveness of IBL and traditional teaching lecture method in science on content-specific CT of grade 8 students,
h) to find comparative effectiveness of IBL and traditional teaching lecture method on general CT skills of grade 8 students,
i) to find comparative effectiveness of IBL and traditional teaching lecture method in science on academic achievement of grade 8 students,

1.5 Study overview

The motivation behind this examination was to limit the vast opening in the exploration of implementing IBL in Pakistan's government educational sector by using technology aid, along with inquiry teaching methodology. It aimed at examining the impact of IBL in science on student's content and general CT skills and academic achievement in science. The focus was on two science chapters of grade 8 named "Pollution and its effects on environment" and "space exploration".

Therefore, the research problem was to assess the effect of IBL on the CT of the grade 8 school students in science. A quasi-experimental study was led with the pre-test and post-test control and experimental group with the participants of 35 each. Quantitative data analysis showed the significant mean difference in both groups and the mean score of experimental group was significantly greater than the control group. Therefore, it was claimed that IBL significantly expands the CT skills and academic achievement of grade 8 students in science.

2. Literature Review

2.1 Constructivist theory of learning

John Dewey (1859-1952) is one of the most influential educational philosopher, pragmatist, progressivist, and social reformer also known as father of modern education. Dewey was a firm adherent to gatherings of individuals meeting up to issue settle in a peaceful manner, through an interaction of " discussion, debate, and decision making". Dewey's convictions about majority rule government, local area, and critical thinking, guided the improvement of his social and instructive methods of reasoning. John Dewey may have been the most notable and powerful rationalist to affect education to date (Williams, 2017).

The central approach to learning through inquiry is based on constructivist learning theory. IBL model is based on the learning theories of John Dewey (1918), who proposed thinking should be connected to action and learning about oneself and the world in which we exist (Friedman et al., 2010). In view of Dewey's way of thinking that learning starts with the interest of the student, his inquiry model has five specific and repeating stages: “asking questions, investigating solutions, creating new knowledge as information is collected, discussing discoveries and experiences, and reflecting on new-found knowledge” (Crippen & Archambault, 2012). Learning in classroom should be connected to the examples of real world and constructs meaning in real world application enables student to be connected with the world otherwise learning process occur in isolation means nothing to student abilities and skills. Constructivist hypothesis implies learning by dynamic development of information in significant settings. The learning process should empower students to effectively think by executing the learning model that builds up their CT abilities, since the idea of activeness is a vital example in developing students' thinking and is one of the establishments of constructivist theory that students are effectively develop their insight and not simply engrossing the information from the instructor (Muzanni et al., 2018).

Dewey was a science teacher and encouraged other K-12 science teachers to implement inquiry method in their classroom. He was incredulous of transmission-based instructional methods that accentuate on obtaining realities that foster thinking and attitudes of brain identified with the manners in which logical information is made. Dewey accepted that the educator ought not just substitute information front of the class and send data to be inactively consumed by students. All things considered, students should be effectively associated with the learning interaction and given a level of command over the thing they are learning. Underscore that this cycle didn't include anything-goes, free-for-all investigation; it was to be guided by exact ways to deal with information creation (Scott & Friesen, 2013).

Constructivism is defined as: "A broad stream of theories in the behavioral sciences and the social sciences emphasizing the active task of the subject and the significance of his/her inner presumptions in the pedagogical and psychological processes as well as the importance of the interaction with the environment and the society; in this meaning is the constructivism also the interactive theory overcoming the one-sidedness of the empiricism and the nativism" (Serafín et al., 2015). In constructivism, learners learn on their own and think and reflect on the process to satisfy their inner motivation. In this definition the teacher becomes the facilitator of student's learning and helps them to find the effective approach of constructing knowledge. Teacher ensures the highest possible level of cognitive development of each and every student with the participation of all (Serafín et al., 2015).

Dewey believed in community learning, he said that school must be illustrative of a social atmosphere and that students learn best when in regular social settings. His way of thinking that students, not content, ought to be the focal point of the educational process, has had an enduring impact on teachers who share in his convictions and methods of reasoning about schooling and how students learn most adequately. (Williams, 2017).

It was Dewey who claimed that learners learn or obtain knowledge best by 'doing'. His idea is the reason behind the importance of learning through inquiry approach. Constructivism's primary thought is that learning is a unique cycle wherein students build novel thoughts or ideas dependent on their encounters and earlier information just as collaborations with the articles and with others (Ismail & Elias, 2006). In IBL students constructs their own knowledge, meaning and understanding of concepts from implementing prior knowledge and learning activities (Rooney, 2012).

Using constructivist models, thinking skills can be accommodated either critical, creative or higher order thinking skills (Zaini, 2016). Constructivist theories based on creating (constructing, reconstructing) the knowledge by the learners rather than transferring the already done information. Dewey pointed out that in traditional education system learners are isolated from all the social interactions and reserved to only one-on-one relationship with the provided learning material. In contrast, progressive education (Dewey's creation) emphasizes on the social aspect of learning in which communication, collaboration with others and use of knowledge in different scenarios is an integral part of learning (Hein, 1991).

Piaget, perhaps the most popular constructivist epistemological scholars, asserted that the students' new information development portrays this present reality where the students resided through. Learning is the result of personal interpretations of experience, exploration of multiple perspectives and an active process in realistic setting. The constructivist classroom is a place where students effectively ask and begin new information and thoughts through communication or dialogue, association, presentation, sharing, and arrangement. In this arrangement, the educators' job is to guide and direct the conversation instead of inactively passing knowledge to the students. Constructivist educators give guidance to the students by connecting with them in inquiry exercises and by animating student's focused dynamic conversation and communicating information, i.e., advancing dynamic learning in a community where students build latest information as indicated by their earlier information, social facts, acquaintances' points of view, and new discoveries (Chowdhury, 2016).

According to Dewey and Piaget, the focal motivation behind instruction is self-sufficiency also called autonomy. They characterize self-sufficiency as the capacity to make rules for themselves to manage circumstances not after the outer controls as outside controls are an obstacle to psychological turn of events. Here, the outer control might be an instructor, or any fixed system given to the students to follow during the learning cycle. During the investigation, self-sufficiency was given to the students in the learning interaction. For instance, the students were self-sufficient in making gatherings of their own and to deal with the time, assets, and gathering arrangement without help from anyone else (A. W. Khan, 2012).

2.2 Inquiry based learning (IBL)

“Education involves a passion to know that should engage us in a loving search for knowledge”. (Freire, 1998)

The literature review conducted by Chowdhury (2016) unsuccessful to produce one single meaning of IBL. The investigated writing expressed numerous meanings of IBL. Some are mentioned below

“IBL is a learning environment focused on a process in which asking questions, thinking critically, and solving problems are encouraged” (Friedman et al., 2010).

“The process which changes the culture of a school into that of a collaborative research community is called inquiry-based learning” (Heindl & Nader, 2018).

“Inquiry” is defined “as a quest for truth, information, or knowledge…seeking information by questioning” (Ismail & Elias, 2006). “The process of inquiry begins with constructing and gathering information and data through applying the human senses” (Ismail & Elias, 2006).

IBL is the teaching method which improves student’s learning outcomes and grow inquiry and research skills by empowering students with the approaches of professional researchers and scientists (Gormally et al., 2009; Hrast & Savec, 2018).

Longo (2012) states that “inquiry is a process driven by the student’s own curiosity, wonder, interest, or passion to understand an observation and solve a problem”. He further added:

> “…concerned with solving problems but it does not require solutions to problems. It involves a flexible yet systematic approach toward solutions. Inquiry learning is learning about the topic being investigated while simultaneously learning about the process of inquiry”.

At whatever point one glances at teaching quality, the picked instructional design plays a significant part. There are two fundamental ideas of teaching in general: instructor focused/teacher centered (regardless of whether the new information is gotten the hang of utilizing numerical definitions, rules, settings, and techniques given by the educator) or understudy focused/learner centered (where new information is found by the learners with pretty much assistance or direct guidance by the educator) (Bruder & Prescott, 2013). The whole focus in IBL is shifted from creating teacher-centered to student-centered environment where students investigate a set of phenomena and draw conclusions. At the same time learning becomes more self-regulated and students have to be instructional designers for themselves (Pedaste & Sarapuu, 2006). Moreover, learners effectively partake in the inquiry learning environment. IBL is a method of posing inquiries, looking for data, and discovering groundbreaking thoughts identified with an occasion. That is, in IBL, learners learn by utilizing circumstances and logical results, rational and CT, and joining both scientific knowledge and activities (Duran & Dökme, 2016).

In the learning process, there is great emphasis on schools to provide autonomy to the learners (A. W. Khan, 2012). According to educationists autonomy can be achieved by IBL due to its historical evolution and its effectiveness in the learning in which students are the active participators in building the knowledge with the help of teachers/facilitators (A. W. Khan, 2012). The art of questioning is the important part of the inquiry process. It is the questions that enable students to think critically and entice them to conduct further investigation. In an inquiry-based education setting, investigation lead by learners initiated by their questions about subject matter. Desks are arranged in groups so that students learn and gain knowledge together. IBL guides leaners to generate meaningful questions and come up with the answers through critical thinking (Ismail & Elias, 2006). It integrates skills in students which make them lifelong learners. The individuals undergo the process of inquiry from birth until they die. In IBL process, students are involved in open-ended, student-centered, hands-on and minds-on activities based on real life issues (Rooney, 2012).

IBL approach is used for solving problems and developing CT skills in students which is essential for them in daily actions (Maxwell et al., 2015; Pedaste & Sarapuu, 2006). IBL not only communicates how to ask questions and find out their answer but also what kind of questions are important to ask and discover (Maxwell et al., 2015). New knowledge is discovered by the learner through their active participation in the IBL approach (Pedaste et al., 2015). Because it is the process in which learners learn and discover new knowledge through formulating their own questions and hypotheses and test those hypotheses by performing experimentation and designed investigations and making observation and answer the anticipated questions (Bruder & Prescott, 2013; Pedaste et al., 2012).

Further studies explain that students get the opportunity to explore their own questions and acquire much knowledge in the process of research. In IBL students ask questions and use these questions to investigate by using appropriate methods and tools then evaluating those evidence to use them logically to build new knowledge and create an explanation to communicate their conclusions to others. The learning process actively involves students in the whole process of inquiry (M. Khan & Iqbal, 2011). Students show curiosity and teaching through inquiry helps teachers to provide multiple resources and tools that enables students to explore, investigate and discuss solutions with others (Ryan & St-Laurent, n.d.).

IBL approach engages students to involve in an authentic scientific discovery process where students act as a professional scientist to investigate or construct knowledge (Pedaste et al., 2015; Longo, 2012). Self-regulated learning alludes the capacity to comprehend and control the learning environment through utilizing objectives, applying beneficial outcome, executing procedures, and utilizing monitoring and reflection (Crippen & Archambault, 2012). Instructions based on Inquiry based learning approach is improved due to electronic learning tools and environment (Pedaste et al., 2015). Inquiry based learning can play vital role in educational reform but its effective implementation is missing in today's classroom (Longo, 2012).

Inquiry instructions invoke thinking and questioning and emphasis on how we did "come to know" this answer. IBL was most encouraging when the procedure of discovery was delicately directed by the educator with the essential information imparted just when vital. Moreover, the problems ought not be excessively difficult yet decreased to a suitable level. Fluctuating the level of the assignments frames the reason for summing up comprehension and for understanding the concepts. In a conventional classroom, the instructor can anticipate the entire exercise, though in an IBL classroom there is a degree of vulnerability related with an unpredictable educating/learning relationship (Spencer & Walker, 2011).

Instructors need to move their concentration to a more intuitive methodology, where students are doing the majority of the talking. By permitting students to assume control over, students feel more free and self-coordinated, managing their own learning. IBL permits students to utilize their interest to manage their inquiries and their learning. Students are more drew in when they make their own examination and can coordinate exercises towards their frame of mind (Wheatley, 2018).

The research studies showed that, IBL is beneficial for students achievement and CT skills (Longo, 2012). The major benefit of IBL is the increment in student engagement and decrement in anxiety. The learning from inquiry is real and authentic in nature as it provides connections with the real world (Ryan & St-Laurent, n.d.). Accordingly, traditional methodologies ought to be limited and moved more towards IBL. Nonetheless, the opportunities IBL provides the students and educators is the development of community learning, multifaceted assessments, enhanced student's achievement and increase critical thinking skills.

2.2.1 Instructional model of Inquiry

The learning process can construct CT skills in students followed by the method/strategy/model implemented by the teacher. The selection of the pedagogical model greatly impacts the outcomes of the final results in increasing student's CT skills. Thus, in this study the IBL framework of Pedaste et al. (2015) was applied.

Pedaste et al. (2015) conducted a literature review using EBSCO host Library of 32 articles. Specific search criteria were used to select articles explaining inquiry phases or whole inquiry cycles. Five distinct general inquiry phases were identified as a result of the analysis of selected articles: orientation, conceptualization, investigation, conclusion, and discussion. No single writing proposed these five stages, rather each proposed an alternate number of stages with a wide range of depictions and names. The authors incorporated the gathered information and proposed a framework for IBL measures with five particular stages. In this framework, IBL starts with orientation and flows through conceptualization to investigation, where a few cycles are conceivable. IBL normally finishes with the conclusion phase (Chowdhury, 2016). Below are the five inquiry phases which are the result of the analysis of the articles done by the author. This model is the key component used in this dissertation.

1. **Orientation:** Inquiry cycle initiated with the orientation i.e., introduction of a topic. According to (Pedaste et al., 2015) some authors simply described it as 'observation' or 'exploration' of the behavior or topic. The aim of all the activities that fall under the phase 'orientation' is to get learner started with the investigation of the topic. The main variable of this phase is problem statement or problem identification. In problem identification students observe carefully, take notes and look for patterns to search investigable questions (Pedaste et al., 2012).
2. **Conceptualization:** This phase is divided into two alternate sub-phases named as 'Questioning' and 'Hypothesis generation'. Depicting what requires to be identified, research questions, asking questions, generating questions, developing questions, setup initial inquiry questions, defining or identifying the problem by raising and revising questions all comes under the 'Questioning'. Setting hypothesis, making predictions, and 'brainstorming solutions' comes under the hypothesis generation which are needed to start the investigation. Some authors mentioned the process of 'analyzing' and

'searching for information on the web' that guide the learners towards hypothesis and questioning (Pedaste et al., 2015). The process of forming theoretical issues and or hypothesis (Morze et al., 2019).

3. **Investigation:** Investigation phase is more systematic and planned. Authors named this phase as 'investigate', 'observe', 'observation', 'explore', 'exploration', 'collect evidence' etc. Two types of investigation processes are mentioned which are the sub-phases: Exploration and Experimentation. In exploration learners do simple observations and in experimentation they collect the evidence regarding the hypothesis, both involve planning. 'Research', 'gather data', 'organize and analyze data' etc. are involved in the planning processes. 'Data interpretation' is one of the sub-phases of the investigation phase, conducted after the planning process together with exploration and experimentation (Pedaste et al., 2015). This last sub-phase of the investigation guides learner to move forward or to revise the experimentation results and go for more exploration.
4. **Conclusion:** IBL ends with the conclusion phase. In some articles it is mentioned in the following terms: 'refinement', 'offer solution', 'refine theory', 'reasoning with model', 'finding relationships and drawing conclusions', 'drawing conclusions and making judgement about them', 'inference', 'report', etc. (Pedaste et al., 2015). In this stage, students demonstrate the results in clear manner (Pedaste et al., 2012).
5. **Discussion:** Discussion is mentioned as the final phase of the inquiry cycle and it is divided into sub-phases: 'Reflection' and 'communication'. Different authors mentioned it as: 'Reflection', 'communicating results', 'discussing with others', 'present inquiry', 'elaborate', 'discussion and presentation of new content', etc. (Pedaste et al., 2015). Reflection is defined as the cognitive process which is carried out in order to learn from the experiences (Leijen et al., 2012). This phase is also seen

in parallel with all other phases where gathered information needs discussion.

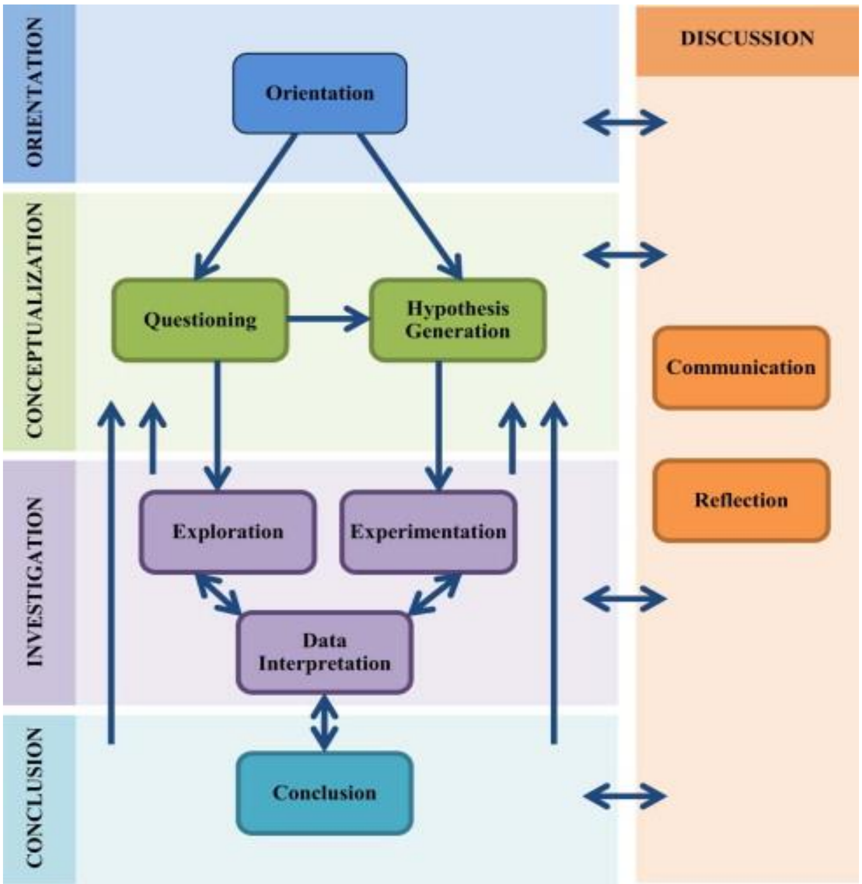


Figure 2.1Inquiry-Based Learning framework (general phases, sub-phases and their relations)

Throughout the inquiry, discussion is an important or active part when activities need collaboration among students (Pedaste et al., 2015). Moreover, when communicating their findings to other people, students need to realize how to plainly clarify their activities and choices with respect to their investigation to a group of people (van Uum et al., 2016).

Students have different options for proceeding their inquiry cycle, either hypothesis-driven approach or questioning-driven approach. Pedaste et al. (2015) suggested the three possible pathways:

1) Orientation - Questioning – Exploration - Data Interpretation - Conclusion (loop between questioning and exploration can be repeated several times and communication and reflection can be added to every phase).
2) Orientation - Hypothesis Generation – Experimentation - Data Interpretation - Conclusion (loop between Hypothesis Generation-Experimentation-Data Interpretation can be repeated several times and communication and reflection can be added to every phase).
3) Orientation – Questioning - Hypothesis Generation – Experimentation - Data Interpretation - Conclusion (loop between Hypothesis Generation – Experimentation - Data Interpretation can be repeated several times and communication and reflection can be added to every phase).

In this research, the first pathway will be followed. Thus, the revised model is given below:

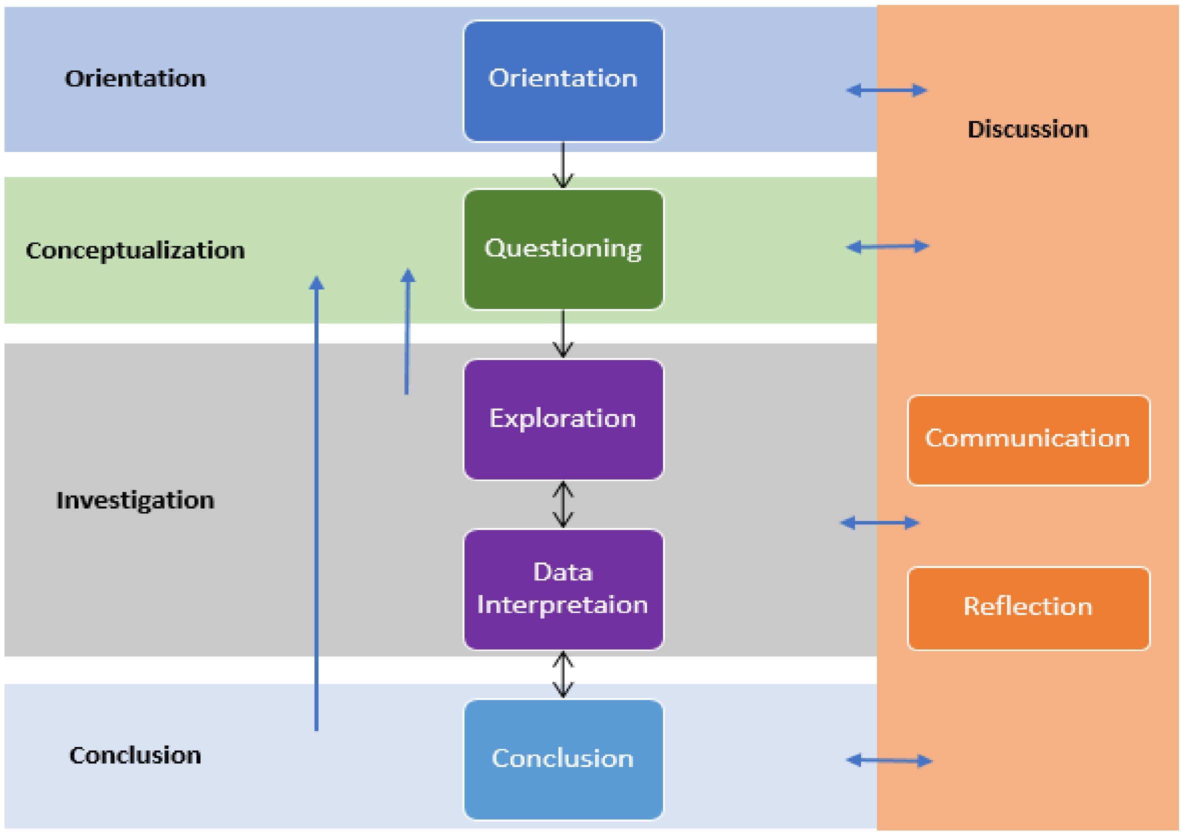


Figure 2.2 Revised IBL model

2.3 Critical Thinking Skills

Critical Thinking (CT) defined as: "an on-going cycle for quest of information and examining a variety of data to make a good understanding and more significant problem solving and decision making for complex issues" (Iwaoka et al., 2010).

Definitions of CT according to cognitive psychology includes "the mental processes, strategies, and representations people use to solve problems, make decisions, and learn new concepts" (Sternberg, 1986).

Other definition according to educational point of view is

"The abilities of students for asking and answering questions for clarification, defining terms, identifying assumptions, interpreting and explaining, reasoning verbally, especially in relation to concepts of likelihood and uncertainty, predicting, and seeing both sides of an issue". (Lai, 2011)

According to (Lai, 2011) researchers agree upon the definition of CT which includes the abilities of "analyzing arguments, claims, or evidence", "making inferences using inductive or deductive reasoning", "judging or evaluating", "making decisions or solving problems", and "identifying and analyzing sources and drawing conclusions".

Empirical study finds that everyone can benefit from CT instructions, regardless of the intellectual abilities of the students. For activating CT, background knowledge is necessary but not sufficient. It can be taught, learn and developed in learning process and assumed that CT skills in children are always evolving. Students acquire this skill as a natural consequence of engaging or interacting with the subject matter. Researchers concluded that CT skill is not gifted, it is for everyone (Lai, 2011; Mabruroh & Suhandi, 2017). Moreover, Pursitasari et al., (2020) stated that students can be trained to think critically by structured explanations students deliberately and frequently done to develop their in-depth thinking as CT is an intellectual process to actively perceive, apply, analyze, create and evaluate the information that is collected by observation. Hill et al., (2010) suggested to teach students that intellectual skills can be acquired. He emphasizes to teach them that brain works like a muscle, it gets stronger when more exercised. Every time they stretch and work hard, their brain forms new connections, and they learn something new and over the time they become smarter, passionate, dedicated, and self-sufficient.

Emily R. Lai (2011) argues that CT skills and abilities can be taught, and it teaches students to respect others in discussion, value reason and truth, be willing to see things from others perspective, considering alternatives before making a decision, using cognitive strategies (asking for examples and questions when something is not clear), and be open-minded. The author concluded in his study that positive results are obtained by instructional interventions aimed at improving CT of the students. It provokes collaboration and cooperation among students, as he highlights the importance of student's relationship with others in developing CT skills.

Theory of Piaget and Vygotsky also emphasizes on social interaction for the cognitive development. CT skills provides ability in students to actively participate or respond constructively in discussions. CT skills of the students can be evaluated by judging student's arguments on the basis of the quality of them rather than the 'correctness' of the answer. Author argued that assessment should be more than just recall of the previous knowledge, questions should require the manipulation of the information in new context. Other suggestion is to ask them to solve real-world problems through scientific process: "generating hypotheses, testing hypotheses, analyzing results, and drawing inferences and conclusion". Teachers should create open-ended tasks and assignments, real world problems and ill-structured questions that urged scholars to think out of the box and recall previous information/knowledge. Such questions should have more than one possible solution. such kind of assessments make student's reasoning skill stronger (Lai, 2011).

CT can be taught in the domain-specific context and in the content related to daily life of the students. CT skills expected to increase if embedded in content-specific instructions (Sadidi & Pospiech, 2019). After reviewing researchers concluded that no superiority found in both, the most preferred is the mixed approach. This means that teachers can incorporate CT in routine educational subjects and by teaching general CT skills as a separate component through instructions. Author describes that the use of "authentic" real-world examples, problems and activities helps teachers to encourage CT skills in students (Lai, 2011).

Authors believe that CT should be embedded during instructions. Researchers concluded in the research field of psychology that adults if not most, lack the CT in various situations. Some pointed out that many adults lack basic reasoning skills. One reason for this is the education system and typical schools whose entire focus is on the coverage of content rather than building the knowledge, which does not support the higher order thinking skills and as a result there is a deficiency of basic reasoning skills. CT skill is an important learning outcome of student learning, which is required for higher education and employment. People who can think critically have the ability to acquire knowledge, ask and generate sensible questions, combine and reduce relevant information, think logically for the information they receive and make reliable conclusions. Therefore, developing the habit of thinking critically is important at various levels of education and it should be the key goal of educational institutes (Friedman et al., 2010; Sadidi & Pospiech, 2019).

The idea of group work and combination of students to get educational objective has been progressively explored and credited all through specialized research. The term group work alludes to a strategy wherein learners at various capability levels cooperate in little gatherings going toward a certain goal. The students are responsible for other people and their own understanding. Thus, the achievement of one student gives different students the sort of certainty to be successful. Followers of group work accept that the interchange of inquiries and answers of students in little gatherings expands interest among the students as well as triggers CT skills (Ghaemi & Mirsaeed, 2017).

External factors influence students' CT skills such as teaching approach or methods, educational paradigm, nature of assessments, teachers' feedback, atmosphere, and attitude whereas internal factors include self-determination, positive attitude, emotional state, intelligence, personality traits and cognitive abilities (Shubina & Kulakli, 2019).

Author argued that we should not expect the dramatic increments in CT due to instructional interventions over a certain period of time, the improvements do occur but at a very slow rate (Lai, 2011). Teaching CT is a continuous process. The effective way of developing higher order thinking of students is to insert it in every lesson in a variety of questions and activities (Zaini, 2016).

2.3.1 Assessment of critical thinking skills

Evaluations can be done in many ways to check the level of knowledge of the students and the effectiveness of the instructions of the teacher in an IBL on student's CT skills (Llewellyn, 2014). To evaluate the performance of students and deep understanding of the content ask them to solve the real-world problems (Scott & Friesen, 2013). Research shows that very limited work is found based on the assessment of CT skills in science in secondary/higher education comparative to the general setting in general context (Hakim & Talib, 2018). The significant objective of science education is the development of CT skills but there is less emphasis on measurement of CT skills in science. Perceiving that sufficiently measuring CT skills infers the evaluation of content-specific and general CT skills equally (Sadidi & Pospiech, 2019).

2.3.1.1 Domain-general CT skills

There are assorted perspectives held among researchers regarding the core processes engaged with CT. Basic CT skills includes the ability to draw substantial inferences, distinguish connections, investigate possibilities, make projections and logical decisions, and confront complicated questions. With an ultimate objective to assess CT ability, various tests were made and supported. Ennis, Millman and Tomko (1985), for example, co-made an area general CT test named the Cornell Critical Thinking Test (CCTT) that accompanying the segments of CT: induction, deduction, prediction, credibility, and exploratory arrangement, and deceptions and presumption Identification (Tiruneh et al., 2017). The CCTT is one of the numerous multiple-choice tests with approved questions that have been accounted for to gauge general CT capacity. The level Z of CCTT contains 52 items and designed for high school gifted students and college students and other adults. The level Z contains 5 elements of CT: induction, deduction, assumption, observation and meaning (Iwaoka et al., 2010). There are 71 multiple choice questions of level X for the students of grade 5-12+. Level X contains 4 items of CT: induction, deduction, credibility, identification of assumptions (*Cornell Critical Thinking Test Level X*, n.d.). CCTT contains content from an assortment of regular daily existence conditions that test-takers at a school level know about. The members of the Illinois Critical Thinking Project assessed the content validity of the CCTT and concluded that the items of the CCTT measure CT as defined by the authors and also shows the positive signs for criterion validity of the test (Verburgh et al., 2013).

General CT skills test characterize as the capability to sensibly react to CT undertakings that don't really need domain-specific substance information, yet rather an information on regular day to day existence.

To evaluate the accomplishment of students in creating CT skills should be upheld by an estimating instrument that can quantify such capacities. Estimation is a significant factor in schooling on the grounds that, through the estimation, the educator would be known precisely where students lie in an activity (Mabruroh & Suhandi, 2017).

2.3.1.2 Domain-specific critical thinking skills

There has been a huge interest among different researchers and educators to implant CT inside specific subject matter guidance. From content-specific tests of CT, it is conceivable to quantify improvements in CT abilities as a feature of students' authority of the subject area being referred to.

CT has also been connected to the Bloom's taxonomy. The six levels of learning in revised Bloom's taxonomy (creating, evaluating, analyzing, applying, understanding, and remembering) are still useful today for instructors develop students' CT skills assessments as in the past decade (Friedman et al., 2010; Rooney, 2012). It is more applicable on creating level than understanding level of learning (Friedman et al., 2010). In this research higher level of Boom's taxonomy (applying, analyzing, evaluating, and creating) are considered for developing domain-specific CT test of science. The structure of the revised Bloom's taxonomy provides a clear and concise visual description of educational goals and objectives. The table below is the description of Bloom's taxonomy:

Table 2.1 Revised Bloom's Taxonomy

Levels of revised Bloom's taxonomy	Description
Remembering	Repossessing, realizing, and evoking related knowledge from long-term memory;
Understanding	Forming meaning from oral, written, and graphic messages through interpreting,

	exemplifying, classifying, summarizing, inferring, comparing, and describing;
Applying	Carrying out or using a process through implementing, or applying;
Analyzing	Breaking material into basic parts, deciding how the parts identify with each other and to a general construction or reason through separating, coordinating, and attributing;
Evaluating	Making decisions based on standards and guidelines through verifying and criticizing;
Creating	Assembling components to shape a simple or useful entire; redesigning components into another example or construction through creating, arranging, or delivering.

(Rooney, 2012)

As the significance of building up students' capacity to think critically on particular domains of science keeps on developing, scientists and experts need to have legitimate and dependable tests to assess the viability of different instructional endeavors. In this study, we contended that a precise and thorough evaluation of CT ought to underline both domain-specific and domain-general CT measurements.

In view of above it is important to develop the instrument tool for assessing the CT abilities of students related to the topic. From the literature search, there are developing amounts of CT abilities evaluation in science and science-related subjects, yet limited, which shows the need to have a CT abilities assessment in a particular area. The domain-specific CT is immense, especially in science since analysts will reliably present inquiries about the reasons that particular events happened and should be refined when one starts to ask "why". By emphasizing in on domain-specific CT abilities in science, it will help learners with separating and evaluate phenomena using a science point of view. Also, there is a necessity for suitable CT abilities evaluation, as student's characteristics and inadequacies in this particular area can be settled and improved using reliable assessment tools (Hakim & Talib, 2018).

2.4 IBL and CT in Science

Inquiry is one of the learning models that has ability to develop CT skills in students, Rahmi et al., (2019) concluded in his quasi-experimental study that the implementation of inquiry learning model has a positive impact on student’s CT skills. Furthermore, thinking abilities mastered through IBL incorporate "… ID of suppositions, utilization of critical and logical reasoning, and consideration of different clarifications" (Friedel et al., 2008).

Teaching and learning using inquiry model could increase students’ CT skills and inquiry instructions results in improving student’s learning outcomes (Zaini, 2016). It facilitates the learning and assist students through CT, scientific processes and better understanding of the concepts than rote memorization (Friedman et al., 2010). Inquiry learning is used in expanding CT skills of the students by adding real-world examples and problems in instructions and curriculum (Longo, 2012). IBL, which is student-centered focusing on the posing of questions and CT, empowers learners to foster abilities required all through their entire lives. IBL is an educational methodology where learners can obtain data and further develop their CT abilities through revelation and examination in real settings (Duran & Dökme, 2016).

To remember a concept for a long time and store in the long-term memory there is a need to involve students directly in the learning procedure because by engaging students they gain/obtain the knowledge which is not in the form rote memorization. According to

(Sucilestari & Arizona, 2020) the learning model that directly involve the students in the learning process and can enhance student's CT skills is IBL. He further added that CT skills cannot be obtained if not trained therefore a process is needed to practice the skill.

In recent years, numerous examinations have featured a disturbing decrease to youngsters' advantage in key science studies and mathematics. Regardless of the various undertakings and activities that are being executed to switch this pattern, the indications of progress are as yet unremarkable (Morze et al., 2019). CT is one of the most universally emphasized goal in education (Grant & Smith, 2018). IBL, like many other educational methods, the ultimate goal is to achieve students' success. IBL in science education in elementary schools can be an extremely beneficial approach to advance conceptual understanding. Moreover, examining the attributes of scientific tests and thoughts, can help in increasing the understanding of the scientific knowledge (Heindl & Nader, 2018).

Research evidence has shown the positive significance of CT in science exercises and its instilling should begin at the elementary levels. By drawing students in CT from the elementary levels, science teachers can establish the framework for capable and moral buyers of scientific change. Nevertheless, there is little proof that tests are being utilized to evaluate student's CT skills in science. A significant part of the trouble lies in the absence of tests to evaluate students' CT skills in elementary school science classrooms (Mapeala & Siew, 2015).

IBL is a way to deal with science instructions that has been around for more than 40 years, a very long time and has numerous positive perspectives, including: CT skills, student's achievement, positive mindsets towards science, and student's engagement (Wheatley, 2018). Maxwell et al., (2015) mentioned that science must be taught and learn through IBL included exercises in which "perceptions, addressing, understanding books and different resources of data, examination, gathering, analyzing, forecasting, clarifying, and conveying results". He further added that retaining facts won't improve abilities in learners of science, however the self-sufficiency to investigate a lot through IBL will. He proposed that to build learner's commitment, higher order thinking abilities and accomplishment in science, learners should be experienced with the dynamic learning methods like IBL.

The main purpose of science education is to improve student's CT skills and understand the concepts. CT is based on reasoning and deciding what to believe or do (Mabruroh & Suhandi, 2017). Ideal learning results in school is not accomplished by traditional teaching lecture method in science. Conventional current course books are intended to show portioned science ideas each in turn and neglect to make associations with real world for students and energize CT. This conventional methodology advances repetition retention over understanding and open thinking. (Chowdhury, 2016).

IBL promotes positive learning environment in science classroom and the results in knowledge enhanced compared to traditional science classroom instructions. CT skills and science processes are difficult to understand through traditional means of teaching that is why inquiry model is used to instruct students and give them opportunities in a cooperative environment where they solve real-world problems and construct or gain new knowledge. Inquiry instructions provide students with opportunity to construct meaning of the scientific processes rather than just memorizing the scientific facts and concepts (Longo, 2012).

CT is a hot topic for academicians and researchers for the past several years to incorporate in classrooms to make students effective problem solver and logical thinkers (Hakim & Talib, 2018). Science learning does not just concern the idea of science to improve the accomplishment of science education, yet in addition to work with the learners to foster their capabilities to become skilled human resources. The advancement of capability in information and abilities in the national curriculum assemble the capacity of learners to comprehend and apply science accurately and to have higher order thinking abilities (Pursitasari et al., 2020).

Sucilestari & Arizona, (2020) mentioned in his study that science learning not just highlights the authority of substance (psychological learning results) yet in addition on the parts of more significant level of higher-order thinking abilities, one of them is CT ability that are imperative to be claimed by students as an arrangement of life in managing different genuine issues in their lives. Moreover, the way scientific information is produced mentions to the mixture of scientific measures, like observing and estimating, with 'scientific information, scientific reasoning, and CT to create scientific information (van Uum et al., 2016).

The link between inquiry approach and science is conspicuous. Learning with inquiry satisfy the curiosity of students and enable them to gain experience and boost interest in the field. They enjoy finding something new that they want to know. They invest class energy posing inquiries and getting one-on-one input and backing for substance, activities, or issues from teacher what they have learned in classroom. Albeit this model of instruction has a lot to bring to the table and might be desirable over numerous current educational practices where students spend a lot of their time in school just listening to the educators. Science classrooms should move away from repetition and rote memorization of ideas to the utilization of CT skills as an essential part in encouraging learning (Friedel et al., 2008).

2.5 Traditional teaching lecture method

As propels in innovation push us forward into the 21st century, techniques for educating and classroom guidance have stayed a lot of something very similar to the traditional time or pre-digital age.

Traditional lecture method is teacher centered and knowledge is limited to books and delivered lecture by teacher. Teacher read and explain information from the textbook to students (Maxwell et al., 2015). Rarely involved students in learning process as students are perceived as empty containers only filled by knowledge given by teacher and assumed to memorize this knowledge without questioning, exploring and analyzing. Resources for teaching is limited to school and does not use technology to enhance student's learning and nurture other skills. Teacher is the only direct or indirect source of knowledge in the class and students are told what is important for the tests and formative assessment and difficult points are explained (M. Khan & Iqbal, 2011).

Traditional education system anticipates from educators to observe the provided outside norms and projects, normalized evaluations and showing theory, which as a rule do exclude explicit acquiring results for CT abilities (Shubina & Kulakli, 2019). During traditional methodologies, learners can be believed to be more off-task or investing additional measures of energy restating a similar assignment. This conduct adds up to lost time learning and more noteworthy learners confusion since learners are more befuddled by muddled headings (Wheatley, 2018).

Different kinds of teacher-centered guidance incorporate direct guidance for the acquiring of explicit abilities and topic and exhibitions of specific abilities and processes. The most widely recognized part of the teacher-centered methodology is that instructor figures out what will be learned and students will in general passive receiver of that information as opposed to being effectively drawn in with their learning (Bruder & Prescott, 2013).

Researchers calls attention to that successful urban instruction is by a long shot perhaps the most difficult issues in education today. With the final product in numerous urban secondary schools bringing about high dropout rates and low student's inspiration, urban instructors should break new ground for instructional significant plans to use in their classrooms (Williams, 2017).

2.5.1 Comparison of Traditional Teaching Lecture and Inquiry-Based Teaching

Table 2.2 Comparison of inquiry-based teaching and traditional teaching lecture method

	Traditional teaching lecture method	**Inquiry-based teaching**
Learning theory	Teacher centered Teacher-imposed knowledge and teacher-directed activities	Student centered Self-directed learning and activities
Teacher's role	Knowledge source	Facilitator of knowledge & learning
Learner's role	Passive receiver: Memorize facts without reflecting and carryout procedures without understanding how or why	Active learner: learners look for patterns and underlying concepts by exploration and investigation of the processes
Resources	Classroom, teacher, typical classroom tools	Depend on the process of learning; can use digital tools and in any learning environment

Social aspect	Isolating learner from social interactions,	Encourage the social interaction through communication, discussion, and application of knowledge
Purpose	Learning isolated facts and theories	Study in association to what else we know and believe
Method/technique	One-way transmission of information through preaching, verbalizing, repetition, narrating	Two-way transmission of knowledge and learning through problem-solving, projects, experiments
Source of knowledge	Only teacher is the source of knowledge	Along with teacher multiple sources of getting information for example internet sources, books, surveys
Expectation	Simple reproduction of answer from the transferred knowledge	Students' better understanding, learning by solving problems, achieving skills
Evaluation/assessment	One-dimensional testing, product-oriented using typical standard tests	Multi-dimensional testing, process-oriented testing using different types of performance tests for example portfolios etc.

2.6 Benefits and challenges of inquiry-based learning

In the fast-pacing world IBL gaining popularity all over the world to prepare learners for the 21st century skills. Traditional teaching methodologies becomes passive and boring for learners as it only prepares students for the rote memorization with little or no involvement of CT and construction of new knowledge that linked with the real world. Instead of rote memorization, IBL promotes problem solving and critical thinking among students. IBL is the approach where students engage in developing their own questions, perform investigation and search for information and share their findings. This process helps students to actively participate in the classroom to construct new knowledge. Despite of all the benefits, IBL has its own challenges. Following are the benefits and challenges of IBL:

2.6.1 Benefits

IBL provides learners with the ability to critically think and analyze data to solve problems and make conclusions. It helps learners to make decision and construct their knowledge with the guidance of the teacher or facilitator. In IBL teachers encourage students to search for the problem and develop their own questions, explore to gather data, investigate the information searched, and share their results in an IBL environment. This process of IBL helps students to build new knowledge by actively participating in IBL classroom setup. IBL cannot dramatically alter the overall student's achievement, but it has other positive effects on the students like dynamic involvement of learners in classroom and higher academic achievement/grades. Moreover, IBL is resulted in greater achievement in standardized test measures along with classroom measures in contrast with the conventional teaching method (Chowdhury, 2016).

IBL has a significant impact in the learner's learning outcome when a IBL strategy is utilized rather than traditional teaching. It emphasizes on the directions that initiate learner's CT rather inactive utilization of conventional lectures. Researchers infer that IBL adds to positive learner results in STEM subjects, including information procurement, advancement of problem-solving skills, CT and decision-making abilities (Hrast and Savec, 2018).

There are following benefits of implementing IBL in classroom mentioned by (Morze et al., 2019):

1. Strengthen Curriculum Content
2. Fostering student passions and aptitudes
3. "Warm Up" the Brain for Learning
4. Encourage student participation and respect their choice
5. Encourage a Deeper Understanding of Content
6. Enhance motivation and engagement
7. Foster curiosity and a love of learning
8. Build Initiative and Self-Direction
9. Help Make Learning Rewarding
10. Teaches self-regulation
11. Develop research skills and make it meaningful
12. Deep understanding of facts
13. Strengthen the significance of asking good questions
14. Empower to take responsibility of their own learning
15. Offer Differentiated Instruction

2.6.2 Challenges

IBL provides endless openings for students to explore, explain, construct and employ knowledge. Nevertheless, implementing IBL in classroom encounter with good number of challenges. There is no standardized definition or cycle of IBL. Implementation of IBL in every classroom on daily basis is not an easy task as it comes with a lot of challenges. Lack of teachers training is the most common barrier; teachers find it time consuming and difficult to implement activities and use other resources in a limited time of classroom. If teachers lack knowledge of IBL, they will not show interest in teaching through IBL techniques in classroom. In most of the schools IBL lesson plans and resources are not available for students and teachers. The common barrier in promoting inquiry-based learning and teaching in classroom is short of time. Moreover, administrative help is uncommon to advance and support IBL. In general, school and classrooms environment are not urging to IBL. (Chowdhury, 2016).

Some studies argued that inquiry instructions may not be the best method for learners who are cognitively less prepared to meet the challenges to increase the science literacy skills as they found that students with high level of cognitive development can easily adopt the complexities of inquiry process as compared to the other students who need special attention and more guidance (Gormally et al., 2009).

According to (Camenzuli, 2012) there are several challenges faced by the teacher to implement IBL in classroom such as: limited resources, only available textbooks, challenges of assessment, difficulties with managing in group work, in-adequate in-service education, acceptance of new role by teacher and students, parental and school administration and other institutional authorities' resistance, and teachers belief. He further added that IBL is more time-consuming approach, fear of losing control over students, preparing effective IBL lessons for instant experiments, lack of resources, students' resistance to inquiry, and difficulty of assessments.

(Silm et al., 2017) divided barriers into three groups: cultural, political, and technical. Cultural barriers are associated with instructors' convictions and qualities and obligation to plan students for the following degree of education. Political barriers concern parental obstruction, odd clashes among educators, and absence of assets/lack of resources. Technical barriers incorporate educators' earlier obligation to course books, difficulties for evaluation of students, and challenges with administering group work.

Other challenge to IBL is students may end up with some incorrect answers, utilize wasteful procedures to find data, or they never find what it is they are attempting to discover or why. For this reason teachers must be facilitator in the process and guide throughout the procedure to keep students on right track (Witt & Ulmer, 2015).

In summary, for creating an IBL environment in classroom there is a lot of challenges which includes, lack of teachers training, resources (tools and materials) and time constraint, need to address curriculum standards, lack of reliable assessment tools for qualitative and quantitative measures. Effective distinguishing proof of the difficulties is the initial step for discovering the arrangements. An increasing number of instructors are adopting this developing teaching approach and researchers came out to propose the approved and inventive answers for these difficulties.

It was difficult to make the balance of pros and cons of this pedagogical approach as much literature have been found in support and positive effects of this approach. The rise and popularity of this approach in last few years make researchers hard to find the effect of this approach on learners.

2.7 Girls and Science: Lagging Behind

Women are underrepresented and marginalized in our society and many others in the fields of science and technology (Brotman & Moore, 2008; Hill et al., 2010; Meyer et al., 2015). The 2030 sustainable development goals for education includes "SDG 5 that focuses on achieving gender equality and empowering all women and girls" (Durrani & Halai, 2018). Greater gender disparities have been found in Pakistan in enrollment in primary and secondary education where "boys outperform girls in all subjects" (Durrani & Halai, 2018). The gap is widely observed in poor households where girls are supposed to do the household chores and take care of younger siblings which restricts the time they spend on learning and results in irregular attendance at school. This also demotivates them to take education when schools actively promote gender differences through the hidden curriculum where home is naturalized as a women's legitimate (Durrani & Halai, 2018). Because in Pakistan, boys are responsible to do job and support the family therefore, girls are not taking interest in making their careers and parents are biased in making decision and spending on education. Parents have higher expectations for boys in pursuing career in science then girls which may contributes in this gender parity (Brotman & Moore, 2008). In Pakistan, boys schools are more than girls schools. For girls, access to school within reach is also the major concern, the government schools, especially at secondary level are typically separated for boys and girls, male teachers for boys in boys' school while female teachers for girls in girls' school (Durrani & Halai, 2018).

Meyer et al., (2015) recommended in his study to eliminate the gender gap in the fields where women are underrepresented, believed to require innate intellectual level for success. He further suggested for future studies for effective interventions to ensure women's participation. In 33 OECD countries "boys outperform girls in science at grades four, eight and twelve" (Baker, 2013; Heindl & Nader, 2018). This lower performance causes women in low rate of economic and employment growth in science field. Therefore, it is mandatory to promote girls for science field, by addressing real-world experiences and examples to boost girls’ interest in science. Baker (2013) mentioned that single-sex classrooms affect expanding girls' certainty about their work and creates more comfortable environment to pose inquiries and conduct inquiry process freely. He asked to connect with girls in real science inquiry and foster academic substance information to boost their interest and CT in science.

According to (Heindl & Nader, 2018), further studies are expected to break down whether IBL can work with inspirational perspectives in young ladies towards science and the learning of science. Girls need trust in science and Finland is the just one out of 72 nations where girls are the top entertainers in science.

The relationship between CT skills and gender has been found in many studies. Some researchers found significant role of gender in differentiating CT skills while others did not support this hypothesis about significance of gender. Some studies of CT abilities shows that gender differences at high level CT skills are significant while at moderate or low level differences are not significant (Shubina & Kulakli, 2019). Moreover, females did not perceive themselves as inventors, and greatly influenced by their environment.

3. Methodology

3.1 Introduction/overview:

The main purpose of this quasi-experimental study (non-randomized control groups, pretest-posttest design) was to understand the impact of IBL in science on content-specific and general CT skills and academic achievement of the female students of grade 8. For this purpose, two chapters from science textbook were selected, "Pollution and its effects on environment" and "Space exploration". Pretest and posttest were designed and conducted in control and experimental group for the purpose of collecting quantitative data. This chapter provides the details of the methodology used for this study.

3.2 Description of the research setting:

Since the purpose of this study was to compare if the IBL had a significant effect on the CT and academic achievement of the participants in science, quasi experimental study was conducted on the participants of the same grade level and school. Islamabad Model School for Girls (IMCG) F-10/2 was selected for the research study after granted permission from the Federal Directorate of Education (FDE) Islamabad. (Appendix-A). The school is one of the urban model schools of Pakistan under Government supervision.

Students are enrolled in the session of 2019-2020 for grade 8 were the population of this experimental study. Two classes of grade 8 were selected for the research study. Total sample size of the study is composed of seventy students. All are female students. Their age ranges from 12 to 15. There are thirty-five students each in control and experimental group chose from two different sections of grade 8 of same school. One section of 35 students were treated with traditional teaching lecture method and named as “control group” while other section of 35 students were treated with the IBL, named as “experimental group”.

Control group is treated by traditional teaching lecture method while experimental group is treated by using IBL framework of Margus Pedaste et al., (2015). According to the framework, lesson plans were made for experimental group. Technology is implemented in experimental group for the effective use of inquiry model.

Table 3.1 Demographics of participants

	Control Group	Experimental Group
Class/Grade	Grade 8	Grade 8
No. of participants	35 (females)	35 (females)

3.3 Description of the research design

3.3.1 Research question:

Following are the research questions addressed in this research:

1. Is there a significant difference in content-specific CT skills of middle school science students who participate in an IBL classes as compared to the students who participate in traditional teaching lecture method?
2. Is there a significant difference in general CT skills of middle school science students who participate in an IBL classes as compared to the students who participate in traditional teaching lecture method?

3. Is there a significant difference in academic achievement of middle school science students who participate in an IBL classes as compared to the students who participate in traditional teaching lecture method?

3.3.2 Variables

Following are the independent and dependent variables:

Independent variables

1. Inquiry-Based Learning
2. Traditional teaching lecture method

Dependent variables:

1. Content-specific critical thinking skills
2. General critical thinking skills
3. Academic achievement (formative assessments)

3.3.3 Hypotheses formulation:

The following Null Hypotheses was formulated:

H_{01}: Participation of middle school students in IBL classes of science has no significant effect on participant’s content-specific CT skills as compared to traditional classes of science participants.

H_{02}: Participation of middle school students in IBL classes of science has no significant effect on participant’s general CT skills as compared to traditional classes of science participants.

H_{03}: Participation of middle school students in IBL classes of science has no significant effect on participant’s academic achievement as compared to traditional classes of science participants.

The Alternative Hypotheses was defined as follows:

H_{A1}: Participation of middle school students in IBL classes of science has significant effect on participant's content-specific CT skills as compared to traditional classes of science participants.

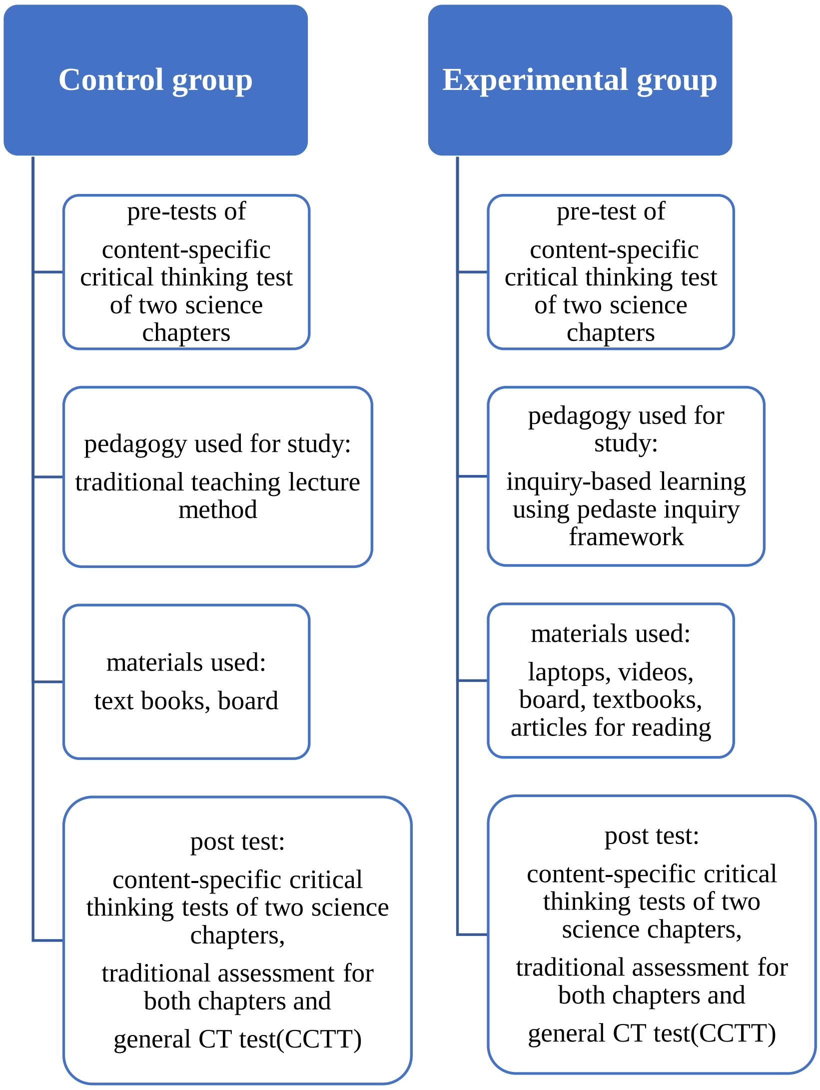
H_{A2}: Participation of middle school students in IBL classes of science has significant effect on participant's general CT skills as compared to traditional classes of science participants.

H_{A3}: Participation of middle school students in IBL classes of science has significant effect on participant's academic achievement as compared to traditional classes of science participants.

3.4 Procedure

To check the effectiveness of IBL in science and its impact on CT skills and academic achievement of the students following procedure was used for the study

Table 3.2 Experimental framework



3.5 Description of the inquiry program/experimental group instructions

The study conducted to assess the impact of IBL on student's CT skills and academic achievement in science. The instructional method used in the treatment group was the Pedaste IBL framework (2015). Lesson plans were made according to each step of this framework. Video-based lessons were implemented in groups of students. Web based articles to gain extra information and for well understanding of the topics were also provided to students for reading. Number of inquiry activities were also conducted in this study includes: worksheets, reflections, and projects (Recycling project).

3.6 Implementation of the Pedaste inquiry model

The Pedaste IBL framework (2015) is a process by which problem is selected, generate questions, explore them and then interpret to give conclusion. Discussion and communication followed at each step. In the first step of "orientation" topics were introduced and discussed with students to engage them in the inquiry process and triggered curiosity for finding the relevant questions and further explore them to find answers. In the second step of "questioning", initial inquiry questions were set for the students and encourage them to find or raise other relevant questions. For better understanding of the phenomenon, engaging video lessons of all the topics were shown to them in groups. Open ended questions were written down for the home task for further "exploration" which is the third step of inquiry framework. In exploration students were guided to find or search answers on their own to understand the concepts by watching videos, web searching and discussion with the peers. Students were instructed to create questions and reflect about the processes involved in lessons which they want to know about the topics for discussion and exploration. For "data analysis" step of the inquiry model, students were instructed to note down all the searched answers as an assignment/home task. Students analyzed the collected data and planned to address the questions after assessing resources or data of their choice. In "conclusion" each answer of the student was discussed with them. Students were asked to reflect upon their answers. In last step of "discussion" one of the best answers was presented by the students in the class for clarifying the confusions and queries. In this whole procedure of the study, it was made sure that every student got the idea of raising questions on their own and find answers so that they can better construct their knowledge and boost their thinking. The same procedure of inquiry went for both intervened chapters of science for the time span of 4 weeks.

3.7 Description of control group instructions

Control group is facilitated by their science teacher using lecture as primary method of instruction. Students of control group followed the same content of primary curriculum of science textbook. Teacher delivered lectures by using only textbook and use whiteboard to mention some key points of the lesson. Explained examples from textbook to clear the concepts of students in classroom. Traditional question and answer session were conducted by the teacher and very few asked from the student’s side. No technology was implemented by the teacher in the classroom. Home task was given to solve the exercise given at the end of the chapter on notebooks. Assessed their knowledge by asking questions and giving short tests. To monitor the progress of students, the weekly checking of notebooks or after completion of chapter.

3.8 Research instruments

To collect the data for the study following instruments were used:

1. Content-specific CT pre- and post-test of chapter “pollution and its effect on environment”.
2. Content-specific CT pre- and post-test of chapter “space exploration”.
3. Post-test of CCTT level X for assessing general CT skills.

4. Post-test of traditional formative assessment of chapter “pollution and its effects on environment”.
5. Post-test of traditional formative assessment of chapter “space exploration”.

3.8.1 Content-specific CT tests:

To achieve the objectives of the study, pre and posttests of chapter “pollution and its effects on environment” and “space exploration” of grade 8 science were prepared on the basis of proper specification, according to higher order thinking skills of Bloom’s taxonomy, after careful review of techniques of preparing test items. Pre and post-test of chapter “Pollution and its effects on environment” comprised of 20 multiple choice questions and pre and post-test of chapter “space and exploration” comprised of 22 multiple choice questions. The specification of marks of Pre and Post-tests were

Table 3.3 Marks specification of tests

Blooms Taxonomy higher order thinking skills	Pre and posttest of Chapter “pollution and its effect on environment”	Pre and posttest of Chapter “space exploration”
Applying	Items=5 MCQ’s Marks= 5	Items=5 MCQ’s Marks= 5
Analyzing	Items=5 MCQ’s Marks= 5	Items=6 MCQ’s Marks= 6
Evaluating	Items=5 MCQ’s Marks= 5	Items=6 MCQ’s Marks= 6
Creating	Items=5 MCQ’s Marks= 5	Items=5 MCQ’s Marks= 5

All multiple-choice questions were included in the test for assessing the content-specific CT skills. The content validity of tests was tested by the professional and experienced teachers of science at school, including the Head of Department of science and senior teachers of the school. They suggested little modifications in some questions from pre-test of chapter “pollution and its effects on environment” of higher difficulty level. In light of their suggestions some test items were revised and after the approval of supervisor and science teachers, the tests were conducted in both experimental and control group. (Appendix-B & Appendix-C).

3.8.2 Cornell critical thinking test (CCTT):

To check the general CT skills of the student, post test was conducted in both groups for comparative analysis. Instrument was taken from the CCTT level X and modified by the researcher and supervisor. Only ten multiple choice questions were selected from each category by keeping in mind the difficulty level of each question and the age group of students. Total time allowed for 10 multiple choice questions were 10 minutes and total marks were also 10 (Appendix-D).

CCTT is one of the multiple choice questions test that has validated questions and used for assessing the general CT ability (Iwaoka et al., 2010). Keeping in mind the context of the research participants, CCTT was selected due to its applicability for grade 5 to 12+ and easy to understand language and feasibility for the large sample size. CCTT developed in 1985 and widely used instrument for assessing general CT ability. The content validity of CCTT is assessed and there are positive indications for the criterion validity. The study conducted by (Verburgh et al., 2013) to critically assess the validation and reliability of CCTT and Halpern Critical Thinking Assessment (HCTA) in higher education system, the results indicates that the content of CCTT is more valid than HCTA as it is according to the definitions of CT mentioned by the author. Furthermore, the results indicate that CCTT is more feasible than the HCTA with regard to its easy checking and less time to administer.

3.8.3 Academic achievement (traditional formative assessment):

Academic achievement of students was measured from the traditional formative assessment conducted by the science teachers of both control and experimental group to check the effectiveness of IBL. Questions were designed by the expert and professional science teachers who has experience of teaching science over 10 years to assess the overall understanding of both chapters.

The teachers of both classes (control and experimental group) were highly experienced in their subject matter and have huge experience of conducting formative assessments. Tests are conducted after approval of Head of department of science, tests are attached in (Appendix-E).

3.9 Time schedule:

The study spanned for 4 weeks in a school. The researcher took 14 classes of experimental group in 4 weeks (7 classes in 2 weeks for each chapter) to cover 2 chapters of science. Control group was taught by their science teacher for the same 4 weeks to cover the same 2 chapters of science by traditional teaching method.

3.10 Data analysis

To find the effectiveness of IBL on academic achievement and CT skills of students in science, a quasi-experimental study was conducted in Grade 8. Data collected for this study by administering the pre and post-test of content-specific critical thinking of two science chapters, post-test of Cornell critical thinking test (CCTT) and post-test of traditional formative assessment. Data is parametric in nature. To discover contrast in content-specific and general CT abilities and academic achievement in science between the experimental and control group, the independent sample t-test was utilized. To compare the effectiveness of each methodology within group, paired t-test was conducted for each group. The null hypotheses were accepted or rejected dependent on the examination of t-tests. Before analysis, the assembled information was prepared. The data was then analyzed using statistical software SPSS. The results and findings of the study are explained in detail in the next chapter.

3.11 Summary:

For quasi-experimental study, pre and post-test of content-specific CT skills and post-tests of general CT skills and post-test of formative assessments for academic achievement were designed. A group size of 35 each was used. The control and experimental groups were two sections of Grade 8 in IMCG F-10/2 Islamabad, Pakistan.

The research question explored was “Is there a significant difference in content-specific CT skills, general CT skills and academic achievement of middle school science students who participate in an IBL classes as compared to students who participate in traditional teaching lecture method?”. The independent variables were IBL and traditional teaching lecture method, the dependent variables were Content-specific CT skills, General CT skills and Academic achievement (formative assessments). The null hypothesis was “Participation of middle school students in IBL classes of science has no significant effect on participant’s academic achievement, content-specific and general CT skills as compared to traditional classes of science participants” whereas the Alternative Hypothesis was “Participation of middle school students in IBL classes of science has significant effect on participant’s academic achievement, content-specific and general CT skills as compared to traditional classes of science participants".

The pre-tests of two science chapters were conducted for both groups. After the tests, 4 weeks intervention was conducted to the experimental group using IBL framework of Pedaste (2015) by the researcher whereas control was instructed by their science teacher. Lastly, the post-tests were conducted for both groups to collect data.

An independent samples t-test and paired sample t-test was used to investigate if the difference between the mean scores of the post-tests were significantly different for both groups or not; and the effect size was calculated. The results and findings of the study are explained in detail in the next chapter.

4. Data Analysis and Results

4.1 Overview

The main aim of this quasi-experimental study was to understand the impact of IBL in science on content-specific and general CT skills and academic achievement of the female students of grade 8. For this purpose, two chapters from science textbook were selected: chapter 1 "Pollution and its effects on environment" and chapter 2 "Space exploration". Pretest and posttest were designed and conducted in control and experimental group for the purpose of collecting quantitative data for content-specific CT skills, posttest of Cornell Critical Thinking Test (CCTT) was conducted for measuring general CT skills and posttests of traditional assessment from both chapters for measuring academic achievement in traditional setting to see the impact of IBL in formative assessments of school. This chapter provides the details of the results and statistical tests to analyze the data.

4.2 Statistical tests of chapter 1 of control and experimental group

Normality test of control group pretest and posttest

Table 4.1 Normality test of CG for chapter 1

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pretest1CG	.199	35	.001	.947	35	.089
Posttest1CG	.113	35	.200*	.972	35	.512

The null hypothesis for normality test is that the data is normally distributed. The p-value of Shapiro-Wilk test is 0.089 of pretest and 0.512 for posttest, which shows that the p-value is greater than the significance level of 0.05. Therefore, the null hypothesis is rejected, and it is concluded that the data of chapter 1 pre and posttest is normally distributed for control group.

Pretest1CG

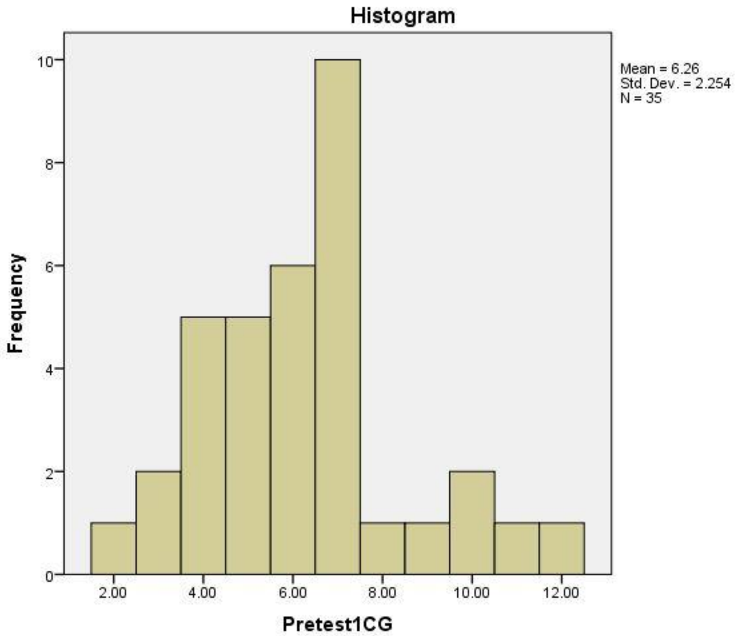


Figure 4.1 Histogram of CG chapter 1 pretest

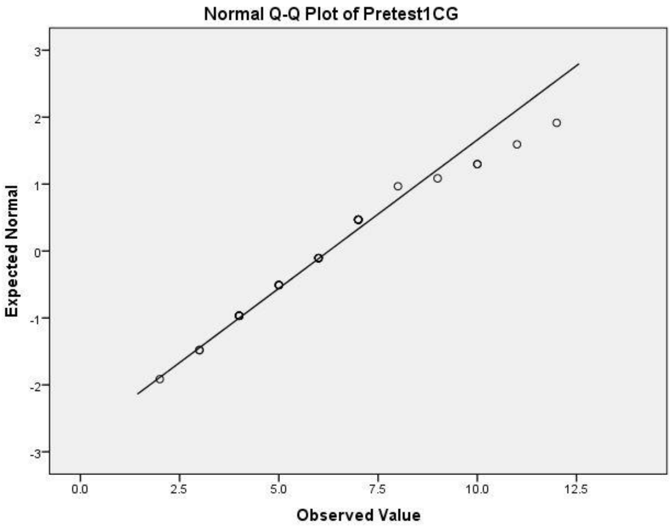


Figure 4.2 Normal Q-Q Plot of CG pretest chapter 1

Posttest1CG

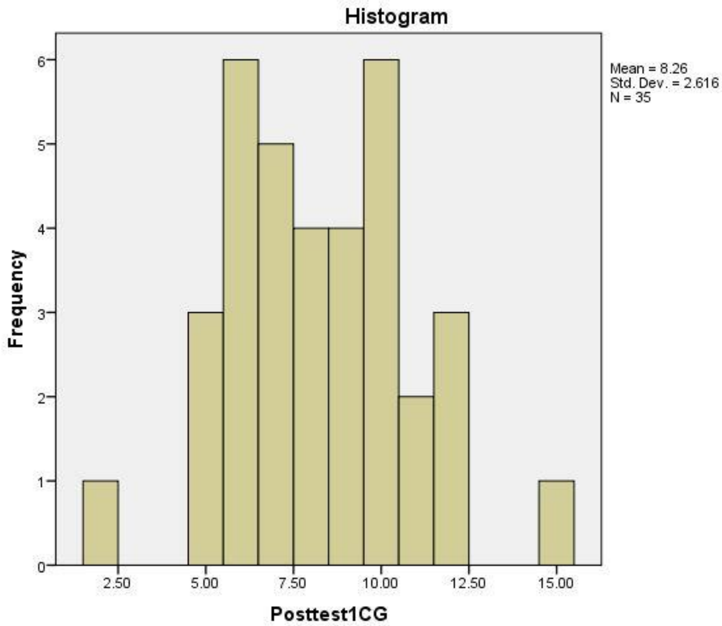


Figure 4.3 Histogram of CG posttest chapter 1

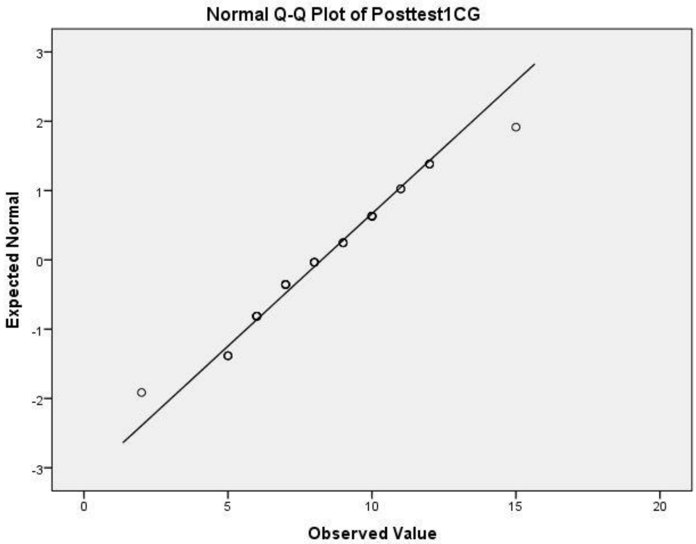


Figure 4.4 Normal Q-Q Plot of control group posttest chapter 1

The histogram and Q-Q plot of pretest and posttest of control group for chapter 1 shows that the data is normally distributed.

Normality test of experimental group pretest and posttest

Table 4.2 Normality test of EG chapter 1

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pretest1EG	.144	35	.066	.948	35	.101
Posttest1EG	.131	35	.137	.962	35	.270

The null hypothesis for normality test is that the data is normally distributed. The p-value of Shapiro-Wilk test is 0.101 of pretest and 0.270 for posttest, which shows that the p-value is greater than the significance level of 0.05. Therefore, the null hypothesis is rejected, and it is concluded that the data of chapter 1 pre and posttest is normally distributed for experimental group.

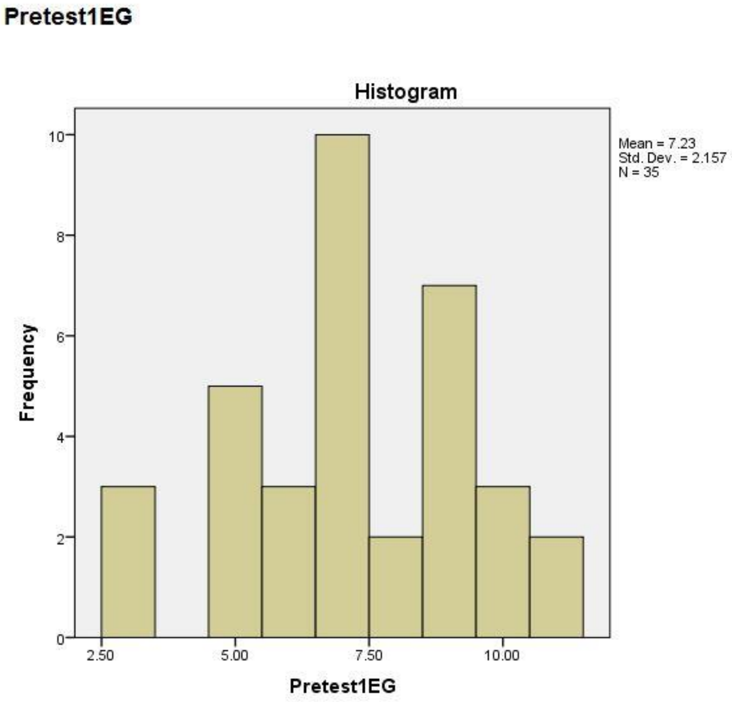


Figure 4.5 Histogram of EG pretest chapter 1

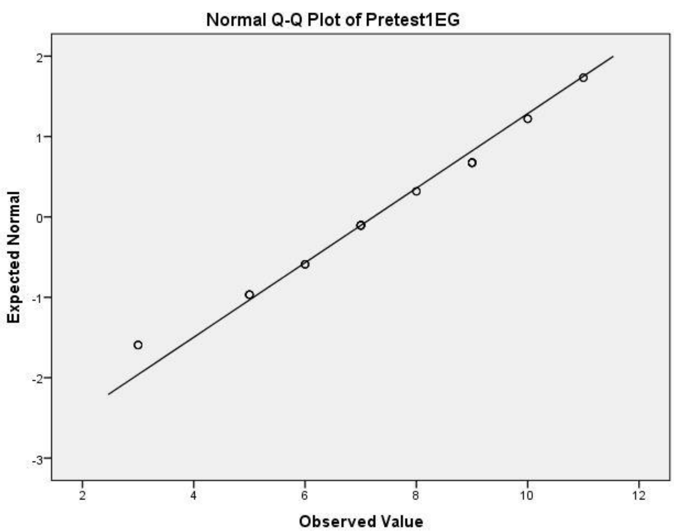


Figure 4.6 Normal Q-Q Plot of EG pretest chapter 1

Posttest1EG

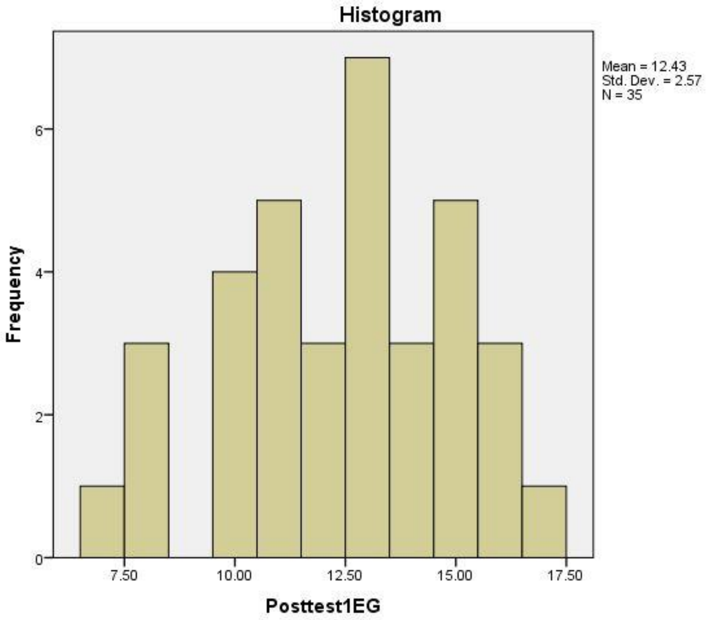


Figure 4.7 Histogram of EG posttest chapter 1

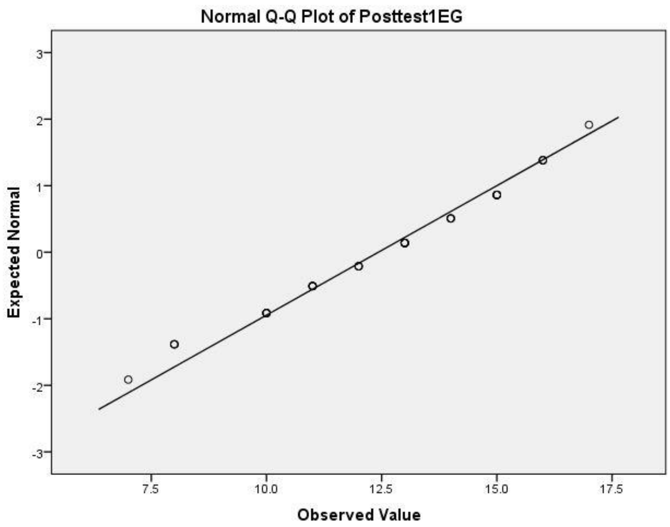


Figure 4.8 Normal Q-Q Plot of EG posttest chapter 1

The histogram and Q-Q plot of pretest and posttest of experimental group of chapter 1 shows that the data is normally distributed.

Paired samples test for control group

Table 4.3 Paired sample t-test for CG chapter 1

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Pretest1 CG	6.2571	35	2.25366	.38094
	Posttest1 CG	8.2571	35	2.61605	.44219

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Pretest1 CG & Posttest1 CG	35	-.156	.370

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Pretest1 CG - Posttest1 CG	-2.00000	3.71008	.62712	-3.27446	-.72554	-3.189	34	.003

The null hypothesis for paired sample t-test is that there is no significant difference in the results of students before and after participation in the traditional teaching lecture method. The p-value is 0.003 which is less than the significance level of 0.05. Therefore, the null hypothesis is rejected, and it is concluded that there is significant difference between the mean score of the students who participated in the traditional teaching lecture method.

The mean score of pretest is 6.2571 with SD 2.25366 and mean score of posttest is 8.2571 with SD 2.61605 which shows a little progress in control group.

The value of correlation is -0.156 which shows the negative correlation. Correlation lies between - 1 and +1 with negative worth implying that the larger values of the first variable are bound to be seen with the small values of the second variable and vice versa. There is huge negative correlation between the scores before and after the intervention.

Paired samples test for experimental group

Table 4.4 Paired sample t-test for EG chapter 1

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Pretest1EG	7.2286	35	2.15687	.36458
	Posttest1EG	12.4286	35	2.57003	.43441

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Pretest1EG & Posttest1EG	35	.099	.573

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Pretest1EG - Posttest1EG	-5.20000	3.18821	.53891	-6.29519	-4.10481	-9.649	34	.000

The null hypothesis for paired sample t-test is that there is no significant difference in the results of students before and after participation in the IBL classroom. The p-value is 0.000 which is less than the significance level of 0.05. Therefore, the null hypothesis is rejected, and it is concluded that there is significant difference between the mean score of the students who participated in the IBL classroom.

The mean score of pretest is 7.2286 with SD 2.15687 and mean score of posttest is 12.4286 with SD 2.57003 which shows a huge difference in progress of experimental group.

The value of correlation is 0.099 which shows the positive correlation. There is significant positive correlation between the scores before and after the intervention in an experimental group.

Independent sample t-test for pretests of control and experimental group

Table 4.5 Independent sample t-test for pretests of CG & EG

Group Statistics

	Students	N	Mean	Std. Deviation	Std. Error Mean
Pretest1	Experimental Group Students	35	7.2286	2.15687	.36458
	Control Group Students	35	6.2571	2.25366	.38094

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
Pretest1	Equal variances assumed	.000	.988	1.842	68	.070	.97143	.52729	-.08076	2.02361
	Equal variances not assumed			1.842	67.869	.070	.97143	.52729	-.08079	2.02365

The null hypothesis for Levene's test for equality of variances states that the equal variances are assumed for two groups. The p-value of the test is 0.988 which is greater than 0.05. therefore, the null hypothesis is accepted, and it is concluded that equal variances are assumed.

The null hypothesis for independent sample t-test for pretest scores of both groups states that there is no significant difference in the results of the students before participation in the IBL classroom and traditional teaching lecture method. The p-value found in test is 0.070. The significance value 0.05 is less than the p-value. Therefore, the null hypothesis is accepted, and it is concluded that there is no significant difference in the pretests of both groups.

Independent sample t-test for posttest of control and experimental group

Table 4.6 Independent sample t-test for posttests of CG & EG

Group Statistics

	Students	N	Mean	Std. Deviation	Std. Error Mean
Posttest1	Experimental Group Students	35	12.4286	2.57003	.43441
	Control Group Students	35	8.2571	2.61605	.44219

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
Posttest1	Equal variances assumed	.000	.996	6.729	68	.000	4.17143	.61988	2.93448	5.40838
	Equal variances not assumed			6.729	67.979	.000	4.17143	.61988	2.93447	5.40838

The null hypothesis for Levene's test for equality of variances is that variances of two groups are approximately equal. The p-value of test is 0.996 which is greater than 0.05, therefore, the null hypothesis is accepted, and it is concluded that equal variances are assumed.

The null hypothesis for independent sample t-test for posttest scores of both groups states that there is no significant difference in the results of the students after participation in the IBL classroom and traditional teaching lecture method. The p-value found in test is 0.000. The significance value 0.05 is greater than the p-value. Therefore, the null hypothesis is rejected, and it is concluded that there is significant difference in the posttest scores of both groups.

The mean posttest score of students in EG (M=12.4286, SD=2.57) was greater than the CG (M=8.2571, SD=2.61 which indicates that there is a huge difference in the two mean scores of posttests.

4.3 Statistical tests of chapter 2 of control and experimental group

Normality test of control group pretest and posttest

Table 4.7 Normality test of CG chapter 2

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
PretestC2	.124	35	.195	.970	35	.443
PosttestC2	.115	35	.200*	.964	35	.306

The null hypothesis for normality test is that the data is normally distributed. The p-value of Shapiro-Wilk test is 0.443 of pretest and 0.306 for posttest of CG, which shows that the p-value is greater than the significance level of 0.05. Therefore, the null hypothesis is rejected, and it is concluded that the data of chapter 2 pre and posttest is normally distributed for experimental group.

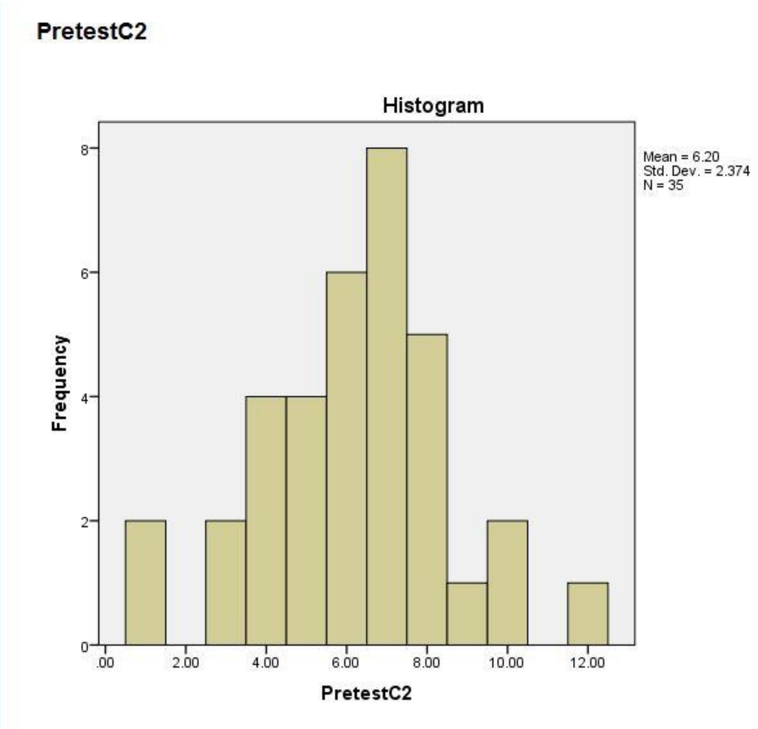


Figure 4.9 Histogram of CG pretest chapter 2

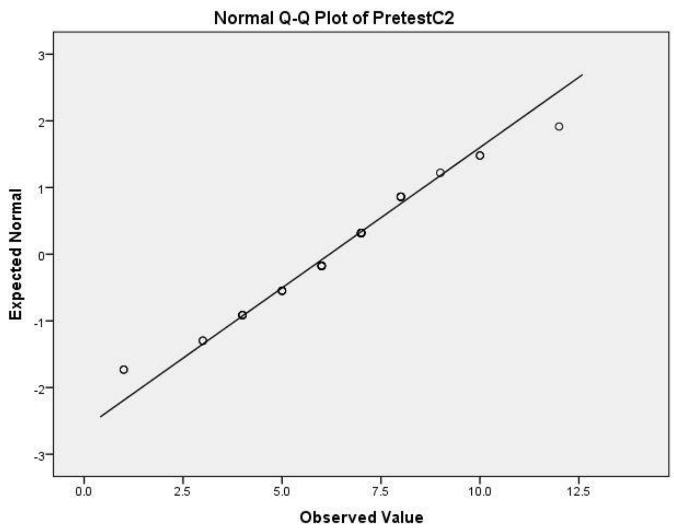


Figure 4.10 Normal Q-Q Plot of pretest chapter 2

PosttestC2

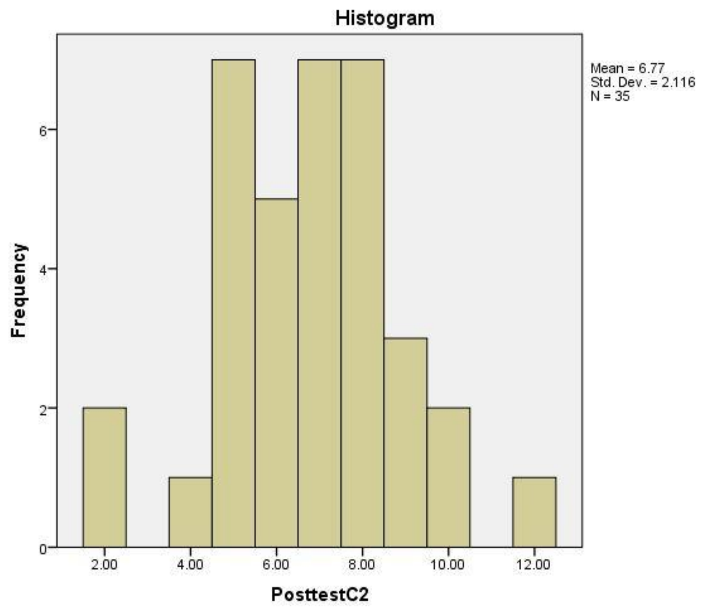


Figure 4.11 Histogram of CG posttest chapter 2

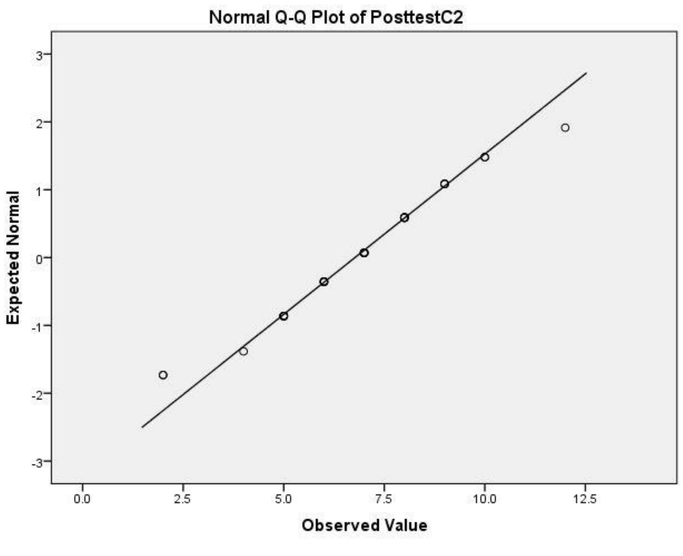


Figure 4.12 Normal Q-Q Plot of CG posttest chapter 2

The histogram and Q-Q plot of pretest and posttest of control group of second chapter shows that the data is normally distributed.

Normality test of experimental group pretest and posttest

Table 4.8 Normality test of EG chapter 2

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
PretestE2	.149	35	.047	.943	35	.067
PosttestE2	.122	35	.200*	.947	35	.093

The null hypothesis for normality test is that the data is normally distributed. The p-value of Shapiro-Wilk test is 0.067 of pretest and 0.093 for posttest of EG, which shows that the p-value is greater than the significance level of 0.05. Therefore, the null hypothesis is rejected, and it is concluded that the data of chapter 2 pre and posttest is normally distributed for experimental group.

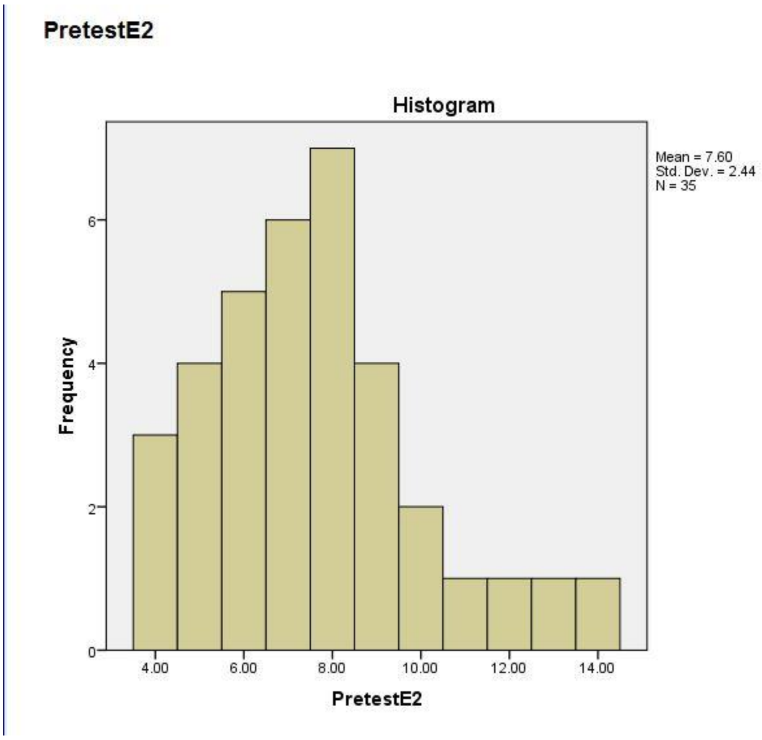


Figure 4.13 Histogram of EG pretest chapter 2

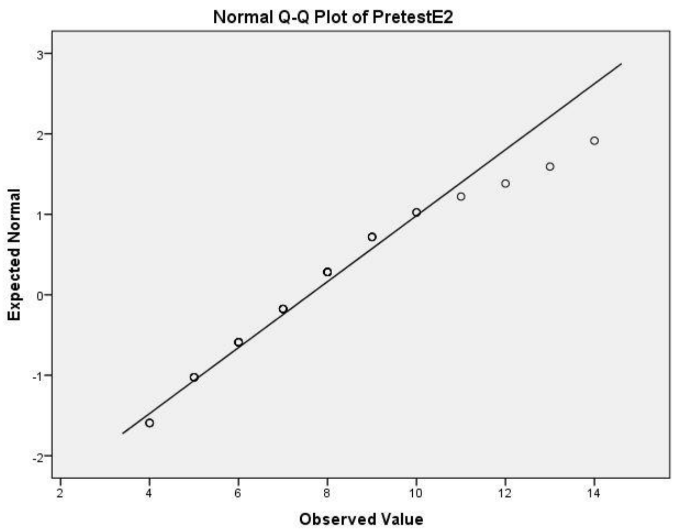


Figure 4.14 Normal Q-Q Plot of EG pretest chapter 2

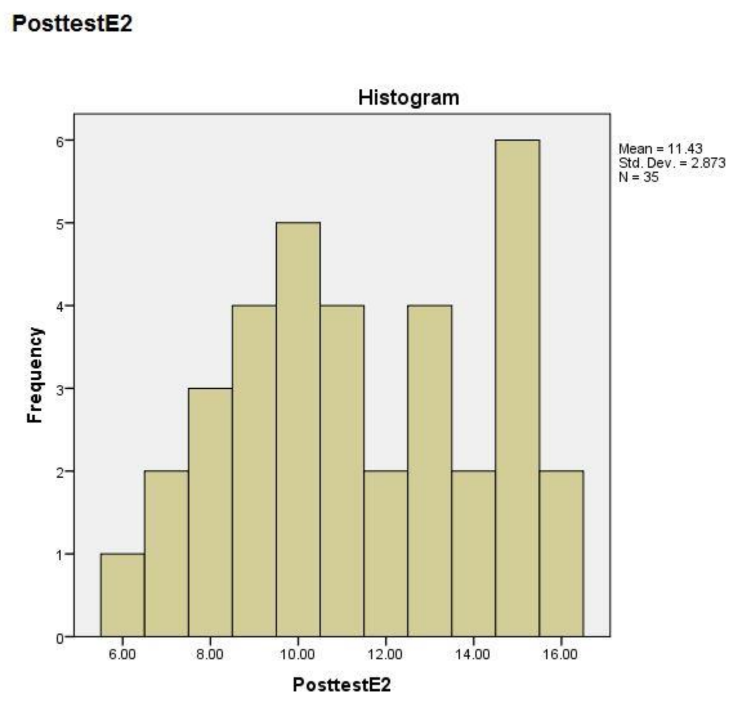


Figure 4.15 Histogram of EG posttest chapter 2

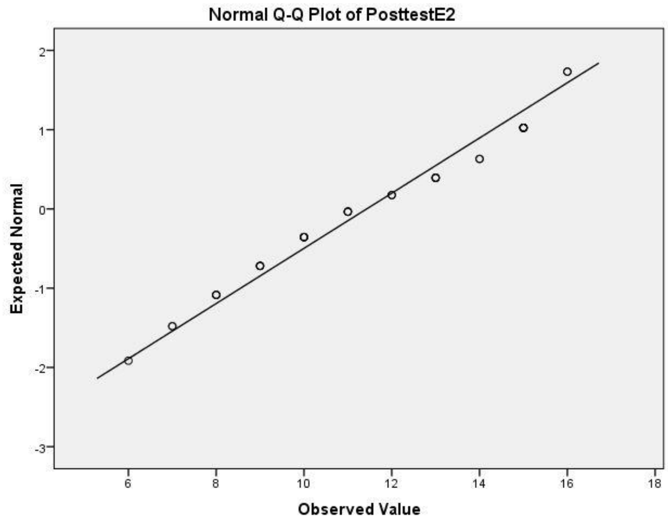


Figure 4.16 Normal Q-Q Plot of EG posttest chapter 2

The histogram and Q-Q plot of pretest and posttest of experimental group of second chapter shows that the data is normally distributed.

Paired sample t-test for control group

Table 4.9 Paired sample t-test for CG chapter 2

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	PretestC2	6.2000	35	2.37388	.40126
	PosttestC2	6.7714	35	2.11557	.35760

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	PretestC2 & PosttestC2	35	.501	.002

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	PretestC2 - PosttestC2	-.57143	2.25292	.38081	-1.34533	.20248	-1.501	34	.143

The null hypothesis for paired sample t-test is that there is no significant difference in the results of students before and after participation in the traditional teaching lecture method. The p-value is 0.143 which is greater than the significance level of 0.05. Therefore, the null hypothesis is accepted, and it is concluded that there is no significant difference between the mean scores of the students who participated in the traditional teaching lecture method.

The mean score of pretest is 6.2000 with SD 2.37388 and mean score of posttest is 6.7714 with SD 2.11557 which shows minimal difference in progress of control group.

The value of correlation is 0.501 which shows the positive correlation. So, it is concluded that there is positive correlation between the scores of before and after intervention in the CG.

Paired samples t-test for experimental group

Table 4.10 Paired sample t-test for EG chapter 2

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	PretestE2	7.6000	35	2.43986	.41241
	PosttestE2	11.4286	35	2.87265	.48557

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	PretestE2 & PosttestE2	35	.436	.009

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	PretestE2 - PosttestE2	-3.82857	2.84383	.48070	-4.80546	-2.85168	-7.965	34	.000

The null hypothesis for paired sample t-test is that there is no significant difference in the results of the students before and after participation in the IBL classroom. The p-value is 0.000, which is greater than the significance level of 0.05. Therefore, the null hypothesis is rejected, and it is concluded that there is significant difference between the mean scores for chapter 2 of the students who participated in the IBL classroom.

The mean score of pretest is 7.6 with SD 2.43 and mean score of posttest is 11.42 with SD 2.87 which shows a huge difference in progress of experimental group.

The value of correlation is 0.436 which shows the positive correlation. Therefore, it is concluded that there is significant positive correlation between the scores before and after the intervention in an experimental group.

Independent sample t-test for pretests of control and experimental group

Table 4.11 Independent sample t-test for pretests of CG & EG chapter 2

Group Statistics

	Students	N	Mean	Std. Deviation	Std. Error Mean
Pretest2	experimental group students	35	7.6000	2.43986	.41241
	Control group students	35	6.2000	2.37388	.40126

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
Pretest2	Equal variances assumed	.036	.851	2.433	68	.018	1.40000	.57541	.25179	2.54821
	Equal variances not assumed			2.433	67.949	.018	1.40000	.57541	.25178	2.54822

The null hypothesis for Levene's test for equality of variances is that variances of two groups are approximately equal. The p-value of test is 0.851 which is greater than 0.05, therefore, the null hypothesis is accepted, and it is concluded that equal variances are assumed.

The null hypothesis for independent sample t-test for pretest scores of both groups states that there is no significant difference in the results of the students before participation in the IBL classroom and traditional teaching lecture method. The p-value found in test is 0.018. The significance value 0.05 is greater than the p-value. Therefore, the null hypothesis is rejected, and it is concluded that there is significant difference in the pretests of both groups for chapter 2.

The mean pretest score of students in EG (M=7.60, SD=2.43) was greater than the CG (M=6.20 and SD=2.37). The SD value indicates that the results are close to the mean in CG as compared to the EG. So, there is a negligible difference in the two mean scores of pretests for chapter 2.

Independent sample t-test for posttests of control and experimental group

Table 4.12 Independent sample t-test for posttests of CG & EG chapter 2

Group Statistics

	Students	N	Mean	Std. Deviation	Std. Error Mean
Posttest2	experimental group students	35	11.4286	2.87265	.48557
	Control group students	35	6.7714	2.11557	.35760

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
Posttest2	Equal variances assumed	6.510	.013	7.723	68	.000	4.65714	.60303	3.45381	5.86048
	Equal variances not assumed			7.723	62.498	.000	4.65714	.60303	3.45189	5.86240

The null hypothesis for Levene's test for equality of variances is that variances of two groups are approximately equal. The p-value of test is 0.013 which is less than 0.05, therefore, do not accept the null hypothesis and conclude that equal variances are not assumed. As long as N>30 and n1≈ n2, t test is robust to violations of homogeneity of variance.

The null hypothesis for independent sample t-test for posttest scores of both groups states that there is no significant difference in the results of the students after participation in the IBL classroom and traditional teaching lecture method. The p-value found in test is 0.000. The significance value 0.05 is greater than the p-value. Therefore, the null hypothesis is rejected, and it is concluded that there is significant difference in the posttests of both groups for chapter 2.

The mean posttest score of students in EG (M=11.42, SD=2.87) was greater than the CG (M=6.77, SD=2.11). The SD value indicates that the results are close to the mean in control group as compared to the experimental group. There is a huge difference in the two mean scores of posttests.

4.4 Statistical tests of Cornell Critical Thinking Test (CCTT)

Normality test of CCTT posttest of control group and experimental group

Table 4.13 Normality test for CCTT

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
PosttestEGCT	.172	35	.010	.941	35	.061
PosttestCGCT	.157	35	.029	.957	35	.186

The null hypothesis for normality test is that the data is normally distributed. The p-value of Shapiro-Wilk test is 0.061 of posttest of CCTT of EG and 0.186 for posttest of CCTT of CG, which shows that the p-value is greater than the significance level of 0.05. Therefore, the null hypothesis is rejected, and it is concluded that the data is normally distributed for both groups.

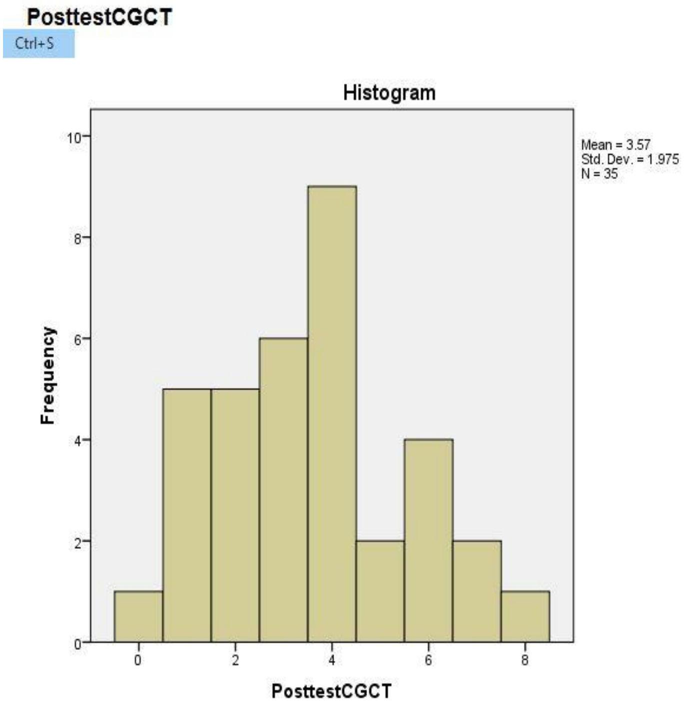


Figure 4.17 Histogram for CG posttest CCTT

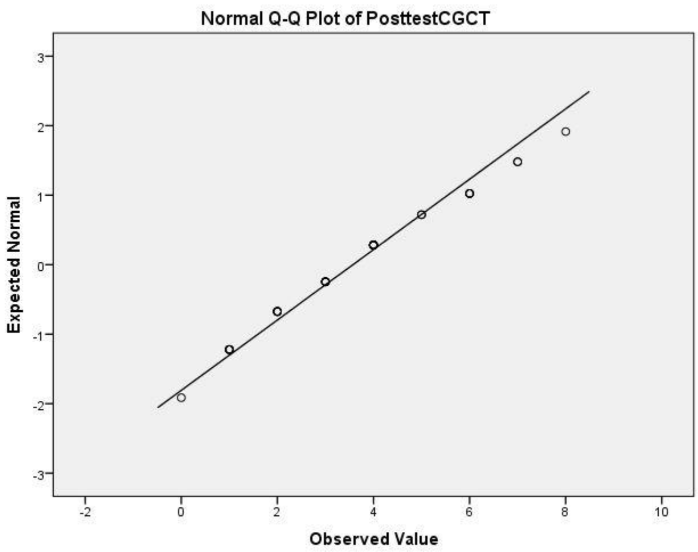


Figure 4.18 Normal Q-Q Plot of CG posttest CCTT

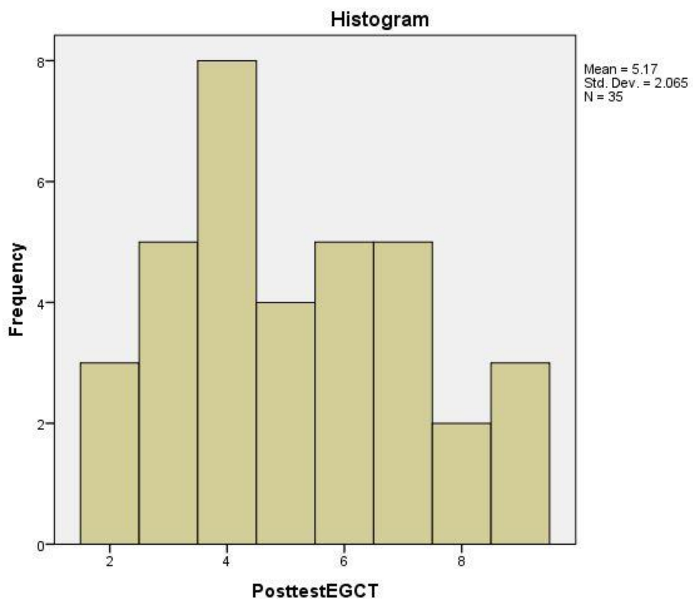


Figure 4.19 Histogram of EG posttest CCTT

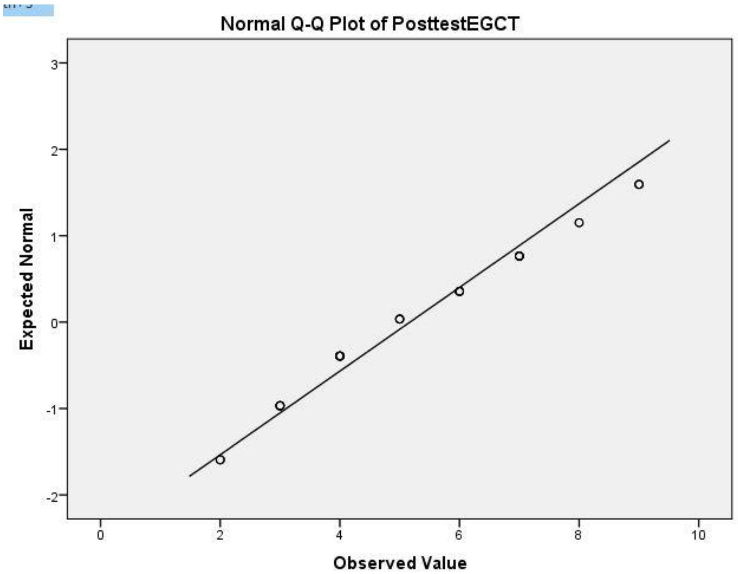


Figure 4.20 Normal Q-Q Plot of EG posttest CCTT

The histogram and Q-Q plot of posttests of experimental and control group of CCTT shows that the data is normally distributed.

Independent sample t-test of CCTT for posttests of control and experimental group

Table 4.14 Independent sample t-test for posttests of CCTT

Group Statistics

	Students	N	Mean	Std. Deviation	Std. Error Mean
PosttestCT	Experimental Group Students	35	5.17	2.065	.349
	Control Group Students	35	3.57	1.975	.334

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
PosttestCT	Equal variances assumed	.341	.561	3.313	68	.001	1.600	.483	.636	2.564
	Equal variances not assumed			3.313	67.865	.001	1.600	.483	.636	2.564

The null hypothesis for Levene's test for equality of variances is that variances of two groups are approximately equal. The p-value of test is 0.561 which is greater than 0.05, therefore, the null hypothesis is accepted, and it is concluded that equal variances are assumed.

The null hypothesis for independent sample t-test for posttest scores of CCTT of both groups states that there is no significant difference in the CT skills of the students after participation in the IBL classroom and traditional teaching lecture method. The p-value found in test is 0.001. The significance value 0.05 is greater than the p-value. Therefore, the null hypothesis is rejected, and it is concluded that there is significant difference in the posttest score of CCTT of both groups.

The mean posttest score of students in EG (M=5.17, SD=2.065) was greater than the CG (M=3.57 and SD=1.975). The SD value indicates that the results are close to the mean in CG as compared to the EG. So, there is much difference in the two mean scores of posttest.

4.5 Statistical tests of Academic Achievement/Traditional Assessments

Normality test of control group chapter 1 and 2

Table 4.15 Normality test of CG TA

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
PosttestCG1_TA	.125	30	.200*	.931	30	.052
PosttestCG2_TA	.147	30	.098	.968	30	.498

The null hypothesis for normality test is that the data is normally distributed. The p-value of Shapiro-Wilk test is 0.052 for chapter 1 posttest TA of CG and 0.498 for chapter 2 posttest, which shows that the p-value is greater than the significance level of 0.05. Therefore, the null hypothesis is rejected, and it is concluded that the data is normally distributed for CG.

PosttestCG1_TA

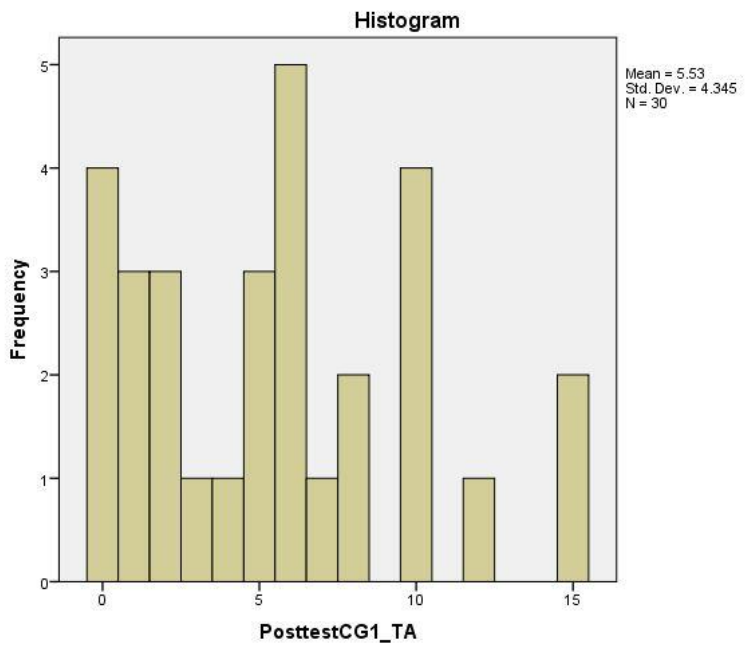


Figure 4.21 Histogram of CG posttest TA chapter 1

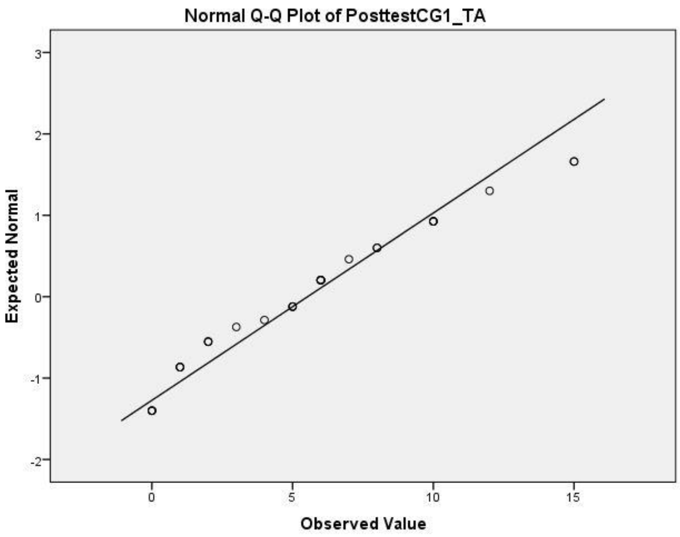


Figure 4.22 Normal Q-Q Plot of CG posttest TA chapter 1

PosttestCG2_TA

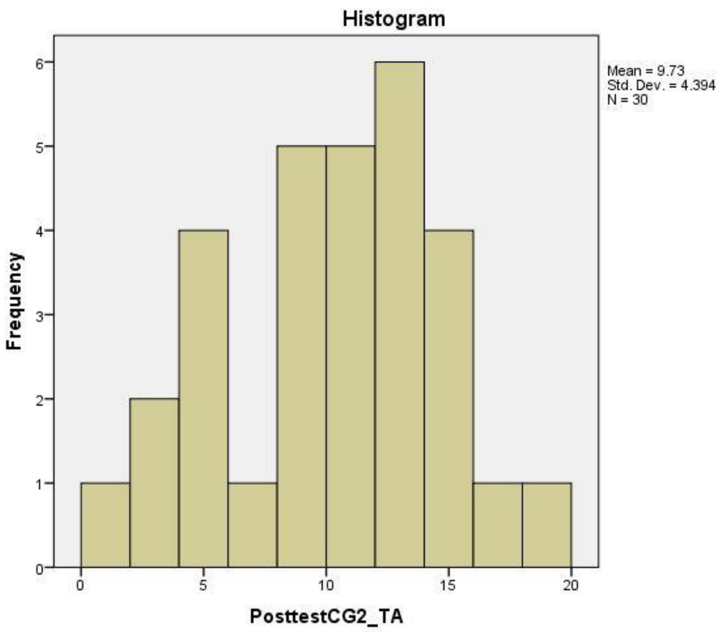


Figure 4.23 Histogram of CG posttest TA chapter 2

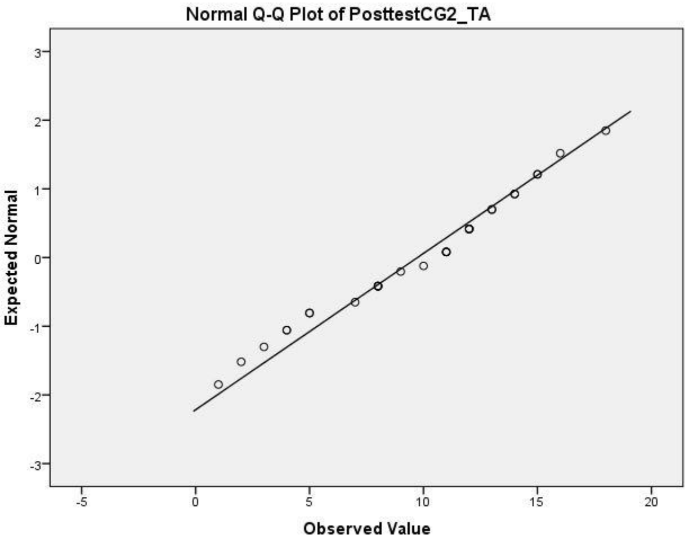


Figure 4.24 Normal Q-Q Plot of CG posttest TA chapter2

The histogram and Q-Q plot of posttests of both chapters of control group shows that the data is normally distributed.

Normality test of experimental group

Table 4.16 Normality test of EG TA

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
PosttestEG1_TA	.106	31	.200*	.933	31	.052
PosttestEG2_TA	.117	31	.200*	.939	31	.079

The null hypothesis for normality test is that the data is normally distributed. The p-value of Shapiro-Wilk test is 0.052 for chapter 1 posttest TA of EG and 0.079 for chapter 2 posttest, which shows that the p-value is greater than the significance level of 0.05. Therefore, the null hypothesis is rejected, and it is concluded that the data is normally distributed for EG.

PosttestEG1_TA

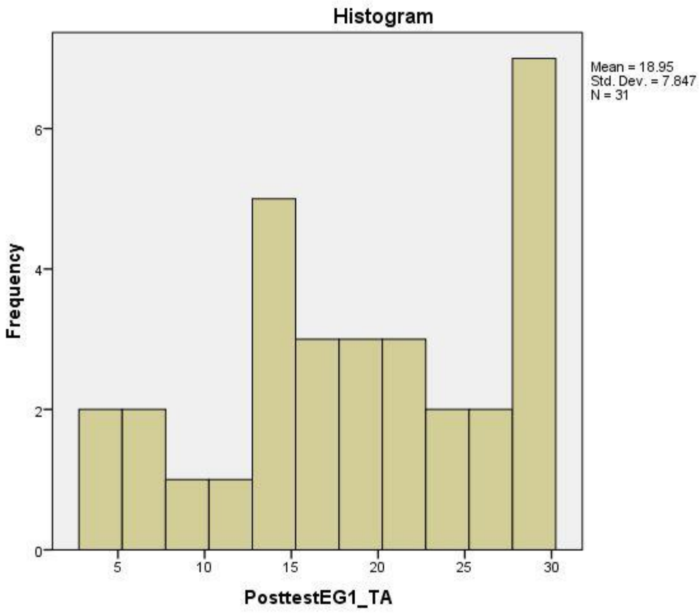


Figure 4.25 Histogram of EG posttest TA chapter 1

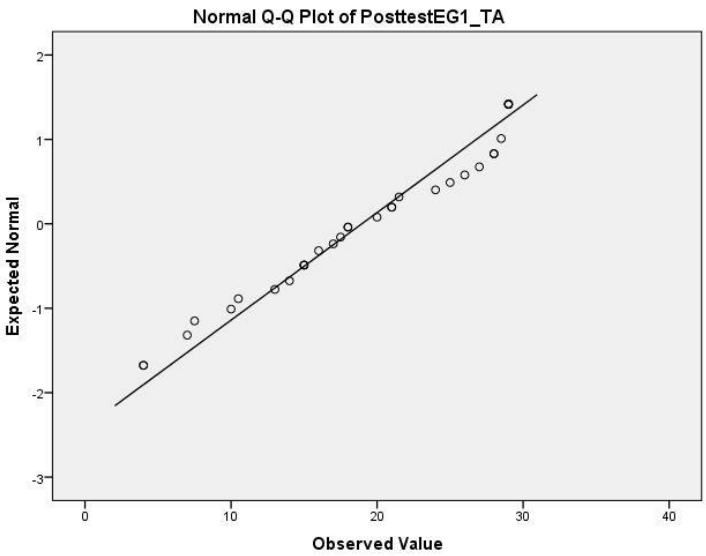


Figure 4.26 Normal Q-Q Plot of EG posttest TA chapter 1

PosttestEG2_TA

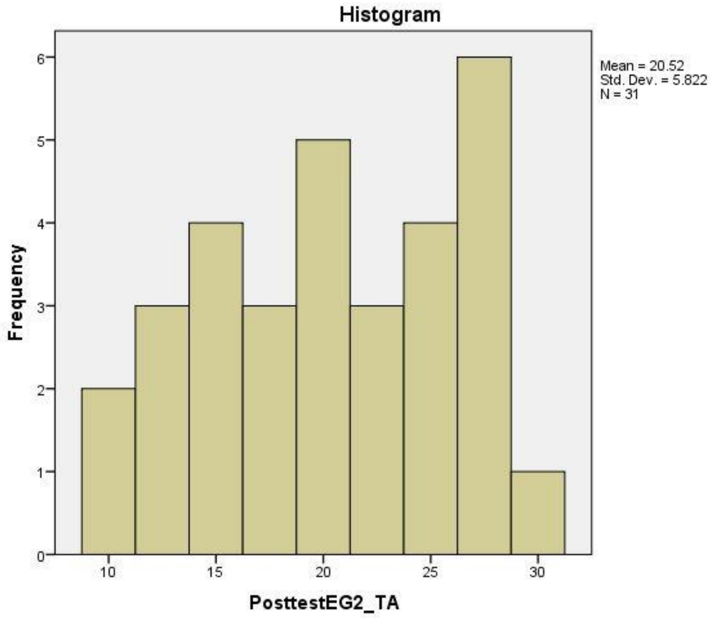


Figure 4.27 Histogram of EG posttest TA chapter 2

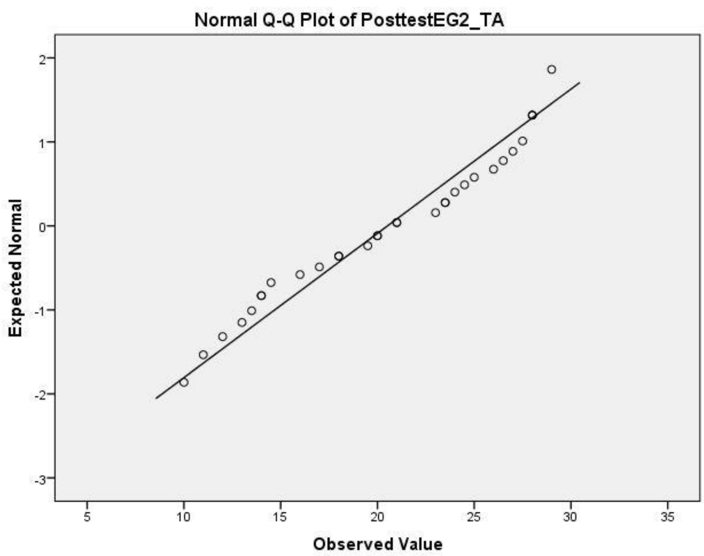


Figure 4.28 Normal Q-Q Plot of EG posttest TA chapter 2

The histogram and Q-Q plot of posttests of both chapters of experimental group shows that the data is normally distributed.

Independent sample t-test of Academic achievement in traditional assessment for posttests of chapter 1 of control and experimental group

Table 4.17 Independent sample t-test of TA chapter 1

Group Statistics

	Students	N	Mean	Std. Deviation	Std. Error Mean
Posttest1TA	Experimental Group Students	31	18.95	7.847	1.409
	Control Group Students	30	5.53	4.345	.793

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
Posttest1TA	Equal variances assumed	12.339	.001	8.224	59	.000	13.418	1.632	10.153	16.683
	Equal variances not assumed			8.297	47.127	.000	13.418	1.617	10.165	16.672

Total 31 out of 35 students are present in experimental group and 30 out of 35 students are present in control group for class test of both chapters.

The null hypothesis for Levene's test for equality of variances is that variances of two groups are approximately equal. The p-value of test is 0.001 which is less than 0.05, therefore, do not accept the null hypothesis and conclude that equal variances are not assumed. As long as N>30 and n1≈ n2, t test is robust to violations of homogeneity of variance.

The null hypothesis for independent sample t-test for posttest scores of TA of both groups states that there is no significant difference in the results of the students after participation in the IBL classroom and traditional teaching lecture method. The p-value found in test is 0.000. The significance value 0.05 is greater than the p-value. Therefore, the null hypothesis is rejected, and it is concluded that there is significant difference in the posttests of both groups for chapter 1.

The mean posttest score of students in EG (M=18.95, SD=7.847) was greater than the CG (M=5.53 and SD=4.345). The SD value indicates that the results are close to the mean in CG as compared to the EG. The result shows that there is much difference in the two mean scores of posttests.

Independent sample t-test of Academic achievement in traditional assessment for posttests of chapter 2 of control and experimental group

Table 4.18 Independent sample t-test of TA chapter 2

Group Statistics

	Students	N	Mean	Std. Deviation	Std. Error Mean
Posttest2TA	Experimental Group Students	31	20.32	5.938	1.066
	Control Group Students	30	9.73	4.394	.802

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
Posttest2TA	Equal variances assumed	5.548	.022	7.896	59	.000	10.589	1.341	7.906	13.273
	Equal variances not assumed			7.935	55.253	.000	10.589	1.335	7.915	13.263

The null hypothesis for Levene's test for equality of variances is that variances of two groups are approximately equal. The p-value of test is 0.022 which is less than 0.05, therefore, do not accept the null hypothesis and conclude that equal variances are not assumed. As long as N>30 and n1≈ n2, t test is robust to violations of homogeneity of variance.

The null hypothesis for independent sample t-test for posttest scores of TA of both groups states that there is no significant difference in the results of the students after participation in the IBL classroom and traditional teaching lecture method. The p-value found in test is 0.000. The significance value 0.05 is greater than the p-value. Therefore, the null hypothesis is rejected, and it is concluded that there is significant difference in the posttests of both groups for chapter 2.

The mean posttest score of students in EG (M=20.32, SD=5.938) was greater than the CG (M=9.73 and SD=4.394). The SD value indicates that the results are close to the mean in CG as compared to the EG. The result shows that there is much difference in the two mean scores of posttests.

4.6 Experimental Group Improvement in Scores

The mean scores from the EG increased from 7.23 in the pretest to 12.43 in the posttest for chapter 1 and for chapter 2 mean score increased from 7.60 in the pretest to 11.42 in the posttest. The mean difference is 5.20 and 3.82 for both chapters, respectively.

Moreover, the mean difference between the CG posttest scores and EG posttest scores is 4.171 and the 95% Confidence Interval of Differences states a minimum increase of 2.934 and maximum increase of 5.408 for chapter1. Similarly, the mean difference of posttest scores of each group is 4.657 and the 95% CI of Differences states a minimum increase of 3.453 and maximum increase of 5.860 for chapter 2. Therefore, the use of IBL model resulted in an increase in content-specific CT skills of students.

For general-specific CT skills the mean score of the EG is 5.17 in the posttest of CCTT and the mean score of CG is 3.57. Therefore, the mean difference is 1.60 and the 95% CI of Differences states a minimum increase of 0.636 and maximum increase of 2.564. This too shows that there is a significant difference in the general-specific CT skills in EG students.

In traditional assessments, the mean score of the EG in posttest of chapter 1 is 18.95 and the mean score of CG is 5.53. The mean difference between the experimental and control group posttest score for chapter 1 is 13.418 and the 95% CI of differences states a minimum increase of 10.153 and maximum increase of 16.683. Similarly, the mean score of the EG in posttest of chapter 2 is 20.32 and the mean score of CG is 9.73. The mean difference between the EG and CG posttest score for chapter 2 is 10.589 and 95% CI of differences states a minimum increase of 7.906 and maximum increase of 13.273. Therefore, the use of IBL model resulted in an increase in the academic achievement of the students in traditional assessments.

5. Discussion

5.1 Findings of the study

Findings of the study based on the comparison of IBL and traditional teaching lecture method in science towards middle school participants.

This research addressed the following research questions:

1. Is there a significant difference in content-specific CT skills of the middle school science students who participate in an IBL classes as compared to the students who participate in traditional teaching lecture method?
2. Is there a significant difference in general CT skills of the middle school science students who participate in an IBL classes as compared to the students who participate in traditional teaching lecture method?
3. Is there a significant difference in academic achievement of the middle school science students who participate in an IBL classes as compared to the students who participate in traditional teaching lecture method?

The data analysis was conducted to test the effectiveness of IBL model on student's content-specific CT skills, general CT skills and academic achievement as compared to traditional teaching lecture method. The results showed improvement in results of experimental group who were taught by using IBL model as compared to the control group who were taught by using traditional teaching method. The findings of the results showed that there is significant difference in content-specific CT skills, general CT skills and academic achievement of the students who received IBL instructions as compared to the students who received traditional teaching lecture method.

The following Null Hypotheses were formulated:

H_{01}: Participation of middle school students in IBL classes of science has no significant effect on participant's content-specific CT skills as compared to the traditional classes of science participants.

H_{02}: Participation of middle school students in IBL classes of science has no significant effect on participant's general CT skills as compared to the traditional classes of science participants.

H_{03}: Participation of middle school students in IBL classes of science has no significant effect on participant's academic achievement as compared to the traditional classes of science participants.

After analyzing the data, all three null hypotheses were rejected, and alternate hypotheses were failed to reject. It is stated that participation of middle school students in IBL classes of science has significant effect on student's academic achievement, content-specific and general CT skills as compared to traditional classes of science participants.

The experimental group showed a significant increase in posttests based on statistical tests and there was a significant difference between the mean score of posttests of the control and experimental groups. This indicates the benefits of using IBL model with the implementation of video lessons and activities in class. Full participation of students and interest was observed in class tasks like asking genuine questions, arising interesting and thoughtful questions during lessons, discussions among each other during watching videos and answering and explaining questions and queries in groups, helping each other in describing concepts through discussion and arguments and they pause and reflect on the concepts explained in videos. Moreover, questioning and exploring answers for those questions increases their critical thinking abilities.

In control group, traditional teaching method was used, the teacher explained the concepts in verbal lecture using white board and textbook only. The difference between pre and post test scores is minimal and very low as compared to experimental group. Students attended class passively and no thought-provoking questions from student's side was observed.

Furthermore, it was seen by the researcher that there are contrasts between the two groups as far as their dedication to go to each class, work with their class fellows, team up, and pose inquiries. The IBL group loved coming to class and felt open to posing inquiries and speaking with the teacher and with one another. Students showed that they sensed they are part for their learning cycle and felt belongingness, they felt smart and confident about their ability to solve problems on their own. When students were asked, which teaching method helps them to understand more and give their opinions about it then one student said, "I learned a lot from videos because it gives a lot of information which cannot be delivered from lecture as effectively as from videos because we make notes during listening and watching and understand on our own". Another student said, "During test I forgot the uses of spacecraft which are mentioned in the textbook, but I remembered the ones mentioned in videos and from worksheets and notes which I wrote on my own". Third students said, "It helps in improving our knowledge and thinking and I like the way that you teach us and asked us to raise questions and find answers on our own because in that way we think on our own and finding those answers helped in improving our knowledge". Another student prefers learning on her own and through exploration as compared to the rote learning, she said "I found it difficult to memorize the long question of "Ozone Depletion" but now we can write in our own words after learning from videos and searching answers on our own". Another student said that" If we learn other chapters of science and other subjects in the same way then we don't need to do rote learning". Another student added "We find those videos very helpful, and we like to explore questions on our own. We never used internet before in a positive way for exploring questions like that. It increases our knowledge". Another student suggested that "It should be implemented in another subjects like history and geography because we find them difficult to memorize". Students complimented that" I am happy that someone thought that students should be taught like this, I feel proud because this is a very good thing, and we learn in a better way and we get the opportunity to explore". This discussion shows that if students were given a more time, an ideal opportunity to become adapted to the new instructional method, there would be a significant positive impact.

The results are in support of the study conducted by (Rahmadhani et al., 2021) that IBL with OE3R (Orientation-Exploration-Explanation-Elaboration-Reflection) effective in increasing student's critical thinking skills than conventional teaching lecture method in chemistry. The result of the study aligns with the study conducted Medriati et al., (2021); Rahmi et al., (2019); & Wijaya et al., (2020) that IBL has the significant impact on student's academic achievement and critical thinking skills. The findings of Hrast & Savec (2018) indicates that students who went to IBL guidelines, seen an amazing arrangement or a considerable number of beneficial outcomes on mental processes. They figure out how to take care of issues or answer the inquiries and assumed liability for their own learning.

5.2 Limitations

The results of this quasi-experimental research study support the use of IBL model in enhancing CT skills of the students in science subject. However, there are a few limitations of this study.

1. Lack of time due to the student's upcoming pre-board exams, more topics could be covered or time for more exploration for students to enhance their knowledge and CT skills.

2. Lack of concentration and disturbance because of ongoing sports week and one week gap due to winter vacations during intervention.
3. Fed up with a lot of tests and worksheets as they knew it was not a part of their exams.

6. Conclusion

The purpose of this study was to minimize the gaping hole in the research by implementing inquiry-based learning in Pakistan's government educational sector by using technology aid, along with IBL model of Pedaste (2015). The traditional teaching lecture method for learning science is still being used in most of the schools of Pakistan (Rehmani, 2006). It is teacher-centered approach and students are the passive learners in classroom with no choice but to adapt to their teacher's restricted methodology and pre-planned lesson plans for gaining knowledge. One of the problem world is facing today in education is the weak learning process in which students are less encouraged to develop their thinking skills and learning is only taking place to memorize information directly without understanding what they remembered (Zaini, 2016). Rote learning does not take part in developing critical thinking skills or any other important skill.

This research aimed at investigating the effect of IBL in science on student's academic achievement, general and content-specific critical thinking skills in science. The focus was on two science chapters of grade 8 named "Pollution and its effects on environment" and "space exploration". The research question explored was "Is there a significant difference in content-specific CT skills, general CT skills and academic achievement of middle school science students who participate in an IBL classes as compared to students who participate in traditional teaching lecture method?". The independent variables were IBL and traditional teaching lecture method, the dependent variables were Content-specific CT skills, General CT skills and Academic achievement (traditional assessments). The null hypothesis was "Participation of middle school students in IBL classes of science has no significant effect on participant's academic achievement, content-specific and general CT skills as compared to traditional classes of science participants” whereas the Alternative Hypothesis was “Participation of middle school students in IBL classes of science has significant effect on participant’s academic achievement, content-specific and general CT skills as compared to traditional classes of science participants”.

The quasi-experimental study was conducted over 4 weeks to collect the quantitative data from pre and posttests of 70 grade 8 students of control and experimental group. It is determined on the basis of the data analysis and discussion that there is incredible positive improvement in the development of the content-specific CT skills of experimental group students who receive IBL instructions as compared to the control group students who receive traditional teaching lectures. There is a significant difference in posttests of CCTT conducted for general CT skills and traditional assessments for academic achievement between the experimental and control group students.

The null hypothesis was rejected, and alternative hypothesis was failed to reject. It was concluded that IBL has a significant effect on student’s CT skills and academic achievement in science.

An assorted and wide collection of exploration recommends that IBL positively impact the student’s ability to understand the core concepts or procedures and critical thinking skills.

Since students are not familiar in conducting the inquiry process before they still need time to practice and gain experience in collecting information and investigate the data.

This study might help and benefit in curriculum development according to IBL to enhance CT skills, science teaching, and construction of valid tests to assess the content-specific and general CT skills among the students. Also guide the future researchers to conduct the study in various fields of science and other subjects.

6.1 Future recommendations

Inquiry is not, at this point simply the language of science and math. It presently contributes in immediate and principal approaches to business, account, health, and defense. For learners, it opens ways to vocations. For residents, it empowers educated choices. For countries, it gives information to contend in an innovative economy.

The purpose of this research is to examine the effect of IBL on critical thinking skills and academic achievement of the middle school students in science. Opportunities exist for future researchers to address areas of improvement in this research. These could incorporate improving the research with more broad systems and technology, adding different data collections tools for CT skills, surveying various kinds of inquiry projects, and gathering information that addresses more sorts of critical thinking capacities and practices. A repeated measures analysis could be directed to evaluate the inquiry program over a more extended time period. By concentrating on the inquiry program in a repeated measures plan, the analyst could distinguish explicit parts of the program helpful to improving CT skills and academic achievement of students.

Effectively implementing IBL in classroom needs understanding of the key elements of IBL and supporting students in understanding the process in relation with the course content. It helps in engaging students, think critically, and learn at a higher level which are necessary for higher education and employment. In order to discourage rote learning, IBL can be implemented for different subjects at different levels of education. To ensure the best results, IBL can be included in teacher's training program especially for science teachers.

Maxwell et al. (2015) argues that lack of time allowed for inquiry, plans for IBL activities and lack of funding or resources creates obstacles in implementing IBL and causes frustration in teachers. Therefore, it is recommended to set up the IBL curriculum keeping in mind all the barriers and limitations and making students learning priority in order to achieve the goal of higher order thinking skills. The learner's propensity for fostering their knowledge and critical thinking skills should be done consistently in different degrees of schooling. Critical thinking skills urge the learners to solve the issues that they face. Thinking critically is an expertise that required to be attained by the learners in future. There is almost no exploration work about IBL in our country. Additional studies are required to further study the relationship between IBL and critical thinking skills. Also, the researcher recommends assessing CT skills with more tools other than multiple choice questions and CCTT, it can be open ended questions and assessing their discussion and presentations which should be the part of the student's grading system so that they can put more cognitive effort in exploring the answers to the questions. To get further into the strands of this investigation, gender can be considered whether it would have an effect diversely on the student's CT skills. Along these lines researchers are recommended to approve the viability of this strategy in various science subjects.

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7. Appendices

Appendix-A

Permission Letter

F.1-107/2008 (Academics) FDE
Government of Pakistan
Federal Directorate of Education
****

Islamabad the 9th December, 2019.

The Principal
Islamabad Model College for Girls,
F-10/2, Islamabad.

Subject: **PERMISSION FOR RESEARCH.**

I am directed to refer to the captioned subject and to say that Ms. Hira Javed a student of MS from School of Electrical Engineering and Computer Science, NUST, Islamabad is doing research study on **"Inquiry-Based Learning in Science Education: Assessing its Impact on Critical Thinking of the Students"**. In this regard she needs to visit your institution for research study. You are requested to extend your cooperation regarding her project.

2. The research scholar is required to forward a copy of her thesis to Federal Directorate of Education after completion of the project.

3. This is issued with the approval of Director (Academics).

(ANJUM ZAHEER)
Assistant Director (Academics)
Phone #. 051-9261146

Copy to:

- **Prof. Dr. Safdar Abbas Khan**
  Assistant Professor
  Department of Computing
  Office A-308, NUST H-12 Campus, Islamabad.
- **Area Education Officer, Urban-II.**

Ms Salma
17.12.2019

Ms Bushra Ahmed
Pl. see the matter
17.12.2019

Appendix-B

Pre & posttest of chapter 1 "POLLUTION & ITS EFFECTS ON RNVIRONMENT"

Name: ______________________________ **Class:** ______________________________

1. Which one of the following is the effect of global warming?
   a) Maintaining sea level c) Desertification
   b) Proper rainfall d) Afforestation
2. Problem of solid waste disposal can be reduced through
   a) Lesser pollution c) Population control
   b) More timber d) Recycling
3. Harmful substance released by power plants and cars is
   a) carbon dioxide c) potassium
   b) oxygen d) magnesium
4. Greenhouse effect is warning due to
   a) Infra-red rays reaching earth
   b) Moisture layer in atmosphere
   c) Increase in temperature due to increase in CO2 concentration of atmosphere
   d) Ozone layer of atmosphere
5. Which of these is NOT a primary pollutant?
   a) Carbon monoxide
   b) Carbon dioxide
   c) Ground level ozone
   d) Oxygen
6. How does increase in temperature affect air pollution?
   a) Higher temperatures reduce air pollution
   b) Higher temperatures increase air pollution
   c) Temperature does not affect the air pollution levels
   d) Humidity factor is also necessary to predict variance of air pollution with temperature.
7. Which of the following is the **current major** contributor to lead air pollution?
   a) Motor vehicles c) Factories
   b) Mines d) CFC
8. Which of the following statement is true?
   a) Global warming is caused due to thicker layer of greenhouse gases around the earth
   b) CO2 is balanced in the atmosphere due to deforestation.
   c) In a greenhouse, sun's heat can come in and can go outside
   d) If there were no greenhouse gases, the earth would be a very hot
9. Which of the following gases are main contributors to acid rain?
   a) Carbon dioxide and carbon monoxide
   b) Sulphur dioxide and carbon dioxide
   c) Sulphur dioxide and nitrogen dioxide
   d) Sulphur dioxide and carbon monoxide
10. Which gases are responsible for greenhouse effect?
    a) CO2, H2SO4
    b) CFCs, CO, CO2
    c) CO2, CH4, N2O
    d) Cl, HCFCs, ODS
11. Which is the major source for Sulphur dioxide?
    a) Volcanic eruptions

b) Coal and crude oil combustion
c) Burning of petrol
d) Sewage treatment process

12. How does increase in temperature affect air pollution?
a) Higher temperatures reduce air pollution
b) Higher temperatures increase air pollution
c) Temperature does not affect the air pollution levels
d) Humidity factor is also necessary to predict variance of air pollution with temperature

13. What effect of air pollution is caused when sulfur dioxide gets high into the atmosphere?
a) Global Warming
b) Respiratory infections, lung cancer and heart diseases
c) Acid rain
d) Damage to the ozone layer

14. Poisonous substances that can be present in industrial wastes does not includes
a) phosphates
b) nitrates
c) mercury and lead
d) oxygen

15. Biological decay, forest fires and volcanic eruptions are example of
a) gaseous pollutants
b) water pollutants
c) human-caused pollution
d) air toxics

16. Which of the following chemicals are responsible for the depletion of the stratospheric ozone layer?
a) Refrigerators
b) Acid rain
c) CO
d) Smoke

17. Which of the following is the major contributor of air pollution?
a) Motor vehicles and industrial processes
b) Burning
c) Natural resources
d) Artificial resources

18. What can you do to reduce air pollution?
a) Take less public transport
b) Use more Sulphur content fuel
c) Recycling
d) Deforestation

19. Layer of atmosphere that absorbs ultraviolet rays from Sun is called
a) troposphere
b) ozone layer
c) thermosphere
d) mesosphere

20. Which one of the following results takes place due to global warming?
a) Maintaining steady temperature
b) Changes in the rainfall
c) Pleasant environment
d) Causing less pollution

Appendix-C

Pre & posttest of chapter 2 "SPACE EXPLORATION"

Name: ______________________________ Class: ____________________________

1) Why Mercury planet is extremely hot in day time and extremely cold at night time?
   a) It has hot molten lava in its inner core
   b) Because of its slow rotation
   c) Because it is nearest to the sun
   d) It has higher atmospheric pressure.
2) Which hottest and brightest planet can be seen in the morning and in the evening known as "morning star"?
   a) Venus
   b) Mars
   c) Mercury
   d) Jupiter
3) Why Mars planet is known as "Red Planet"?
   a) Scientist gave this name to distinguish it from other planets
   b) It is hottest and nearest to the sun
   c) The red color is caused by water ice chemically bound in surface rock.
   d) Because of the presence of red soil and rocks
4) Most of the electricity used in spacecraft is produced by using
   a) Nuclear energy
   b) Solar energy
   c) Natural gas
   d) Thermal energy
5) The astronauts communicate with other astronauts in space and to the ground through
   a) Sound waves
   b) Micro waves
   c) Radio waves
   d) Electrical waves
6) A point where light rays pass and converge is called its
   a) reflect point
   b) refract point
   c) focal point
   d) objective lenses
7) At higher altitudes air is comparatively
   a) thinner
   b) thicker
   c) denser
   d) higher
8) In space, when you move away from earth the gravity will be
   a) Lesser
   b) Greater
   c) No change in gravity in the space around earth
   d) No gravity
9) Theory which proclaims that an explosion created universe is called the
   a) law of gravity
   b) big bang theory
   c) Darwin theory
   d) Earth theory
10) Earth is a part of
   a) universe
   b) solar system
   c) milky way
   d) galaxy
11) If an astronaut is not careful, his food will float away. Food floats in space because ______.
   a) Space air is too dense.
   b) There is less gravity in space.
   c) Gravity is strong in space.
   d) All astronaut food is turned into a light powder.
12) Which of the following is NOT a general difference between a planet and a star?
   a) Planets are smaller than stars.
   b) Planets are dimmer than stars.
   c) All planets are made of rock and all stars are made of gas.
   d) Planets orbit stars, while stars orbit the center of the galaxy
13) Our solar system consists of __________.
   a) the Sun and several nearby stars, as well as the planets and other objects that orbit the stars
   b) the Sun and all the objects that orbit it
   c) a few hundred billion stars, bound together by gravity
   d) the Sun and the nine planets, and nothing else

14) A typical galaxy is a _________.
   a) system consisting of one or a few stars orbited by planets, moons, and smaller objects
   b) nearby object orbiting a planet
   c) large, glowing ball of gas powered by nuclear energy
   d) collection of a few hundred million to a trillion or more stars, bound together by gravity
   e) relatively small, icy object orbiting a star
15) What do astronomers mean by the Big Bang?
   a) The event that marked the beginning of the expansion of the universe
   b) The explosion of a massive star at the end of its life
   c) A gigantic explosion that blew all the galaxies in the universe to smithereens
   d) The event that marked the birth of our solar system
16) What do we mean when we say that the universe is expanding?
   a) Everything in the universe is gradually growing in size.
   b) The statement is not meant to be literal; rather, it means that our knowledge of the universe is growing.
   c) Average distances between galaxies are increasing.
   d) Average distances are increasing between star systems within galaxies.
17) Which of the following has your "cosmic address" in the correct order?
   a) You, Earth, solar system, Milky Way Galaxy, Local Group, Local Supercluster, universe.
   b) You, Earth, Local Group, Local Supercluster, solar system, Milky Way Galaxy, universe.
   c) You, Earth, solar system, Local Group, Milky Way Galaxy, Local Supercluster, universe.
   d) You, Earth, Milky Way Galaxy, solar system, Local Group, Local Supercluster, universe.
18) In which of the following cases would you feel weightless?
   a) While parachuting from an airplane
   b) While accelerating downward in an elevator
   c) While falling from a roof
   d) While walking on the Moon

19) Why are astronauts weightless in the Space Station?
   a) Because the Space Station is traveling so fast
   b) Because there is no gravity in space
   c) Because the Space station is moving at constant velocity
   d) Because the Space station is constantly in free-fall around the Earth
20) Which of the following statements best describes the two principle advantages of telescopes over eyes?
   a) Telescopes can collect far more light with far better angular resolution.
   b) Telescopes collect more light and are unaffected by twinkling.
   c) Telescopes can collect far more light with far greater magnification.
   d) Telescopes have much more magnification and better angular resolution.
21) In what way is Venus most similar to Earth?
   a) Both planets have very similar atmospheres.
   b) Both planets have similar surface geology.
   c) Both planets have warm days and cool nights.
   d) Both planets are nearly the same size.
22) Why is the sky blue (on Earth)?
   a) Because the Sun emits mostly blue light
   b) Because molecules scatter red light more effectively than blue light
   c) Because deep space is blue in color.
   d) Because gas molecules in the atmosphere scatter blue light more effectively than red light

Appendix-D

Revised Cornell Critical Thinking Test (CCTT) Level X Time allowed: 10 mins

Name: __________________ Grade: __________________ Age: ___________________

INSTRUCTIONS:

DO NOT GUESS WILDLY. There is a scoring penalty for guessing wrong. If you think you have the answer, but are not sure, mark that answer. But if you have no idea, then skip the question.

The meaning of the possible answers:

A. YES: *It must be true.*

B. NO: *It can't be true.*

C. MAYBE: *It may be true, or it may not be true. You weren't told enough to be certain whether it is* "YES" *or* "NO".

Sample question:

Suppose you know that

The pit is inside of the mouth of the fox.

The cherry is inside the mouth of the fox. Then would this be true?

The pit is inside the cherry.

A. YES

B. NO

C. MAYBE

The correct answer is C, "MAYBE". All you are told is that the pit and the cherry are both in the mouth of the fox. There is no way to be certain whether the pit is in the cherry or not.

1. Suppose you know that
   All the cars in the garage are Mr. Smith's.
   All Mr. Smith's cars are Fords. Then would this be true?
   All of the cars in the garage are Fords.
   A. YES
   B. NO
   C. MAYBE

2. Suppose you know that
   All of Mary's books are about horses. None of the books on the shelf are about horses. Then would this be true? At least some of Mary's books are on the shelf.
   A. YES
   B. NO
   C. MAYBE

3. Suppose you know that
   All of Bill's five uncles are allowed to drive.
   All people who have a license have passed a driving test. All people who are allowed to drive have a license. Then would this be true? At least one of Bill's uncles has not passed a driving test.
   A. YES
   B. NO
   C. MAYBE

4. Suppose you know that
   All the members of the school band have been in Boston.

No one in Frank's class has been in Boston. Then would this be true?
At least some members of the school band are in Frank's class.

A. YES
B. NO
C. MAYBE

5. Suppose you know that
All the second-grade children are out on the playground. Then would this be true?
All the children out on the playground are in the second grade.
A. YES
B. NO
C. MAYBE

6. Suppose you know that
All pencils are heavy. Nothing made of wood is heavy. Then would this be true?
At least some pencils are made of wood.
A. YES
B. NO
C. MAYBE

7. Suppose you know that
All the cookies Jane made for the fair had nuts in them. All the cookies with nuts in them were sold.
Then would this be true? All the cookies Jane made for the fair were sold.
A. YES
B. NO
C. MAYBE

8. Suppose you know that
All members of the football team weigh over 150 pounds. Henry does not weigh over 150 pounds.
Then would this be true? Henry is on the football team.
A. YES
B. NO
C. MAYBE

9. Suppose you know that
All the pencils in the box are green.
All Sue's pencils are sharp. All the green pencils are Sue's.
Then would this be true? At least some of the pencils in the box are not sharp.
A. YES
B. NO
C. MAYBE

10. Suppose you know that
All of the boys in the class collect stamps. All students who are not members of the Stamp Club also do not collect stamps. Then would this be true?
At least some of the boys in the class are not members of the Stamp Club.
A. YES
B. NO
C. MAYBE

Appendix-E

Traditional assessments

Chapter # 1 "POLLUTION AND ITS EFFECTS ON ENVIRONMENT"

SHORT QUESTIONS

Q # 1: Define the following terms		Total marks
i.	Ozone Depletion	2
ii.	Acid Rain	2
iii.	Greenhouse Effect	2
Q # 2: What causes the greenhouse effect?		2
Q # 3: What converts ozone into oxygen?		2

EXTENSIVE QUESTIONS

Q # 1: What are the sources, properties, and harmful effects of chlorofluoro carbons?	3+3+3
Q # 2: What are the effects of global warming on Earth? And how human activities contributes in this?	6+4

Chapter # 2 "SPACE EXPLORATION"

SHORT QUESTIONS

Q # 1: Define the following terms		
i.	Radio waves	2
ii.	Electromagnetic radiations	2
iii.	International space station	2
Q # 2: What are Global Positioning Satellites?		2
Q # 3: Describe uses of spacecraft?		4

EXTENSIVE QUESTIONS

Q # 1: Describe a refracting telescope with diagram of its working principal.	4+2
Q # 2: Why is it risky to send human in space? If a person sent in space such as astronaut how will he survive there?	5+5