CHAPTER II

CONCEPTUAL FRAMEWORK

2.1 INTELLIGENT TUTORING SYSTEMS

2.2 ANDES INTELLIGENT TUTORING SYSTEM

2.3 PROBLEM SOLVING ABILITY

2.4 CRITICAL THINKING
CONCEPTUAL FRAMEWORK

Conceptual Framework helps the investigator to connect the existing knowledge and the research work under study. It describes the theory that explains why the research problem under study exists. It helps the researcher to explain, predict, and understand the variables involved to challenge and expand the existing knowledge. Since the present study was intended to develop a Strategy based on Andes Intelligent tutoring System for enhancing Problem Solving Ability, Critical Thinking and Achievement in Physics of Students at Higher Secondary level, a detailed understanding of the concepts related to Andes Intelligent Tutoring System, Problem Solving Ability and Critical Thinking is necessary.

2.1 INTELLIGENT TUTORING SYSTEMS (ITS)

Intelligent tutoring systems (ITS) are computer systems that provide customized instruction and immediate feedback to learners usually without requiring intervention from a human teacher (Psotka and Mutter, 1988). ITS enables learning in a meaningful and effective way by using variety of computing technologies. ITSs are designed with the goal of providing access to high quality education to each and every student. ITS uses the benefits of one-to-one personalized tutoring apart from one-to-many instruction from a single teacher (e.g. Classroom lectures).

2.1.1 History of Intelligent Tutoring Systems

a. Pascal’s Machine

The possibility of intelligent machines has been discussed for centuries. In the 17th century, Blaise Pascal developed the first calculating machine capable of mathematical functions called Pascal’s Calculator. These early work forms the base for the development of the computer and future applications.
b. Pressey’s Machine

Sidney Pressey of Ohio State University in 1924 created a mechanical teaching machine to teach students without a human teacher (Fry, 1960). His machine closely resembled a typewriter with several keys and a window to provide questions to the learner. The user can input the data using this machine and the machine provide immediate feedback by recording their score on a counter (Shute and Psotka, 1994). The Pressey’s machine was developed based on the laws put forward by the learning theorist Edward. L. Thorndike such as law of effect, law of exercise and the law of recency. This attempt of Pressey set an early precedent for future projects.

Figure 2.2 Pressey’s Teaching Machine


c. Skinner’s Teaching Machine

B. F. Skinner of Harvard University disagrees with Thorndike learning theory and Pressey’s machine. He believed that learner should not rely on recognition but has to construct their answers. By 1950’s and 1960’s he
developed a teaching machine that would reward students for their correct responses to questions (Fry, 1960).

![Figure 2.3 Skinner’s Teaching machine](https://commons.wikimedia.org/wiki/File:Skinner_teaching_machine_08.jpg)

The mechanical binary systems were replaced by binary based electronic machines after the Second World war which were considered as intelligent when compared to their predecessors as they had the capacity to make logical decisions.

**d. Turing Test**

A well known Mathematician and computer Scientist, Alan Turing, linked computing systems to thinking. He developed a hypothetical test to assess the intelligence of a machine which came to be known as the Turing Test. This acts as the base for the present Intelligent Tutoring Systems. The test requires a person communicate with two other agents- a human and a computer. The person asks questions to both the agents. The computer passes the test if it responds in similar to the human respondent.

![Figure 2.4 The Turing Test](https://www.mensxp.com/work-life/success-stories/40897)
e. The Logic Theorist

The Logic Theorist was a program developed by Allen Newell, Clifford Shaw, and Herb Simon that allowed complex symbol manipulation and generation of new information without direct human control and is considered as the first Artificial Intelligent (AI) program. The term Artificial Intelligence was named in 1956 by John Mc Carthy at the Dartmouth Conference (Buchanan, 2006).

f. Computer Assisted Instruction

The development of ALGOL programming language in 1958 enabled the development of Computer Assisted Instruction Programs (CAI). In 1960’s and 1970’s many Computer Assisted Instruction (CAI) were developed which shows the advances in Computer Science. The programming language LOGO created in 1967 by Wally Feurzeig, Cynthia Solomon, and Seymour Papert, PLATO, an educational featuring developed by Donald Bitzer in the University of Illinois in the early 1970s were some of the CAI programs.

g. Intelligent Tutoring Systems (ITS).

In 1970, Jaime Carbonell suggested that computers could act as a teacher rather than just a tool. Computer Assisted Instruction (CAI) was replaced by Intelligent Computer Assisted Instruction (ICAI) or Intelligent Tutoring Systems (ITS) that focused on the use of computers to intelligently coach students called. CAI followed Skinner's theory and ITS has its root in cognitive psychology, computer science, and especially artificial intelligence (Larkin and Chabay, 1992). The first ITS Dendral was created by Seymour Papert and Ira Goldstein, which is a system that predicted possible chemical structures from existing data. These changes had big implications for how computers could be used in instruction. The technical requirements of ITS, however, is higher and more complex than CAI systems.

Researches conducted in Cognitive Psychology and Artificial Intelligence fuelled the new principles of ITS. Psychologists considered how a
computer could solve problems and perform 'intelligent' activities. An ITS programme should be able to present, store and retrieve knowledge and even search its own database to derive its own new knowledge to respond to learner's questions.

2.1.2 Basic Components of Intelligent Tutoring Systems

According to Nwana (1990), Freedman (2000) and Nkambou et al. (2010), the Intelligent Tutoring Systems consist of four basic Components. They are

- The Domain model – It takes into account all possible steps required to solve a problem. This part contains the concepts, rules and problem solving strategies to be learned. It acts as a source of expert knowledge, evaluates student’s performance and detect errors.

- The Student model – It is the core of ITS. It gives special attention to student's cognitive and affective states. As the student progress their problem solving through various steps, the ITS engages in a process called model tracing. If the student model deviates from the domain model, the system identifies it and reports that an error has occurred.

- The Tutoring model- accepts information from the domain model and student model and makes choices about tutoring strategies and actions. At any point in the problem-solving process if the learner request guidance on what to do next or when the system recognizes the learner has deviated from the rules, it provides timely feedback for the learner, resulting in a shorter period of time to reach proficiency with the targeted skills (Anderson and Koedinger, 1997).

- The User interface model – It provides knowledge about patterns of interpretation, and action within dialogues; domain knowledge
needed for communicating content; and knowledge needed for communicating intent. (Padayachee, 2002, p. 3).

2.1.3 Design and development of ITS

According to Corbett et al. (1997), ITS design and development consist of four iterative stages:

a. Needs Assessment,

b. Cognitive Task Analysis,

c. Initial Tutor Implementation

d. Evaluation

The first stage known as needs assessment is common to any instructional design process, especially software development. This involves a learner analysis, consultation with subject matter experts and with the instructors. At this stage, the researcher should specify the learning goals and prepare a general plan for the curriculum. Another important aspect to be addressed in this stage is cost effectiveness of the interface. Moreover, the entry characteristics such as prior knowledge of teachers and students must be assessed since both groups are going to be system users.

During the second stage, the whole program is developed.

In the third stage a problem solving environment will be set up to enable and support an authentic learning process. This stage is followed by a series of evaluation activities.

The fourth stage, evaluation includes pilot studies to confirm basic usability and educational impact, formative evaluations of the system under development, parametric studies that examine the effectiveness of system features and finally, summative evaluations of the final tutor's effect.
2.1.4 Principles of ITS

Eight principles usually guides the principles of ITS as proposed by Anderson et al. (1987). “They are

1. Represent student competence as a production set.
2. Communicate the goal structure underlying the problem solving.
3. Provide instruction in the problem solving context.
4. Promote an abstract understanding of the problem-solving knowledge.
5. Minimize working memory load.
6. Provide immediate feedback on errors.
7. Adjust the grain size of instruction with learning.
8. Facilitate successive approximations to the target skill”.

2.1.5 Intelligent Tutoring Systems in Education

- **Algebra Tutor** - engages students in anchored learning problems and uses modern algebraic tools to engage students in problem solving and in sharing of their results.

- **Mathematics Tutor** - The Mathematics Tutor (Beal, Beck & Woolf, 1998) “helps students solve word problems using fractions, decimals and percentages. The tutor records the success rates while a student is working on problems”. The subsequent problems that are selected are based on student ability and a desirable time in is estimated in which the student is to solve the problem.

- **eTeacher** – “It is a pedagogical agent, that supports personalized e-learning assistance. It builds student profiles while observing student performance in online courses. e-Teacher then uses the information from the student’s performance to suggest a personalized courses of action designed to assist their learning process (Schiaffino, Gracia and Amandi, 2008)”.

• **ZOSMAT** - “ZOSMAT was designed to address all the needs of a real classroom. It follows and guides a student in different stages of their learning process. This is a student-centered ITS does this by recording the progress in a student's learning and the student program changes based on the student's effort. ZOSMAT can be used for either individual learning or in a real classroom environment alongside the guidance of a human tutor” (Keles, Ocak, Keles and Gulcu, 2009).

• **REALP** – “REALP was designed to help students enhance their reading comprehension by providing reader-specific lexical practice and offering personalized practice with useful, authentic reading materials gathered from the Web. The system automatically build a user model according to student's performance. After reading, the student is given a series of exercises based on the target vocabulary found in reading”. (Hefferman et al., 2006).

• **Why2-Atlas** - Why2-Atlas is an ITS that analyses students explanations of physics principles. The students input their work in paragraph form and the program converts their words into a proof by making assumptions of student beliefs that are based on their explanations. In doing this, misconceptions and incomplete explanations are highlighted. The system then addresses these issues through a dialogue with the student and asks the student to correct their essay. A number of iterations may take place before the process is complete.

• **Smart Tutor** – “The University of Hong Kong (HKU) developed a Smart Tutor to support the needs of continuing education students. Personalized learning was identified as a key need within adult education at HKU and Smart Tutor aims to fill that need. Smart Tutor provides support for students by combining Internet technology, educational research and artificial intelligence” (Cheung, Hui, Zhang and Yiu, 2003).
• **Auto Tutor** –“Auto Tutor assists college students in learning about computer hardware, operating systems and the Internet in an introductory computer literacy course by simulating the discourse patterns and pedagogical strategies of a human tutor. Auto Tutor attempts to understand learner's input from the keyboard and then formulate dialog moves with feedback, prompts, correction and hints” (Graesser, Hastings, Hastings and Kreuz, 1999).

• **Active Math**- “Active Math is a web-based, adaptive learning environment for mathematics. This system strives for improving long-distance learning, for complementing traditional classroom teaching, and for supporting individual and lifelong learning” (Melis and Siekmann, 2004).

• **Andes** – helps problem solving in Physics of Undergraduate students. Provide hints and immediate feedback for students when students have trouble answering the questions.

• **ESC101-ITS** –“The Indian Institute of Technology, Kanpur, India developed the ESC101-ITS, an intelligent tutoring system for introductory programming problems”.

### 2.1.6 Strengths and Weaknesses of ITS

“The strengths of ITS are their ability to provide immediate feedback (positive and negative), individual task selection, on-demand hints, and support mastery learning” (Koedinger, Kenneth, Alven and Vincent, 2007).

Intelligent tutoring systems are expensive both to develop and implement. It requires the cooperation of subject matter experts. Also some students immediately turn to the hints before attempting to solve the problem. Also Intelligent tutoring systems are less capable than human tutors in the areas of dialogue and feedback.
2.2 ANDES INTELLIGENT TUTORING SYSTEM

Andes is an Intelligent tutoring System in Classical Physics developed by researchers at the Learning Research and Development Center (LRDC) at the University of Pittsburgh and the United States Naval Academy (USNA). Andes allows students to solve problems in Physics in an environment that provides visualization, procedural help, immediate feedback and conceptual help (Schulze et al., 2000). It is an artificially intelligent homework helper for Physics. That is, it replaces the pencil and paper that students would ordinarily used to solve physics homework problems. Students draw diagrams, enter equations and define variables with the same freedom that they have when using paper; yet, unlike a piece of paper, Andes tells students whether their entry is correct or not and provides hints when asked.

Andes ITS is a combination of two existing technologies – Cascade, a rule based cognitive model of Physics problem solving and Olae, an online assessment system. It provides hints and feedback on student work. The fundamental objective of the Andes ITS was to interact with physics students using the method of coached problem solving, whereby the ITS and the student collaborate through the problem – solving process.

2.2.1 Instructional Objectives of Andes

The goal of Andes is to replace pen and paper for homework submission. It also add some “tutoring” features that help students understand and correctly complete the problems. The two main instructional objectives of Andes ITS are,

a) Students must master all major and minor principles, so Andes explicitly teaches all of them. These include i) major physics principles ii) unnamed principles that appear widely in textbooks iii) special cases of
more general laws iv) rules of mathematics v) common sense entailments of a proper understanding of physics concepts.

b) Andes encourages students to think about problems in terms of their major principle.

2.2.2 Principles to design Andes

Four general principles guided the design of Andes.

a) **Transfer** - facilitated by making the ITS interface as similar to a pencil – and – paper solution as possible. To satisfy the principle the number of structured entry fields in the ITS is minimized. Thereby, the Andes interface consists of four different panes: two entry panes, one for diagrams and one for equations, one pane for variable definitions and one for hints.

When a problem is first presented, students are asked to do a qualitative problem analysis by drawing a diagram in the diagram pane. When an object is drawn in this pane, a dialogue box is presented that instructs students to define it. The next step in the problem – solving process is to define relevant variables in the variable definition pane. Once relevant variables have been defined, students can enter equations into the equation pane. Once all relevant variables and equations are defined and numerical values for the variables are entered, a calculator finds the numerical solution to the problem.

b) **Flexibility** - the student is provided with flexibility in the order in which actions are performed and is allowed to skip steps when applicable. According to this principle, variables and equations can be entered in any order.

c) **Immediate Feedback** - to minimize wrong paths and to maximize the opportunities for learning immediate feedback is provided. The capacity to provide students with different types of feedback is one of the unique characteristics of Andes. Andes provides immediate feedback once a
student completes an action; if the entry is correct, it is coloured green and if it is incorrect, it is coloured red.

d) **Simple Hints** - Andes encourages the students to construct their own knowledge by receiving simple hints that require them to derive most of the problem solution on their own. Once an entry is marked red, students can either correct their mistake without receiving any help or they can select the entry and click on a help button, which automatically offers the student a relevant hint.

### 2.2.3 Features of ANDES ITS

a) **Good Problem Solving Technique**

To solve problems in Physics using Andes, students must define quantities, draw diagrams, use units and write down intermediate steps in a solution just like solving problems manually. It encourages students to work with algebraic (rather than numerical) expressions. By solving a problem, students can identify implicitly which principle of physics they are using by writing down an equation. So we can say that the problem solving through Andes is effective.

b) **Immediate Feedback**

Unlike a piece of paper, as soon as an action is completed, Andes gives immediate feedback. Entries are coloured green if they are correct and red if they are incorrect.

c) **Hinting Strategies**

Andes provides three different kinds of instructional assistance

- When the error is recognized as a slip, which is defined as an error due to a lack of attention (Leaving a blank entry in a dialogue box) rather than a lack of knowledge, Andes pops up an error message. When an error is not recognized as a slip, Andes colors the entry red. Then the students can have the following types of hints.
When the entry is turned red, students can request help by selecting it and clicking on a help button. Since the student is essentially asking, “What is wrong with that?” we call this What’s wrong help.

If students are not sure what to do next, they can click on a button that will give them a hint. This is called Next step help.

Thus for errors that are likely to be careless mistakes (slip), Andes gives help only through error messages, while for errors where some learning is possible, Andes gives help only when asked.

d) Model Tracing Strategy

The Andes always compare the student’s solution to a model solution of the problem already developed by the experts. Therefore, the hints in Andes are generated by comparing the student actions to the model solution of the problem. Thus when the student asked for “Next Step Help”, it matches the student entries to a model solution and provides hints associated with the first uncompleted step in the model solution.

e) Grading

As the student solves a problem, Andes computes and displays a score. The score is based on the number of correct entries with penalties for the number of incorrect entries (red) and the number of bottom – out hints received. The penalty on the bottom – out hints encourages the students to use the help but discourages the help abuse. Andes puts little weight on the final answer, encouraging students to show their work.

f) Online vs. offline

Andes can be used both ‘offline’ and ‘online’. When used offline, students print their homework and submit it to instructors. When used online, students submit their problem solutions via the web.
2.2.4 Technical Specification of Andes

Andes is an interactive software in which the student works a physics problem. The Andes interface generally referred to as the Workbench consists of several panes and multiple tools. As the students enter objects on the workbench, they are provided with immediate, visual and coloured feedback (Shulze, et al.).

![Figure 2.5 The Andes Workbench](image)

The toolbar across the top contains the typical buttons to open, close, print, cut and paste. It has a comment button the student can use to provide annotated comment. In addition it has a help button that provides help strictly with using the interface that can be selected to receive help on why an object has been turned red and a generic hint button that the student can select when he has no idea what to do next. There is a solve button that will solve an equation for a specified variable, a Greek keyboard button that will allow the student to type Greek characters and a calculator button.
The toolbar running down the left side of the workbench contains buttons to aid in drawing vector quantities. There are buttons that allow the students to construct a body, an axis, a force vector, an acceleration vector etc. Any buttons that are irrelevant to the specific problem are disabled and appear greyed out.

![Figure 2.6 Problem Solving part of Andes Intelligent Tutoring System](image)

The main window of the workbench is divided into four panes: two entry panes, one for diagrams and one for equations, one pane for variable definitions and one for hints. Students read the problems and analyze the figures (if any) on the top of the upper left window, draw vectors and coordinate axes that may help to visualize the problem in the bottom of the upper left window (diagram pane), receives error messages and hints in the lower left window (hint pane) define variables in the upper right window (variable definition pane) and enter equations in the lower right window (equation pane).
2.2.5 Functions and Behaviour of Andes

I. Steps to solve Problems using Andes

1. Qualitative Analysis
   When a problem is first presented, students are generally called upon to do a qualitative problem analysis by drawing a diagram in the diagram pane. The area allows for a wide range of different drawings, including free body diagrams, vectors, co-ordinate systems, angles between vectors and axes, and components of circular paths. When an object is drawn in this pane, a dialogue box is presented that instructs students to define it.

2. Define Relevant Variables
   The next step in the problem solving process is to define relevant variables. In Andes, in order for a student to enter an equation, they are first required to define what each of the variables refer to. If students include an undefined variable in the equation, the equations turns red and a message box pops up indicating which variable is undefined. Students can define variables in two ways a) by assigning a variable name to a component of their diagram b) by entering variables in the variable definition menu.

3. Enter Equations
   Once all relevant variables have been designed, students can enter equations into the equation pane. Equations can be entered using conventional syntax ( =, +, -, *, /, ^ and _ ). Also variables and equations can be entered in any order.

4. Find Solutions
   Once all relevant variables and equations are defined, and numerical values for the variables are entered, a calculator find numerical solutions to the problem.

5. Enter Values in the answer box
   After finding solution to the problem, the student must enter his numerical answer along with the unit in the answer box given in the upper left pane.
II. Feedback Process in Andes

Many studies have indicated that giving immediate feedback to students while they are solving a problem can greatly increase their learning. Immediate feedback means not just telling the students when the final answer is correct, but telling after each step in the derivation of an answer whether that step is correct. It makes easier for students to determine which missing or incorrect beliefs caused their errors and prevents students from wandering down unproductive paths, thereby saving time and preventing them from losing motivation.

For immediate feedback to be effective, it is best if it is provided quickly (Shulze et al., 2001). The capacity to provide students with different types of feedback is one of Andes unique characteristics. Andes provides immediate feedback once a student completes an action. If the entry is correct, it is coloured green and if it is incorrect, it is coloured red.

Andes provides four kinds of help.

- The first is a simple help system where the student can choose to run a video demonstrating how to interact with the workbench (Shulze et al).
- Andes pops up an error message whenever the error is due to lack of attention (slip) rather than lack of knowledge. Typical errors are leaving a blank entry in a dialogue box, using an undefined variable in an equation or leaving off the units of a dimensional number. This type of error connection is termed as self repair.
- If the error is not recognized as a slip, Andes merely colours the entry red. Students can request help on a red entry by selecting it and clicking on a help button named What’s wrong help. What’s wrong help usually generate a hint sequence. The hints are printed in the lower left window. In order to force the students to attend to it, the other windows deactivate and turn gray. Hints are generally available in a sequence of three:
A pointing Hint – calls attention to the location of the students error, so that if the student has the relevant knowledge, the mistake can be easily corrected.

A teaching Hint – If the student again gets stuck, the teaching hints provide students with a relevant piece of knowledge that could be used towards a solution.

After first two hints, Andes displays two buttons labeled “Explain More” and “O.K”. If the “O.K” button is pressed, the problem solving windows became active again, the lower left window becomes gray and the student resumes work on the problem. If the student presses on “Explain more”, then he get the next hint.

Bottom – Out hint – tells the student exactly what to change.

If students are not sure what to do next, they can click on a button located on the top of the tool bar that will give them a hint. This is called Next Step Help. If the students are not satisfied with this hint he can select the “Explain Further” option in the hint or click again on What’s Next button (Shulze, et al, 2000).

What’s wrong help and Next step Help usually generate a hint sequence. The hints are printed in the lower left window.

III. Scoring

As the student solves a problem, Andes computes and displays a score. The score is a function of the correctness of the students’ answer and the number of hints received. Andes puts little weight on answers, because it provides such a good help that students almost always get the answer right. Instead it measures the proportion of entries that were made correctly (green). Counting hints tends to discourage them, so Andes only subtracts points when students ask for bottom – out hints. In addition to making the score a function of degree of correctness and number of hints, Andes tries to encourage good problem solving habits by awarding points for entering certain information
explicitly. For instance, students get points for entering equations for fundamental principles that do not have given values or other values substituted into them. The overall score on a problem is continually displayed in the lower right corner. If students print their solution or use print preview, they see the sub scores from which their score was computed.

IV. Online versus Offline

Andes can be used both offline and online. When used offline, students print their homework and hand it in on paper. Instructors who grade such homework save time because it is easier to read printed equations than hand written ones. When Andes is used online, students submit their problem solution via the web. The Andes scores are sent to the instructor’s grade book, which looks and acts like a spread sheet. The cell contains the students score on a problem as computed by Andes, clicking on the cell displays the student’s solution.

2.2.6 Pedagogical Features of Andes

The following are some of the pedagogical features of Andes that are intended to either facilitate student learning or to facilitate the instructor’s use of the system.

i. Homework Helper

Andes acts as a homework helper that facilitate learning from homework without attempting to constrain or replace the rest of the courses learning activities.

ii. Hundreds of Problems

Andes contains a vast number of homework problems. Andes currently contain 356 problems that cover most of the primary topics of the full-year physics course.
iii. User Interface training

In the current version of Andes, short videos are implemented for the user interface training. When students open a new chapter’s problem set, it checks to see if they have viewed the training video for that chapter. If not, it strongly suggests that they do. The video demonstrates both how to use any new notations and how to solve a simple problem.

iv. Unintelligent Help

Like most conventional tutoring systems, word processors and other end – user software, Andes includes help that is not sensitive to the current problem solving state. Such “Unintelligent” help consists of text and other passive material that the student searches for useful information. An example is Andes cheat sheet, which is shown in the figure below. It is a hierarchical menu of all the equation – generating concepts known to Andes.

v. Flexibility

Andes provide flexibility in the allowed solution paths. One type of flexibility is – students can define the variables and can enter the equations in any order. Another type of flexibility is that it is possible to slve a problem in different ways ( Shulze et.al, 2000).

vi. Student Environment

The student environment, developed by the researchers at Learning, Research and development Center (LRDC) at the University of Pittsburgh, provides four capabilities. First it allows the students to solve problems in such a way that the tutor can monitor virtually every step of the solution process. Second it provides immediate feedback on each step, by colouring it red if it is wrong and green if it is correct. Third it provides help if the students ask for it. Fourth it provides an assessment of the student’s knowledge in physics.

vii. Macro Adaptation and Student Modelling

When the student finishes one problem, the system decides which problem the student should do next or whether the student has done enough
problems for this textbook chapter and can go on to the next. Letting the system choose problems to fit the students' needs is called macro-adaptation. Macro-adaptation requires that the system maintain an assessment of the student's competence on the current chapters' instructional objectives. The assessment also includes student's propensity to use hints. This assessment of the student is often called the student model.

### viii. Highly Motivative Scoring

As the students solve a problem, Andes computes and displays a score step-by-step. It depends on the correctness of the answer and the number of hints received. The overall score on a problem is continually displayed in the lower right corner. Some students seem to be highly motivated by their Andes score, even though they understand that nothing depends on it.

### 2.3 PROBLEM SOLVING ABILITY

Problem-solving has been accepted as a skill that promotes better understanding of the concepts learned in Science and Maths (Aina, 1986; and Garrett, 1987). The development of Problem Solving was therefore considered as a crucial part of education and the right place for its development is the physics classroom. Problem solving requires varying levels of thinking such as analysis, comprehension, judgment, critical thinking, visualization and conceptualization (Adams, 1979).

Robert M. Gagne (1966) states that “Problem solving is a process by which the learner discovers a combination of previously learned rules which can be applied to achieve a solution for a novel situation”. The activity of Problem Solving is thus a natural extension of Rule learning.

According to Polya (1957) problem solving is "finding a way out of a difficulty, a way around an obstacle, attaining an aim that was not immediately attainable."
Mayer (1992) summarizes three major aspects of problem solving. They are

i. Problem solving is cognitive, because it occurs internally within the problem solver's cognitive system.

ii. Problem solving is a process, because it involves manipulating or performing operations on the problem solver's knowledge and

iii. Problem solving is directed, because the problem solver is attempting to achieve some goal

2.3.1 Historical origin of Problem Solving

The history of research on Problem solving and thinking was started by 1901. They fall within three categories – Behaviourist, Gestalt and Cognitive. Behaviourist approach (began in the first half of the 20th century) viewed Problem Solving as a reproductive process of applying those which was successful on a previous occasion. But it fails to explain Creative Problem Solving. The Gestalt approach (between 1920 and 1930 in Germany) viewed problem Solving as a productive process of the mental reorganization of the elements of Problems so that they fit together in a new way. So a flash of insight developed by interconnecting various elements in the given problem will help to find out the solution. The Cognitive approach (began in late 1950) integrates the positive features of the above two approaches. To them problem solving involves a series of mental processes to solve a problem.

2.3.2 Problem Solving Skills

Problem-solving requires application of a previously learned theory by the solver (Heller, Keith and Anderson, 1992; Schultz & Lockhead, 1991; Foster, 2000). This requires analytical capacity that is a capacity to analyze a problem and solve it.

The Problem Solving Ability depends on the nature and familiarity of the Problem, the mental set and past experience of the Problem Solver, positive
attitude (Interest, motivation and confidence) and cognitive ability of the Problem Solver (Knowledge, memory and metacognition). Skills involved in Solving Problems are Reading, Writing, Understanding, Organizing, Tabulating, Relating, Discovering and interpreting the data given, questioning, developing concepts, attaining concepts, doing Problems in a systematic way with sequential order, identifying relationships between the known and the unknown, from the empirical experience and constructing knowledge from the data. Thinking skills like Logical thinking, Divergent thinking, Reflective thinking, Creative thinking, Decision making are necessary to approach problems in a novel way. Skills of obtaining accurate and precise answers, doing problems quickly in an efficient manner, Concentration, Observation, Discussion, Self Learning and Stating the specific problem effectively are also required for effective Problem Solving. If skills required for solving problems are properly cultivated through the teaching of Science, the student can apply this skill to solve problems in his personal and social life.

The skill of solving problems has been used in Science Education for many years mainly as a tool which enables teachers to evaluate students’ ability to transfer concepts and understanding from the classroom to the real life situations. When he solves problems by himself, teaching and learning are said to be effective. In solving Problems both the hemispheres are involved. The logical analytical aspect of the problem will be dealt by the left hemisphere and the intuitive-holistic aspects by the right hemisphere. Finding a solution to problems, or finding a novel solution which is superior to known solutions will certainly be an act of creativity. So in order to solve problems one should have the ability to think creatively.

Teaching students problem solving skills helps to 1) increase scientific process skills 2) boost students understanding of physics content 3) help retain physics content in memory 4) improve students’ achievement and 5) improve the achievement of students' attitude and motivation.
2.3.3 Theoretical Formulations of Problem Solving

The various theories so far known related to problem Solving is presented below.

1. *Dewey's Description Theory of Problem Solving*

Dewey (1933) characterised thought as a Problem Solving behaviour. This conception emphasizes that thought may have grown out of man's need to adopt himself to a difficult and often hostile environment. Dewey remarks that reflective thinking begins when there is doubt that leads to a search for material that will resolve the doubt and dispose the perplexity. The first phase is the pre-reflective which establishes the nature of the problem to be solved. The last phase is the post-reflective which result in a feeling of mastery and satisfaction, between these two phases are the states of thinking which include - suggestions in which the mind anticipates possible solutions, recognition of the nature of the problem, use of hypothesis to initiate and guide the search for relevant material, mental testing of the hypothesis and actual testing of hypothesis.

2. *Cognitive and Gestalt views on Problem Solving*

Gestalt psychologists and other holistically oriented psychologists have pointed to the integrative aspects of thought, the ways in which our understanding of a problem, and of the tools that may lead to its solution is more than a sum of the parts. It can be restructured by the interactions among the parts and by the unique whole, including attention, set and expectations and even by the whole past experience and personality of the person attempting a solution.

3. *Duncker’s Funnelling theory of Problem Solving*.

Duncker (1945) proposed a new explanation on the nature of Problem Solving. According to him, Problem Solving consists of series of restatements of the problem – which finally narrow down to a statement until the final solution is reached. His analysis shows that when an individual starts solving problem, his concepts can be described as progressing through three major
stages - from the general range, through a functional solution to a specific solution.

4. **Gagne's theory of hierarchy of learning**


6. **Mayers Design for Teaching Problem Solving**

   According to Mayer (1992) Problem Solving can be taught and can be strengthened through training and exercise (eg., mathematical problem-solving skill or language skill). Second, Problem Solving can be taught by emphasizing the product of Problem Solving (namely, getting the right answer), or by emphasizing the process of Problem Solving (that is the method or steps that one goes through to arrive at an answer). Third, Problem Solving can be taught in a general, in hope of promoting transfer across many domains or within the context of specific subject domains such as mathematics, social studies, or writing, with the expectation that students are generally able to apply a problem-solving strategy only within a particular domain. Mayer suggests that Problem Solving is most effectively taught when the focus is on teaching the component skills rather than a single general ability, on process rather than product, and on domain-specific rather than context-free settings.

**2.3.5 Strategies, Models and Approaches in Problem Solving**

1. **Serway and Jewett’s Approach in Problem Solving**

   Serway and Jewett developed a general problem solving strategy which constitute the following steps:
1) Conceptualize – Read the problem several times until you understand it, draw diagrams if necessary, focus on the numerical information given, focus on the variable to be calculated, incorporate information from your knowledge.

2) Categorize – simplify the problem by removing the unwanted details, assign values to variables, lay out a plan to solve it.

3) Analyze – Select the equation, calculate the result

4) Finalize – Check the answer, its units and symbols

2. Young and Freedman’s (2008) approach

As cited in Fink and Mankey (2010), Young and Freedman identified an approach to Problem Solving which contained the following steps 1) identify, 2) set up, 3) execute and 4) evaluate.

3. Tipler and Mosca’s (2007) approach

As cited in Fink and Mankey (2010), The Tipler and Mosca’s approach in Problem solving includes 1) picture, 2) solve, and 3) check.

4. Explicit Problem-Solving Strategy (EPSS)

EPSS help to improve students problem solving performance better than traditional method (Heller, Keith, and Anderson 1992; Van Heuvelen, 1991a & b; Larkin and Reif, 1979). It has five steps as follows; Focus a problem, describe the problem, Plan the solution, Execute the plan and evaluate the solution.

5. Greeno’s (1973) five-state model

As cited in Ogunleye (2011), Greeno proposed a five state model which contained five steps such as reading the text, interpreting the concepts, retrieving relevant information from long-term memory, constructing a solution plan, and carrying out the operations required to solve the problem.

6. Polya’s prescription for solving problems

Polya (1957) proposed four steps in Problem Solving. They are

1. Understanding the problem- Ask yourself, What you are looking for? and What is given in the Problem?
2. Devising a plan for solving the problem – Check whether you know similar problems, Restate the Problem and carry out the operation.

3. Looking Back - Check What the result indicate

7. Schoenfeld approach to Problem Solving

Schoenfeld (1992), investigated expert and novice problem-solving behaviour and based on this, he proposed five steps in Problem Solving. They are

1. Survey the problem (read, analyse)
2. Activate student’s prior knowledge (explore)
3. Make a plan (plan)
4. Carry out the plan (implement)
5. Check the answer (verify the answer)

8. KD Model and ME Model of Problem Solving

According to Wenning (2002) and Chi et al., (1981), there exist difference among the problem solving between experts and novices. This lead to the formulation of two major models for problem solving. According to Larkin et al. (as cited in Wenning, 2002), expert problem solving is typified by the KD model, the so-called knowledge-development approach whereas novice problem solving is typified by the ME model, the so-called means-end approach. In the ME model the student typically works "backward" from the unknown to the given information. Under this scenario the novice problem solver (NPS) essentially writes an equation and then associates each term in the equation with a value from the problem. In the KD model the expert proceeds in the opposite direction, working forward from the given information.

9. Bransford’s 'ideal' thinking strategy.

Bransford and Stein (1993) list the 5 steps that they believe lead to effective Problem Solving: Identify, Define, Explore, Act and Look and Learn. It may be noticed that the first letters of the steps spell "ideal". To apply this strategy one should identify the problem, define it clearly and then explore the
possible solution and relevant knowledge. Next he should act by trying a possible solution or hypothesis. Finally he should look at the result and learn from them. Of course each attempted solution may identify sub problems. These can again be tackled with the 'ideal’ steps until a final satisfactory solution is found.

2.4 CRITICAL THINKING

Everyone thinks, it is our nature to do so. But much of our thinking is biased, partial, distorted or uninformed. Yet the quality of our life depends on the quality of our thought. Good thoughts were goal directed, self corrective and based on evidence. It never stick on to a particular mode of thinking but uses a variety of thinking based on the nature of the problem. Those varieties include scientific thinking, moral thinking, philosophical thinking, mathematical thinking, economic thinking etc. The person who uses different modes of thinking for solving a problem is called a critical thinker and the process is called critical thinking.

Critical thinking is considered as a 21st century skill. But it is a concept that has been developing throughout the past 2500 years. The intellectual base of critical thinking was laid by Socrates, who discovered a method of probing questions, which is now known as ‘Socratic Questioning’ – the best critical thinking teaching strategy ever known. John Dewey, the American Philosopher, Psychologist and educator is considered as the father of Modern ‘Critical Thinking’(as cited in Fisher, 2001). He called it as ‘Reflective Thinking’ and defined it as ‘Active, Persistent and careful consideration of a belief or superpose form of knowledge in the light of the grounds which support it and further conclusions to which it tends.’ In the middle of the twentieth century, the term critical thinking was introduced by B. Othanel Smith (as cited in Buffington, 2007) as a process for evaluating the accuracy of information.
2.4.1 Philosophical and Psychological view of Critical Thinking

There are many variations on the definition of critical thinking. Researchers’ views also differ on whether critical thinking is an ability to solve problems or to construct new knowledge (Orszag, 2015). The definition of Critical thinking solely depends on the area of research. For example, according to Educational researcher Ennis (1985, p.45), “critical thinking is reflective and reasonable thinking that is focused on deciding what to do or believe.” Siegel (1990), who is influenced by educational philosophy, defines critical thinking as rational thinking or “being moved by reasons”. These definitions highlight the different emphasis that researchers put on particular aspects of critical thinking (as cited in Orszag, 2015). Thus there is philosophical and psychological view of Critical thinking. The philosophers emphasis is on the nature and quality of critical thinking and the psychologists focus on the cognitive process and components used to investigate the problems. The following are some of the definitions of Critical Thinking offered by various scholars.

Critical Thinking is the ability to analyze facts, generate and organize ideas, defend opinions, make comparisons, draw inferences, evaluate arguments and solve problems (Chance, 1986, p. 6);

Critical Thinking is a reasonable, reflective thinking that is focused on deciding what to believe or do (Norris and Ennis, 1989).

Critical Thinking is a conscious and deliberate process which is used to interpret or evaluate information and experiences with a set of reflective attitudes and abilities that guide thoughtful beliefs and actions (Mertes, 1991, p.24);

Critical Thinking is the intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information gathered from, or generated by, observation, experience, reflection,
reasoning, or communication, as a guide to belief and action (Scriven & Paul, 1992);

According to Scriven, Critical Thinking is skilled and active interpretation and evaluation of observations and communications, information and argumentation. (Fisher and Scriven, 1997).

According to Critical Thinking Cooperation (2006) critical thinking is an ability which is beyond memorization. When students think critically, they are encouraged to think for themselves, to question hypotheses, to analyze and synthesize the events, to go one step further by developing new hypotheses and test them against the facts. Questioning is the cornerstone of critical thinking which in turn is the source of knowledge formation and as such should be taught as a framework for all learning.

The art of thinking about thinking in order to make thinking better” Paul and Elder (2008)

2.4.2 Critical Thinking Skills

Critical thinking is the ability to make wise and unbiased decisions by carefully analyzing the facts, data or evidence related to a problem or a situation. So it is not a single skill, but encompasses a group of skills based on the nature of the problem. In this session we are going to discuss about the Critical thinking skills listed by various scholars.

Edward Glaser listed the following abilities which he see as basic to Critical Thinking (Glaser, 1941,p.6). They are to recognize problems, to find workable means for meeting those problems, To gather and marshal pertinent information, To recognize unstated assumptions and values, To comprehend and use language with accuracy, clarity and discrimination, To interpret data, To appraise evidence and evaluate statements, To recognize the existence of logical relationships between propositions, To draw warranted conclusions and generalizations, To put to test the generalizations and conclusions at which one
arrives, To reconstruct one’s patterns of beliefs on the basis of wider experience, To render accurate judgments about specific things and qualities in everyday life.

Fisher (2001) listed the following skills as the fundamental Critical Thinking skills such as Identify the reasons and conclusions, Identify and evaluate Assumptions, Clarify and Interpret Expression and Ideas, Judge the acceptability and credibility of claims, Evaluate arguments of different kinds, Analyse, Evaluate and Produce Explanations, Analyse, Evaluate and Make decisions, Draw inferences and produce Arguments

“One of the most comprehensive multidisciplinary research that tried to identify critical thinking skills was conducted by Facione in 1990. Facione asked 46 experts in the USA and Canada to identify and describe core critical thinking skills. The experts were composed of males and females from various disciples (Facione, 2013). Facione used the Delphi Method, which used a central investigator to question these experts. The central investigator then summarized all of the responses, grouped them into categories, and then asked the experts to comment on them. This limited the authority of some experts that could influence the other experts (Facione, 2013). Altogether six core skills were identified in the study: interpretation, analysis, evaluation, inference, explanation, and self-regulation (Facione, 2013, p. 9.).

**Interpretation** means being open-minded and to understand various phenomena, as well as considering different cultural or individual perspectives that can shape each phenomenon.

**Analysis** refers to identifying stated and unstated relationships between ideas from different sources in order to evaluate information and evidence, gain different perspectives, or to solve problems.
**Evaluation** is used to determine if a stated or unstated statement or argument is valid. This is done by looking at the evidence and taking into account different perspectives and relationships between the statements.

**Inference** is being aware of unstated or stated views and to be able to use these views to form conclusions, hypotheses, or judgments.

**Explanation** is demonstrating one’s thoughts in a rational manner, providing clarity and accuracy, so that these thoughts cannot be misinterpreted.

**Self-regulation** refers to monitoring one’s own thoughts, being aware of personal biases, and understanding the reasoning behind one’s own thinking” (as cited in Orszag, 2015)

Halpern (2010) identified five critical thinking skills such as Decision Making and problem Solving – Decision making is the process of generating and selecting from alternatives based on criteria and problem solving is finding solutions to a situation.

**Thinking as Hypothesis Testing** –

**Argument Analysis** – The ability to seek and provide reasons and to recognize the differences between conclusions and assumptions is critical for good thinking. It is the difference between uninformed opinions and reasoned thinking.

**Likelihood and Uncertainty** - A basic understanding of probabilities and how they affect the likelihood of an outcome and how to use probabilities in uncertain situations are an essential component of critical thinking, but these skills are unlikely to develop beyond a rudimentary level without formal instruction.

**Verbal Reasoning** - The ability to understand how natural language influences thinking is also an essential component of critical thinking
2.4.3 General and Specific Critical Thinking Skills

Critical thinking can be general or specific. General Critical thinking is the ability to reasonably respond to CT tasks that do not necessarily require specific content knowledge, but require knowledge of everyday life (Tiruneh, et al., 2015). Subject specific Critical thinking is essential to enhance a student’s individual subject knowledge and to unlock the unique and complex mysteries of each subject. It is necessary to apply the learned concepts to new and unfamiliar situation. The ability to think critically is understood to be highly dependent on specific content knowledge, and thus an in-depth knowledge and understanding of a particular domain is required for competent performance in various thinking tasks (Davies, 2013).

According to Tiruneh, et al. (2015) both general and Specific CT tests need to be administered for an accurate and comprehensive understanding of the development of CT. Moreover, in order to accurately examine the transferability of CT skills acquired in a specific subject (e.g. Physics) to everyday life problems, both specific and general CT tests need to be administered. For example, If a general CT test targets problem-solving and reasoning skills in the context of real-life situations, a parallel specific CT test that targets the same CT skills within the context of a specific subject needs to be administered. Such practice to develop specific and general CT tests would make it possible for researchers and educators to test for near and far transfer of CT skills (Tiruneh, et al., 2015)

2.4.4 Critical Thinking in Education

One of the major aims of education is to create learners who are well informed, i.e. they should be able to discriminate the ideas that are useful and not. Another is to create learners who have the desire to think analytically and critically, to use what they know to enhance their own lives and to contribute to their society, culture and civilization. Education is futile if it does not enable the harmonious development of Physical, mental, social and moral abilities of
an individual. According to Meyer (1976) the aim of education is to nurture the individual, to help, to realize the full potential that already exists inside him or her. To realize the inner potentialities he should possess strong thinking abilities beyond mere memorization. As Cotton (1991) indicates: “If students are to function successfully in a highly technical society, then they must be equipped with lifelong learning and thinking skills necessary to acquire and process information in an ever changing world”. Also they must be able to transfer the learned concepts to new and unfamiliar situations. Also, education must prepare individuals who are able to think well and for themselves. This will be possible only if one possess strong critical thinking skills.

Critical thinking is a term used by educators to describe forms of learning, thought, and analysis that go beyond the memorization and recall of information and facts. Both learning and thinking are the concepts which support and complete one another. If anyone combines learning and critical thinking, then this will make wonders in his life. In common usage, critical thinking is an umbrella term that may be applied to many different forms of learning acquisition or to a wide variety of thought processes. Critical thinking occurs when students analyze, evaluate, interpret, or synthesize information and apply creative thought to form an argument, solve a problem, or reach a conclusion. Ct skills is considered as the 21st century skills (Orszag, 2015) which is most essential they will need to be successful in higher-education programs and modern workplaces. This session can be summarized in the words of Martin Luther King (1947), “Education must enable one to sift and weigh evidence, to discern the true from the false, the real from the unreal and the facts from the fiction. The function of education, therefore, is to teach one to think intensively and to think critically.”

2.4.5 Characteristics of a Good Critical Thinker

Critical thinking is not universal. No one is born as a critical thinker. In the course of time, everyone is subjected to episodes of undisciplined or
irrational thoughts. Its quality determines whether he is a critical thinker or not. This quality is merely based on his experience throughout his life. So the development of CT skills is a lifelong process.

According to Reichenbach (2002) Critical thinking involves using a cluster or group of interconnected skills to analyze, creatively work with, and evaluate what you read and hear so that you can decide whether or not to believe something or to take a specific action. Fisher (2011) defined critical thinking as an active process in which you think things through yourself, raise questions yourself, find relevant information yourself, etc rather than learning in a passive way from someone else. From these definitions it is clear that a good critical thinker follows certain characteristics. Reichenbach (2002) listed the following characteristics of a good critical thinker.

- Raises relevant questions pertaining to the problem.
- Accurately interprets information, statements, problems, graphs etc.
- Make deductions from the general ideas to solve a particular problem.
- Discriminate things.
- Analyses and evaluates information.
- Develop insights.
- Recognize underlying assumptions.
- Suggests alternative solution to a particular problem.
- Justifies inferences and opinions.
- Active listeners and Communicates effectively with others regarding the problem.
- Provides positive as well as negative appraisal.
- Examines and evaluates the arguments carefully.
- Open minded – consider the view points of others.
- Intellectually honest – accepts their lack of knowledge.
- Willing to change the position when the evidence is sufficient to do so.
- Love truth and curious about a wide range of issues.
Objective – They identify the goal, stay focused and never let their emotions to cloud their judgement.

Self – Confident in one’s own reasoning.

Observe the relationship between ideas.

Able to apply the CT skills to wide variety of subjects.

Transforms ideas to new and unfamiliar situation.

Critical thinking individuals are people who research, question, refuse the information’s as it is, active, think analytically and synthesis, evaluate the information and explain with true basis, treat open-minded and aware of thinking processes (Karakoc, 2016). Paul and Elder (2008) revealed a list about the characteristics of critical thinkers. They are, Raises vital questions and problems, formulating them clearly and precisely; Gathers and assesses relevant information, using abstract ideas to interpret it effectively; Comes to well-reasoned conclusions and solutions, testing them against relevant criteria and standards; Thinks open-mindedly within alternative systems of thought, recognizing and assessing as need be, their assumptions, implications, and practical consequences; Communicates effectively with others in figuring out solutions to complex problems. (Paul & Elder, 2008, p. xxiii)

2.4.6 Development of Critical Thinking

Development of student critical thinking skills is dependent on many variables, including the learning environment, the social context of learning, and the teaching style of the instructor (as cited in Brahler, Quitadamo and Johnson, 2002). It also occurs through various stages. The development of Critical Thinking can be discussed under the following heads.

Stages in the Development of Critical Thinking

Some researchers have even identified stages that critical thinkers progress through (Elder & Paul, 2010; King & Kitchener, 2004). Some of them are discussed below.
Garrison developed a theory of critical thinking, as a kind of problem-solving process (Garrison 1992). According to him, Critical thinkers move through 5 stages, identifying a problem, defining it more clearly, exploring the problem and possible solutions, evaluating their applicability, and then integrating this understanding with existing knowledge.

**Stage 1: Problem identification** - Students start by identifying a problem and gather information on it.

**Stage 2: Problem definition** - In the problem definition phase students define problem boundaries, ends, and means. At this point students brings information from textbooks or own experience to clarify the problem.

**Stage 3: Problem exploration** - The phase of problem exploration can be regarded as the creative generation of new ideas, since it is the most creative part of the critical thinking process. Here students have to explore the problem and possible solutions. They use both logical reasoning and creative thinking to extend their understanding beyond the basic problem definition (Newman et al., 1995). Moreover, this is the phase were students come with new ideas.

**Stage 4: Problem evaluation/applicability** - In the fourth stage, students critically evaluate possible solutions, link ideas together, and try to find out if these proposed solutions can work in practice. Judgmental skills like making decisions, statements, appreciations, evaluations, and criticisms are needed in this phase.

**Stage 5: Problem integration** - In this stage, students integrate the solutions into existing knowledge, they need to validate the solution within the group. This is the stage where the solutions are grounded in the real world. This requires feedback.

King and Kitchener (2004) have developed the Reflective Judgment model, which mention the seven stages of development of critical thinking that can be grouped into three levels:

- **The pre-reflective level** (stages 1-3) - The pre-reflective level is when students think that there are absolute answers to questions, and that knowledge is certain. Here “knowledge is gained through the word of an authority or through first hand observation, rather than, through the evaluation of evidence. Also they believe that what they know is absolutely correct” (King & Kitchener, 2002, p. 39).

- **The quasi-reflective thinking level** (stages 4 and 5) - Here students start to recognize that knowledge is individually constructed. "knowledge contains elements of uncertainty, and try to obtain the evidence through various methods. Although they use evidence, they do not understand how evidence entails a conclusion" (King and Kitchener, 2002, p. 40).

- **The reflective level** (stages 6 and 7) - The last level is reflective thinking, when individuals consistently and confidently use evidence to support their conclusions. They accept "that knowledge claims cannot be made with certainty, rather, they make judgments that are "most reasonable" based on their evaluation of available data. They believe they must actively construct their decisions. They also readily admit their willingness to re evaluate the adequacy of their judgments as new data or new methodologies become available" (King & Kitchener, 2002, p. 40).

Critical thinking Stages by Elder and Paul (2010)

These stages in the intellectual development of the critical thinker are paraphrased from the article “Critical Thinking Development: A Stage Theory” by Linda Paul and Richard Elder, available at www.criticalthinking.org.
Stage One: *The Unreflective Thinker* - Unreflective thinkers are largely unaware of the determining role that thinking is playing in their lives. Unreflective thinkers lack the ability to explicitly assess their thinking and improve it thereby. They do not identify concepts or assumptions behind ideas, and they rarely assess the logic of their opinions or conclusions. They may have developed some skills in thinking (compare and contrast, analyze, conclude, etc). These thinkers are unable to adopt new strategies to solve problems.

Stage Two: *The Challenged Thinker* - These thinkers have become aware of the role thinking in their lives. They recognize that productive thinking requires effort and deliberate attention. They have an understanding of the basic elements of reasoning (concepts, assumptions, questions at issue, purpose, point of view, information, implications and consequences, etc.) and standards for the assessment of thinking (clarity, accuracy, relevance, etc). They believe that they have critical thinking abilities, but they may not recognize that they apply these critical thinking abilities inconsistently in their lives, thus making it harder for them to improve their thinking skills.

Stage Three: *The Beginning Thinker* - These thinkers try to enhance the quality of their thinking in several areas of their lives. They take deliberate measures to monitor and improve their thinking. They are aware of the need to assess and improve their thinking, but they “lack a systematic plan for improving their thinking. These thinkers are aware of the elements of reasoning and the standards for assessing reasoning, and they understand the need to internalize these and begin using them consistently. They welcome critiques of their own thinking and know that their thinking needs to be self-monitored.

Stage Four: *The Practicing Thinker* - Thinkers at this stage not only recognize that problems exist in their thinking, but they also recognize the need to attack these problems globally and systematically. Based on their sense of
the need to practice regularly, they are actively analyzing their thinking in a number of domains. However, since practicing thinkers are only beginning to approach the improvement of their thinking in a systematic way, they still have limited insight into deeper levels of thought, and thus into deeper levels of the problems embedded in thinking.

**Stage Five: The Advanced Thinker** - Thinkers at this stage have now established good habits of thought which are “paying off.” Based on these habits, advanced thinkers not only actively analyze their thinking in all the significant domains of their lives, but also have significant insight into problems at deeper levels of thought. These thinkers have a well-developed sense of their own egocentric nature, and they strive to be fair-minded. They have a developed understanding of the relationships between thoughts, desires, emotional needs, and feelings. Though they understand that egocentrism will always play a role in their thinking, they are able to control the extent of their egocentrism through careful monitoring of their thoughts.

**Stage Six: The Accomplished Thinker** - Accomplished thinkers not only have systematically taken charge of their thinking, but are also continually monitoring, revising, and re-thinking strategies for continual improvement of their thinking. They have deeply internalized the basic skills of thought. Through extensive experience and practice in engaging in self-assessment, accomplished thinkers are not only actively analyzing their thinking in all the significant domains of their lives, but are also continually developing new insights into problems at deeper levels of thought. Accomplished thinkers are deeply committed to fair-minded thinking, and have a high level of, but not perfect, control over their egocentric nature.

**2.4.7 Teaching Critical Thinking**

Several researchers claim that the development of critical thinking happens naturally parallel with getting older and gaining more educational experience although the reasons behind it and the way it happens are still
unknown (Flores, Matkin, Burbach, Quinn, & Harding, 2012; King & Kitchener, 2002). Most researchers argue that critical thinking is not necessarily natural, but it can be developed in the classroom (Barnett & Francis, 2012; Ennis, 1989; Facione, 2013; Prawat, 1991; Smith, 2001; Tsui, 1999). According to Butler (2017) critical thinking can improve with training and the benefits have been shown to persist over time. Also he argued that anyone can improve their critical thinking skills. According to Walsh and Paul (1988), critical thinking is a skill which can be developed. In short we can say that, critical thinking is a skill that can be developed in the classroom if there is proper training. Now we are going to discuss the possible ways to improve the critical thinking skills along with classroom learning.

As cited in Karakoc (2016), there are several ways of organizing instruction in critical thinking: Some of them are discussed below.

✧ **Instructional approaches to teach Critical Thinking by (Ennis, 1989)**

Ennis (1989) put forward some instructional approaches to teach Critical Thinking skills. They are,

- **General /stand-alone** approach: Critical Thinking is taught separately as a general course.
- **Infusion** approach: Critical Thinking is taught related to a particular subject matter. Students are encouraged to think critically by making principles and strategies of critical thinking explicit.
- **Immersion** approach: Similar to the infusion approach, but critical thinking strategies and principles are not made explicit.
- **Mixed-methods** approach: It is the combination of general approach and the infusion or immersion approach. Here Students are introduced to critical thinking in a general course, and then apply the principles and strategies in subject-specific courses.

Among the four approaches, the most popular course structure that is used to develop students’ critical thinking is based on the principles of the immersion approach. This could be because it is the most widely studied and it
Conceptual Framework

does not require the explicit teaching of critical thinking. Behar-Horenstein and Niu (2011) stated that fifty-two percent of the empirical studies that they examined in their literature review of critical thinking investigated courses adopting the immersion approach at the undergraduate level. In fact, some researchers have found that the immersion approach produced the lowest percentage of students’ critical thinking development compared to other approaches (Barnett & Francis, 2012; Behar-Horenstein & Niu, 2011).
Also there seems to be very little research on the infusion and the mixed-methods approaches.

- Instructional approaches to teach Critical Thinking by Halonen (1995)

Halonen (1995) has identified three main approaches to teach Critical thinking in Classrooms. They are,

1. The trait or dispositional approach: it sees critical thinking as an innate ability that will naturally develop over time.

2. The emergent approach: underpinned by Piaget’s ideas, this approach views critical thinking as emerging when one interacts with the environment.

3. The state approach: it focuses on the demonstration of critical thought with the focus being on skills (typically listed by a national educational organization). This approach focuses more on testing than the process of critical thinking itself.

From the above discussions it is clear that Critical thinking can be developed in the classroom, also it takes place through various stages. Halonen (1995) reminds us that when students are first introduced to critical thinking, it can be overwhelming for them, so it is important to adjust these classes to the level of the students. She recommends developing foundation skills (e.g. identifying assumptions) first and slowly incorporating more complex skills (e.g. problem solving). Similarly, some researchers have argued that the course structure might not be as important in developing critical thinking as classroom
instruction (Tsui, 1999). Behar-Horenstein and Niu (2011) found that the critical thinking were more strongly influenced by the instructor than the approach itself. Critical thinking skills can be developed, if instructors encourage students to use them in various tasks and if they provide examples from daily life (VanderWal, 1999). This suggests that teachers seem to have a crucial role in developing students’ critical thinking.

2.4.8 Teacher and Critical Thinking

The instructor plays an important role in cultivating critical thinking skills, as well as serving as the domain-specific content expert. Effective teachers facilitate student critical thinking skill development when they implement learning activities that have authentic, real-world contexts and personal relevance to the student (Andrews, 1996). If a teacher itself demonstrates critical thinking skills, students can use teacher as a model which may help them to develop their own critical thinking skills. Jenkins’s (2011) findings show that teachers who feel more confident in their own critical thinking tends to use more critical thinking in the classroom compared to teachers who are less confident.

According to (Bonnstetter, 1988 and Elder & Paul 1997), well designed, open-ended questions and investigative activities by the instructor facilitates students critical thinking. They also argued that instructors promote critical thinking when they 1) pose questions that have more than one correct answer, 2) provide an appropriate length of time for students to think before responding, and 3) avoid asking questions that require only a “yes” or “no” response.

Barak and Shakhman (2008) identified three types of teachers when researching teachers’ use of critical thinking in the classroom:

1. False users: teachers who have an idea of how to promote deeper cognitive processes but use contradictory instruction. These teachers synthesize the information for the students instead of allowing the students to reflect on different perspectives or trying to find the key
points. If this approach is used in the class, students cannot develop higher order thinking skills, such as synthesizing, and could develop a reliance on others.

2. **Instrumental users**: teachers who incorporate critical thinking into the class occasionally as a way to raise students’ achievement or to meet course requirements. They have the underlying belief that by teaching the content students will develop critical thinking, and thus they rarely use activities explicitly focusing on critical thinking in class. This is similar to the immersion approach, which puts more emphasis on the content, giving students the impression that more content knowledge will make one a better thinker.

3. **Intended users**: teachers who feel that developing students’ cognitive abilities is one of the major goals of the course. They were able to explain why they did a particular activity and were able to name the skills that students should develop through that activity. These teachers were more aware of how to use talk and reflection in their teaching. One of the goals of critical thinking is to be able to reflect on one’s own thoughts and actions.

To summarize this section, teachers need to be aware of critical thinking if they are incorporating critical thinking into their classroom, which also includes identifying what type of thinkers they are. Teachers also need to be aware of students’ critical thinking ability, which could influence what types of critical thinking activities they use in the classroom. These two factors are crucial for teachers to reflect on if they want to incorporate more thinking into the classroom and develop students’ abilities. Teachers must also be patient with students because some students will develop faster than others, but this does not mean that students cannot develop into critical thinkers. Barak and Shakhman (2008) emphasize that teachers’ knowledge, beliefs, and instructional behaviour are all related. Therefore, teachers should be aware of
this interrelatedness and adjust their teaching practice so that they can more effectively promote critical thinking in the classroom.

**2.4.9 Strategies to Develop Critical Thinking in the Classrooms**

Various Strategies, methods and techniques are identified so far to develop Critical thinking among students. They are described below

- **Cooperative Learning Strategies:**
  According to Cooper (1995), learning in group is the best way to foster critical thinking. "In properly structured cooperative learning environments, students perform more of the active, critical thinking with continuous support and feedback from other students and the teacher".

- **CAT (Classroom Assessment Techniques):**
  According to Angelo (1995) the use of classroom assessment techniques facilitate students' critical thinking. An example of is to ask students to write "One Minute Paper" regarding "What was the most important thing you learned in today's class? Which part of this session remains uppermost in your mind?"

- **Questioning:** According to King (1995) the following two types of questioning promotes Critical Thinking in Classrooms.

  *Reciprocal Peer Questioning:* After delivering contents through Lecture, the teacher asks questions such as, "What are the strengths and weaknesses of.....?". students discusses the questions in small groups. Then, the whole class discusses the questions from each small group

  *Reader's Questions:* Students write questions on assigned reading and present them at the beginning of the class. Then few questions were selected which acts as the momentum for class discussion.
• **Case Study /Discussion Method:**
  According to McDade (1995) facilitates Critical Thinking. The teacher presents a case (or story) to the class without a conclusion. Using prepared questions, the teacher then leads students through a discussion, allowing students to construct a conclusion for the case.

• **Use Writing Assignments:**
  According to Wade (1995), writing is fundamental to the development of Critical Thinking skills. "With written assignments, an instructor can encourage the development of dialectic reasoning by requiring students to argue both sides of an issue".

• **Dialogues:**
  Robertson and Rane-Szostak (1996) identified two methods of conducting dialogue based discussions in the classroom:

  *Written dialogues:* Give students written dialogues to analyze. In small groups, students must identify the different viewpoints of each participant in the dialogue. Must look for biases, presence or exclusion of important evidence, alternative interpretations, misstatement of facts, and errors in reasoning. Each group must decide which view is the most reasonable. After coming to a conclusion, each group acts out their dialogue and explains their analysis of it.

  *Spontaneous Group Dialogue:* One set of students were assigned roles to play in a discussion (such as leader, opinion seeker, information giver and disagreeer). Four observer groups were formed to determine what roles are being played by whom, identifying biases and errors in thinking, evaluating reasoning skills, and examining ethical implications of the content.

• **Conference Style Learning:**
  The teacher does not "teach" the class through lecture, instead acts as a facilitator of conference. Students should read all required material
before starting the class. Assigned readings should be in the zone of proximal development. That is, the reading should be understood by students. Then students ask questions each other and discuss these questions. The teacher helps, "direct and mould discussions by posing strategic questions and helping students build on each others' ideas" (Underwood & Wald, 1995, p. 18).

- **Ambiguity:**
  To enhance Critical Thinking in Classrooms, Strohm & Baukus advocate to produce much ambiguity in the classroom. They suggest not to give students clear cut material. Instead, give them conflicting information that they must think their way through.

2.4.10 Advantages of Critical Thinking

Elder and Paul (2010) identified the following advantages of Critical thinking

- If students (in general) possess strong CT skills then they:
  - learn content at a deeper and more permanent level
  - are better able to explain and apply what they learn,
  - are better able to connect what they are learning in one class with what they are learning in other classes,
  - ask more and better questions in class,
  - understand the textbook better,
  - follow directions better,
  - understand more of what you present in class,
  - write better,
  - apply more of what they are learning to their everyday life,
  - become more motivated learners in general,
  - become progressively easier to teach.

2.4.11 Assessment of Critical Thinking

Several tests are there to measure Critical Thinking. The details of the Internationally accepted five Critical Thinking Tests are given below.

The Watson-Glaser Critical Thinking Appraisal measures five skills-Inference, Recognition of Assumptions, Deduction, Interpretation and Evaluation of Arguments using five sub tests. There are a total of 80 items of 40 minutes duration. The test is suitable for individuals of Grade 9 and above.

b. Cornell Critical Thinking Test (CCTT Ennis, Millman and Tomko, 1985)

The Cornell’s Critical Thinking test is based on Ennis conception of Critical Thinking. The test is available in two levels-X and Z. Level X contain 71 Multiple Choice Item and is suitable for students in Grades 5 to 12. It measures the following skills such as Induction, Deduction, Credibility and Identification of Assumptions. Level Z contains 52 Multiple Choice Item prepared for highly gifted high school students, College students and other adults. It measures the following skills such as Induction, Deduction, Credibility and Identification of Assumptions, Semantics, Definition and Prediction.

c. California Critical Thinking Skills Test (CCTST, Facione-1990)

This test is designed for Under graduate and Graduate level students. It contain 34 Multiple Choice Questions and measures the following Critical Thinking skills such as Analysis, Evaluation, Inference, Inductive and Deductive Reasoning.

d. Ennis-Weir Critical Thinking Essay Test (EWCTET, Ennis and Weir-1985)

This follows an open – ended essay based assessment of Critical Thinking. It measures the ability to analyse, respond and evaluate to arguments and debates in real world situations.

e. Halpern Critical Thinking Assessment (HCTA, Halpern- 2010)

This test also utilizes the open – ended format. It consist of 25 open ended questions based on everyday situations. The test measures the following skills such as Hypothesis Testing, Verbal Reasoning, Argumentation, Judging likelihood and uncertainty and Problem Solving.
2.4.12 Critical Thinking and Some Related Terms

There are certain variables like metacognition, Intelligence Analytical thinking etc that gets confused with the term Critical Thinking. Let us compare and contrasts these terms with critical thinking.

- **Critical thinking and Metacognition**

  Metacognition refers to thinking about thinking. According to Cross and Paris (1988), metacognition is “the knowledge and control children have over their own thinking and learning activities” and “the monitoring and control of thought” (Martinez, 2006) and “awareness of one’s own thinking, awareness of the content of one’s conceptions, an active monitoring of one’s cognitive processes, an attempt to regulate one’s cognitive processes in relationship to further learning” (Hennessey, 1999). Flavell (1979) takes critical thinking as a ‘construct’ of metacognition. He explains, “critical appraisal of message source, quality of appeal, and probable consequences needed to cope with these inputs sensibly” can lead to “wise and thoughtful life decisions”. On the other hand, some scholars such as Facione (1990) and Schraw, Crippen & Hartley (2006) claimed that metacognition is all about self-regulation which defines “our ability to understand and control our learning environments. Thus metacognition is only a part of Critical Thinking.

- **Critical thinking and Creativity**

  According to Paul and Elder (2006, p. 34.), these two concepts cannot be separated, and in fact, they should be viewed as different aspects of thinking. Creativity involves creating something new or original and critical thinking involves logic and reasoning. Creativity is related to right hemisphere of the brain whereas CT is mainly related to the left part. According to Paul and Elder (2007) while Creativity masters is a process of making or producing, CT is a process of assessing or judging. Although there is a difference between creativity and critical thinking, but a good thinking process requires both. A
Critical thinker gathers, analyzes, examines, and evaluates information; a critical thinker can also distinguish between opinion and fact. (Paul and Elder, 2007) Critical thinkers are influenced by straightforward information and detail, and they play a key role in our thought processes. Creative thinkers come up with ideas and look at things from different perspectives, and these types of thinkers make typical connections and look at things in new ways. A creative thinker "takes risks" and goes against the normal viewpoint. A hallmark of critical thinkers is their openness and their disposition to deal with complexity, searching for alternatives that are not readily available, being willing to make errors and try again because their goal is not to have absolute right answers (Ruggiero, 2004). Creative thinking means creation and CT means analysis. Both, when used in conjunction, can create a powerful process of higher order thinking.

**Critical Thinking and Analytical Thinking**

Analytical thinking is the mental process of breaking down complex information or comprehensive data into fundamental parts or basic principles. It involves examining the information, collecting the facts and checking whether the statement follows logically in identifying causes and effects.

Critical thinking is the mental process of carefully evaluating information and determining how to improve it in order to make a sound judgement. It is the ability of an individual to seek information, analyze alternatives and making conclusions or forming opinions. It includes the analytical thinking and uses it to generate a standpoint for someone’s world view.

**Critical Thinking and Intelligence**

Critical thinking is not equal with intelligence and shouldn’t be misunderstood with it (Karakoc, 2016). According to Butler (2017), Intelligence is largely determined by genetics. Critical thinking, though, can
improve with training and the benefits have been shown to persist over time. People who score higher on intelligence tests tend to go on to do better academically and in their careers. But many of us know intellectual titans who still make grave errors of judgment in their lives (Fradera, 2017).

IQ is – crudely speaking – a measure of the mental horsepower we have for handling abstract content, some researchers say that “critical thinking” – the ability to make judgments dispassionately without jumping to false conclusions – is a separate ability. Sternberg, Ennis, and Lipman assert that CT skills are not a fixed entity but a form of intelligence that can be taught. There is a great difference between being intelligent and being a critical thinker. Being intelligent does not imply that a person is a critical thinker. A profound genius may have irrational beliefs or unreasonable opinions, but CT is how we use our intelligence and knowledge to reach objective and rational goals. Opinions and beliefs based on CT are firmer as compared to those formulated through less rational processes. Critical thinkers are usually better equipped to make decisions and solve problems. CT is a vehicle that is powered by the power of intelligence.

Gardner’s Theory of Multiple Intelligence views that CT is not just a feature of “verbal-linguistic intelligence” or “logical-mathematical intelligence.” It comes into play massively in the areas of “visual-spatial intelligence,” “inter/intrapersonal intelligence,” “musical intelligence,” and virtually any other “intelligence” you want to define. CT is of paramount importance in professions like Architecture, Song Writing, Diplomacy or Self-Help. According to Elder (1996) CT provides the crucial link between intelligence and emotions in the “emotionally intelligent” person. CT enables us to take active command of not only our thoughts, but also of our feelings, emotions and desires. CT provides us with the mental tools needed to explicitly understand how reasoning works and how to steer what we think, feel, desire and do. Despite the fact that cognition, feelings and volition are equally important functions of mind, it is cognition or thinking, which is the key to the
other two. If we want to change a feeling, we must identify thinking that ultimately leads to the feeling.

**Conclusion**

An overview of the concepts and theories related to Andes Intelligent tutoring System, Problem Solving Ability and Critical Thinking helped the investigator to build a strong foundation for the development of the strategy based on Andes Intelligent Tutoring System for enhancing Problem Solving Ability, Critical Thinking and Achievement in Physics of students at Higher Secondary Level.