CHAPTER I

Introduction

Science has been derived from the Latin word “Scientia” which means knowledge. It is a systematized body of knowledge, which may pertain to any subject or field of life. ‘Science is a organized commonsense.’ ‘Science is an interpretation of the natural phenomenon.’ ‘Science is a heap of truth.’ ‘Science is a way of investigation’.

“Science is an interconnected series of concepts and conceptual schemes that have developed as a result of experimentation and observation and are fruitful of further experimentation and observations.”

Science and technology are playing an important role in our lives. They have become an integral part of our social and cultural life. Various activities are controlled and governed by Science. It has helped man to acquire supremacy over nature. (James B. Conant)

Science is first of all a set of attitudes. It is a disposition to deal with facts rather than with what someone has said about them.

(B.F. Skinner)

“Science is an accumulated and systematized learning, in general usage restricted to natural phenomenon.”

(Columbia dictionary)

On the basis of these definitions, we can conclude that

1. Science is study of natural phenomenon.
2. It is an organized and systematized learning.
3. It is a body of cumulative and ordered observations.
4. It is the knowledge based on observation, experiment and inference.
5. Science is a process as well as the product of that process.

The Science teaching is generally divided into two main categories
1. Life Sciences or Biological Sciences – e.g. Botany and zoology
2. Physical Sciences e.g. Physics, Chemistry.

Science grows through processes of Science; scientific knowledge is replicable, holistic, humanistic and tentative in nature.

It provides essential background of knowledge for cultural developments. It helps in developing and fostering the scientific attitude, scientific interest and scientific outlook among children by providing solutions for day to day problems. It helps in training the children for developing scientific temper and scientific creativity. It studies non living things, material and substances. It always remains in search for truth.

Science education is at present undergoing period of change.

Life → Social norms → Aims of Education → General objectives of teaching Science → Specific objectives of teaching Science.

In this modern age, the psychological viewpoint tells that the study of any subject cannot be successful and complete unless it is based on the age, characteristics and needs of the child. Thus in the field of Science along with its content, teaching methods play an important role.

Methods of teaching Science –

Question answer method, Role playing method, Brain storming method, Sensitivity training method, Independent study method, Laboratory method.

“In the absence of the correct directions/ true path, a person can’t reach his destination, in the same way in the absence of proper Method; the student cannot be given correct knowledge.”

Selection of proper teaching method helps in achieving the objectives of teaching Science, the knowledge of the Science teacher of that particular method, the availability of apparatus and materials in the schools. The experimental nature of method, class, age and capability of students, Opportunities for catering the needs of individual differences.

Science is referred as systematized body of knowledge. Many methods are used to acquire the knowledge of nature. Science includes the investigation of new phenomenon, analyzing ideas, comparing previous theories.

Science is an investigation of observation, identification, theoretical explanation of the phenomenon occurring in nature, investigation. Based on these components different workers have attempted to define the term Science.

The word Science makes us visualize the performance which is systematic and accurate. This means the concept of Science is broad and all pervasive. We certainly know that Science is a boon to man, and that human life has become happier, healthy and comfortable because of Science, therefore, someone is bound to ask, “What is Science?” Every individual provides different answer to this question according to his own experiences, his field of work, intellectual ability and according to his needs. Science is no longer a school subject; it has become an inseparable part of human life. Science is the method for man to lead his life. Such is the intimate relationship between Science and man life.
The word ‘Science’ is coined from the Latin word ‘Scientia’ which means knowledge. Science is the knowledge of all that is knowledge and understandable. Therefore, all agree that Science means special knowledge.

There are various definitions of the word ‘Science’.
The method of investigating nature, that discovers reliable knowledge about it, is called as Science.

(Rene decartes)

‘An attempt to make the chaotic diversity of our sense experience correspond to logically uniform system of thought is called as Science.

(Albert Eienstein)

Science is the organization of our knowledge in such a way that it commands or makes possible the explanation of more of the hidden potentialities found in the environment.

(J.Bronowski)

Science is the purest form in the simple extension of human curiosity.’

( Arthur Clarke)

Science is an ordered knowledge of natural phenomena and the rational study of the relation between the concepts in which the phenomena are expressed

(W. C. Dampier)

Science is an accumulated and systematized learning in general usage restricted to natural phenomena. The progress of Science is marked not only by an accumulation of fact by the emergence of scientific method and of the scientific attitude.

(Columbia Encyclopedia)

By the analysis of definitions Science, following points can be identified as regards the nature of Science.
**Nature of Science**

Science is process as well as the product of the process. In its process form it suggests the ways and means of exploring the truth and in its product form it presents systematic and organized body of useful knowledge. The process form of the Science is more important than its product form as the way of exploring the truth and acquiring knowledge is always given more preference in Science than the mere memorization or gaining knowledge of accumulated facts. Science constantly remains in search for truth and what it gets in account of this search, can never be taken as absolutely and permanently true. The method or process adopted by Science is known as scientific method and is characterized by qualities like validity, reliability, impartiality and objectivity in its procedure and approach.

Science develops scientific attitude among its readers by providing solution to day to day problems. The development of such attitude is known as scientific attitude.

Thus, Science may be seen to discharge two types of responsibilities, namely

1. Investigation and exploration of the facts.
2. Building of a systematic and organized body of facts as a result of such explanation.

Human mind is always busy in the pursuit of exploring the unknown. Man by his keen observation and faculty of reasoning has come to the conclusion that there cannot be any event in nature without any reason. In the process of search for knowledge and truth, man has accumulated a vast store of knowledge known as Science.
Evolution of Science in India during Ancient, Medieval and Modern Period

In India, the evolution of Science can be traced back to the Indus valley civilization, which flourished 3000B.C. The process of evolution of Science went on further during the ages of medieval and modern. Some of the landmarks in the process of evolution of Science in India can be presented as follows.

Science in Ancient Period

The people of Indus valley civilization made use of the wheel plough, smelted elaborate fire and flood controls for their farms. They used standardized burnt bricks for their buildings. The people mastered wide ranging scientific skills which were directed towards social benefit. They constructed their towns, cities on scientific principles. They possessed high technical skill in construction. They not only used standardized burnt bricks for their building, but planned their cities with symmetrically arranged streets and an elaborate drainage system. That speaks of their sophisticated awareness of sanitation and hygiene. The streets were meeting at right angle to each other. The people of Indus valley civilization have a pictographic script and decimal numeral system.

Science in Medieval India

Even though the medieval period is recognized as Dark Age in the evolution of Science in medieval India. The education system in the medieval period was of religious type. The religion was the centre of the education system. Even though, the education was the typically religious in nature, a number of kings contributed to the development of Science. From 6th century B.C. the technical skills began to develop the signs of excellence in iron metallurgy and steel, copper, bronze working, ceramic
etc. The huge copper statue of Buddha at Sultanganj in Bihar and famous iron pillar at Delhi show the extraordinary skills of the metal smiths of medieval time.

The technology of engineering assumed new dimensions in the medieval period as evidenced by the impressive gamut of monuments. Some of them are noted for their extraordinary acoustical features such as the musical pillars of the temples at Hamphi and the whispering gallery and the multiple echo effect in the GolGumba at Bijapur.

Science in Modern India

The colonization of India by British changed the future course of India’s Scientific Development. Due to this western Science began to show its impact on the growth of India’s Science. The growth of Science in India under British was not systematic. British Government established a number of scientific institutions in India. These institutions acted to provide the required data for the colonial expansion and exploitation. Some of the institutes established were Botanical survey of India, Geological survey of India, Indian Marine Survey Department and Indian Coastal Survey. They also set up observations at Madras, Calcutta and Bombay.

Historical Background of Science

The developing countries today are struggling against three major problems that is population explosion, poverty and environmental pollution. The developmental efforts of these countries are hindered by uncontrolled population growth and growing poverty. If properly utilized and geared towards the development processes, education can be one of the potent instruments. Science education plays an important role in solving these problems.
There are various reasons for which modern Science did not make significant headway in India during the British period. The new language made the process of assimilation in Indian culture difficult although the character of Science was not radically different from the earlier scientific traditions.

Due to the language problem, the new knowledge and information on Science couldn't reach the art sans and crafts men to make an impact on their trades and crafts. This did not help them to move out of their stagnation and to improve upon their old industries. This was no sufficient breakthrough in the scientific outlook of the people as the social and intellectual dialogue could not take place in a sufficiently large scale. The result was that India remained far behind in scientific and technological development as compared to countries in the West. The end of 18th century marked the neglect of the teaching of Science by universities and it had no place in school curriculum. To study the development of Science education in India during the modern period, the history of Science in the west is important because whatever happened in the west was followed in India though at a slower pace. The history of teaching Science commenced with the mechanics. According to the report of the Royal commissions of education it is found that none of the schools taught Science as an independent subject and further reports that at Rugby, natural Science was taught to boys who elected to study it instead of languages. They suggested that natural Science should be taught and should include two main branches one comprising Physics and Chemistry and the other comparative physiology and natural history. In 1837 Physics was introduced and in 1859 Botany, Chemistry and Geology were introduced at Rugby.

In 1854, three eminent scientists, T.H.Huxley, John Tyndall and Faraday urged the claims of Science as an essential part of general
education. Herbert Spencer (1861) believed that knowledge of life was the important knowledge for all "Moral and Physical"

T.H. Huxley was the most staunch advocate of teaching Science in the sixties and seventies of that century. The way for the inclusion of Science in the curriculum of secondary schools was paved by the start of natural Science course in the universities of Oxford and Cambridge. In 1895, Devonshire commission report gave a full survey of position of Science teaching in secondary schools.

The beginning of twentieth century saw adequate increase in the equipment and facilities for teaching Science in schools. The modern world felt the importance of general Science triggered the most outstanding contribution to the history of teaching Science in the last quarter of nineteenth century was that of H.E. Armstrong Professor of Chemistry in the Central Technical College, City of Guildes of London Institute. He was very much dissatisfied with the Science work in schools and was critical of the teaching methods that were adopted. The beginning of twentieth century saw adequate increase in the equipment and facilities for teaching Science in schools.

**Contribution of Scientists**

The scientists from various countries have dedicated their whole life for the cause of social betterment through scientific research. They have worked in their areas of specialization and contributed to the progress of society. Various problems facing to human race have been solved due to research carried out by scientists. Various diseases have been cured and the life span of man has been extended. The yield of food grains has been increased due to the advance technology used in the farming crops have been made resistant against disease by genetic engineering technique. The perennial problem of energy is being solved
through various means. Thus scientists have worked to make human life more sophisticated.

**Practical use of Science**

It is a hard reality that Science has revolutionized our way of living to the extent that it is now termed as "modern living". Our thinking, our attitudes, our interests, our outlook have undergone tremendous change. Man's material environment has been radically transformed by the magic wand of Science. The average span of human life has been doubled. The release of nuclear energy and green revolution are far reaching benefits of Science. Such observations about the unique importance of Science led the Kothari Commission (1964 - 66) to remark as under:

"The basic approach and philosophy underlying the reconstruction of education adopted by us in this report on our deep conviction that the progress, welfare and security of the nation, depend critically on a rapid, planned and sustained growth in the quality and extent of education and research in Science and technology”.

**Science and Education**

Facilities for the study of engineering and medicine in different branches have grown steadily the number of students who are taking to the study of pure Science has risen phenomenally. In India in 1968, 33000 students were studying Physics, Chemistry, and Biology at the graduate level and above. To facilitate the study of pure Science there are now more opportunities and financial aids. The Science talent search scheme run by National Council of Educational Research and Training, New Delhi, enables the students to study Science from the high school level right up to doctorate level. There are other schemes to aid young men and women take scientific education in the field of agriculture and
veterinary Sciences. There are a high proportion of students who get scholarships. This investment in manpower yields adequate returns when the student goes back to village where he is able to apply the knowledge and skill to the farm, cattle breeding, poultry farming.

There are two types of Science education. Formal Science education and Non formal Science education.

In the formal type of Science education the syllabus to be taught gets fixed the activities of the teacher while teaching, examples to be given, teaching aids to be presented while teaching and finally the methods to evaluate the students learning are also fixed.

When Science is taught through various media like Science club, scientific hobbies, Science exhibitions and fairs, Science museums called as Non formal Science education.

Categories of Science education: The Science teaching is mainly divided into two main categories:

1. Biological Sciences/life Sciences
2. Physical Sciences

I. Life Sciences

According to Sharma "life Sciences is the new nomenclature by which Biology i.e. Botany and Zoology is referred to in the new set up and it is quite apt, that the Science of life and living things is so termed. It would be our endeavor to try some of the new ways in the new ways, in the discipline of life Sciences for a proper and utilitarian outlook in the teaching methods".
II. Physical Sciences

Physical Sciences group includes those branches of Science which are related with the study of non living material. Thus physical Sciences include mainly two subjects’ Physics and Chemistry.

1. **Physics** - It is the branch of Science which deals with nature and natural phenomena. It is the Science which explains the natural phenomenon or the behavior of a natural system on the basis of the established laws of nature. Physics is the study of the properties of matter and energy and concern both the macroscopic and microscopic state of the matter.

2. **Chemistry** - It is the branch of Science which deals with the study of material substances, particularly about their composition, properties and reactions that changes them into other substances. Chemistry is the study of the materials that makes up the universe and the changes which these materials undergo. The development of Chemistry is based upon the systematic approach of the scientist in carrying out different experiments recording careful observations and making scientific inferences and generalizations.

What is Physics?

Physics is often described as the study of matter and energy. It is concerned with how matter and energy relate to each other, and how they affect each other over time and through space. Physicists ask the fundamental questions how the universe began. How and of what is it made? How does it change? What rules govern its behavior?
Physicists may be roughly divided into two camps: experimental physicists and theoretical physicists. Experimental physicists design and run careful investigations on a broad range of phenomena in nature, often under conditions which are atypical of our everyday lives. They may, for example, investigate what happens to the electrical properties of materials at temperatures very near absolute zero (460 degrees Fahrenheit) or measure the characteristics of energy emitted by very hot gases. Theoretical physicists propose and develop models and theories to explain mathematically the results of experimental observations. Experiment and theory therefore have a broad overlap. Accordingly, an experimental physicist remains keenly aware of the current theoretical work in his or her field, while the theoretical physicist must know the experimenter's results and the context in which the results need be interpreted.

It is also useful to distinguish classical physics and modern physics. Classical physics has its origins approximately four hundred years ago in the studies of Galileo and Newton on mechanics, and similarly, in the work of Ampere, Faraday, Maxwell and Oersted one hundred fifty years ago in the fields of electricity and magnetism. This physics handles objects which are neither too large nor too small, which move at relatively slow speeds (at least compared to the speed of light). The emergence of modern physics at the beginning of the twentieth century was marked by three achievements. The first, in 1905, was Einstein's brilliant model of light as a stream of particles (photons). The second, which followed a few months later, was his revolutionary theory of relativity which described objects moving at speeds close to the speed of light. The third breakthrough came in 1910 with Rutherford's discovery of the nucleus of the atom. Rutherford's work was followed by
Bohr's model of the atom, which in turn stimulated the work of de Broglie, Heisenberg, Schrodinger, Born, Pauli, Dirac and others on the quantum theory. The avalanche of exciting discoveries in modern physics continues today.

Given these distinctions within the field of physics experimental and theoretical, classical and modern it is useful to further subdivide physics into various disciplines, including astrophysics, atomic and molecular physics, biophysics, solid state physics, optical and laser physics, fluid and plasma physics, nuclear physics, and particle physics.

Major Branches of Physics

Acoustics studies the production and properties of sound.

Atomic physics examines the structure, properties, and behavior of the atom.

Biophysics applies the tools and techniques of physics to the study of living things and the life processes.

Cryogenics is the study of extremely low temperatures.

Electrodynamics analyses the relationship between electrical and magnetic forces.

Fluid physics deals with the behavior and movements of liquids and gases.

Geophysics is the study of earth and its atmosphere and waters by means of the principles of physics.
Health physics involves the protection of people work with are near radiation.

Mathematical physics is the study of mathematical systems that stands for physical phenomena.

Mechanics deals with the behavior of objects and systems in response to various forces.

Molecular physics examines the structure, properties, and behavior of molecules.

Nuclear physics is concerned with the structure and properties of the atomic nucleus, and with nuclear reactions and their applications.

Optics is the study of the nature and behavior of light.

Particle physics, also called high energy physics, analyses the behavior and properties of elementary particles.

Plasma physics is concerned with the study of highly ionized gases- that is, gases that have been separated into positively and negatively charged particles.

Quantum physics includes various areas of study based on quantum theory, which deals with matter and electromagnetic radiation, and the interactions between them.

Solid-state physics, also called condensed-matter physics, examines the physical properties of solid materials.

Thermodynamics is the study of heat and other forms of energy, and of the conversion of energy from one form to another.
Problem-Solving & Scientific Reasoning

In addition to mathematics (which is a form of problem-solving), it is helpful for the prospective physics student to have a more general knowledge of how to tackle a problem and apply logical reasoning to arrive at a solution.

Among other things, you should be familiar with the scientific method and the other tools physicists use. Study other fields of science, such as biology and chemistry (which is closely related to physics). Again, take advanced placement courses if you qualify. Participating in science fairs is recommended, as you will have to come up with a method of answering a scientific question.

In a broader sense, you can learn problem-solving in non-science contexts. I attribute a lot of my practical problem-solving skills to the Boy Scouts of America, where I frequently had to think quickly to resolve a situation that would come up during a camping trip, such as how to get those stupid tents to actually stay upright in thunderstorms.

Read voraciously, on all topics (including, of course, science). Do logic puzzles. Join the debate team. Play chess or video games with a strong problem-solving element.

Anything that you can do to train your mind to organize data, look for patterns, and apply information to complex situations will be valuable in laying the foundation for physical thinking that you will require.
Technical Knowledge

Physicists use technological tools, especially computers, to perform their measurements and analysis of scientific data. As such, you need to be comfortable with computers and different forms of technology to. At the very least, you should be able to plug in a computer and its various components, as well as know how to maneuver through a computer folder structure to find files. Basic familiarity with computer programming is helpful.

One thing that you should learn is how to use a spreadsheet to manipulate data. I, sadly, entered college without this skill, and had to learn it with lab report deadlines looming over my head. Microsoft Excel is the most common spreadsheet program, although if you learn how to use one you can generally transition to a new one fairly easily. Figure out how to use formulas in spreadsheets to take sums, averages, and perform other calculations. Also, learn how to put data in a spreadsheet and create graphs and charts from that data. Believe me, this will help you later on.

Learning how machines operate also helps provide some intuition into work that will come up in fields such as electronics. If you know someone who's into cars, ask them to explain to you how they run, because many basic physical principles are at work in an automotive engine.

Good Study Habits

Even the most brilliant physicist has to study. I coasted through high school without studying much, so I took a long time to learn this lesson. My lowest grade in all of college was my first semester of
physics, because I didn't study hard enough. I kept at it, though, and majored in physics with honors ... but I seriously wish I'd developed good study habits earlier.

Pay attention in class and take notes. Review the notes while reading the book, and add more notes if the book explains something better or differently than the teacher did. Look at the examples. And do your homework, even if it's not being graded.

These habits, even in easier courses where you don't need them, can help you in those later courses where you will need them.

The scientific method is a set of techniques used by the scientific community to investigate natural phenomena by providing an objective framework in which to make scientific inquiry and analyze the data to reach a conclusion about that inquiry.

Steps of the Scientific Method

The goals of the scientific method are uniform, but the method itself is not necessarily formalized among all branches of science. It is most generally expressed as a series of discrete steps, although the exact number and nature of the steps varies depending upon the source. The scientific method is not a recipe, but rather an ongoing cycle that is meant to be applied with intelligence, imagination, and creativity. Frequently, some of these steps will take place simultaneously, in a different order, or be repeated as the experiment is refined, but this is the most general and intuitive sequence. As expressed by Shawn Lawrence Otto in Fool Me Twice: Fighting the Assault on Science in America:
There is no one "Scientific method"; rather, there is a collection of strategies that have proven effective in answering our questions about how things in nature really work. Depending on the source, the exact steps will be described somewhat differently, but the following are a good general guideline for how the scientific method is often applied.

1. **Ask a question** – determine a natural phenomenon (or group of phenomena) that you are curious about and would like to explain or learn more about, then ask a specific question to focus your inquiry.

2. **Research the topic** – this step involves learning as much about the phenomenon as you can, including by studying the previous studies of others in the area.

3. **Formulate a hypothesis** – using the knowledge you have gained, formulate a hypothesis about a cause or effect of the phenomenon, or the relationship of the phenomenon to some other phenomenon.

4. **Test the hypothesis** – plan and carry out a procedure for testing the hypothesis (an experiment) by gathering data.

5. **Analyze the data** – use proper mathematical analysis to see if the results of the experiment support or refute the hypothesis.

If the data does not support the hypothesis, it must be rejected or modified and re-tested. Frequently, the results of the experiment are compiled in the form of a lab report (for typical classroom work) or a paper. It is also common for the results of the experiment to provide an opportunity for more questions about the same phenomenon or related phenomena, which begins the process of inquiry over again with a new question.
Key Elements of the Scientific Method

The goal of the scientific method is to get results that accurately represent the physical processes taking place in the phenomenon. To that end, it emphasizes a number of traits to insure that the results it gets are valid to the natural world.

Objective – the scientific method intends to remove personal and cultural biases by focusing on objective testing procedures.

Consistent – the laws of reasoning should be used to make hypotheses that are consistent with broader, currently known scientific laws; even in rare cases where the hypothesis is that one of the broader laws is incorrect or incomplete, the hypothesis should be composed to challenge only one such law at a time.

Observable – the hypothesis presented should allow for experiments with observable and measurable results.

Pertinent – all steps of the process should be focused on describing and explaining observed phenomena.

Parsimonious – only a limited number of assumptions and hypothetical entities should be proposed in a given theory, as stated in Occam's Razor.

Falsifiable – the hypothesis should be something which can be proven incorrect by observable data within the experiment, or else the experiment is not useful in supporting the hypothesis.

Reproducible – the test should be able to be reproduced by other observers with trials that extend indefinitely into the future.
It is useful to keep these traits in mind when developing a hypothesis and testing procedure.

**Misconceptions:**

Misconceptions might also be referred to as preconceived notions, non-scientific beliefs, mixed conceptions, or conceptual misunderstandings. Basically, in Science these are cases in which something a person knows and believes does not match what is known to be scientifically correct.

Most people who hold misconceptions are not aware that their ideas are incorrect. What is especially concerning about misconceptions is that we continue to build knowledge on our current understandings. Possessing misconceptions can have serious impacts on our learning. Therefore it is necessary to work on this problem.

The process through which children form Misconceptions is as follows - Misconceptions form in a variety of ways. Often misconceptions are passed on by one person to the next. In other cases, students may be presented with two correct concepts, but combine or confuse them. Sometimes students make what to them seems like a logical conclusion, but is simply drawn from too little evidence or lack of experience. One of the most common sources of misconceptions is the fact that our everyday language is often at odds with Science; common vernacular doesn't always match the precise language used by scientists.

Though the connotation of "misconception" is negative, we must remember that the formation of these ideas often represent a child's effort to organize and understand the world around him/her. The success of
these efforts will depend both on the developmental stage of the child and the experiences to which he/she is exposed.

A teacher who expects to simply point out students' mistakes to them will be met with little success; as stated previously, misconceptions are not easily given up. Often children work very hard to process information and arrive at their ideas. It takes just as much work to deconstruct those ideas and let go of the incorrect ones.

The first step is to be aware of and diagnose student’s misconceptions. This involves going beyond the multiple choice assessment-- to asking open ended questions and truly listening to students' ideas. Next, it involved structuring experiences and the learning environment so that there are opportunities for students to "test out" their ideas and prove the correct concepts to them. This method is often referred to as teaching for conceptual change.

A better understanding of the social aspects of learning, how students use their conceptual understandings outside the classroom, and how their experiences grow into scientific models that they find satisfactory will help teachers better understand their role.

**Common Misconceptions in Physics**

Misconception – Light has no mass.  
Correct Physics – Whenever you see someone use the term mass you need to make sure you understand exactly what he or she means by it since the term mass when used unqualified, can refer to several different things. It can refer to proper mass, inertial mass, passive gravitational mass or active gravitational mass. Only when one is referring to proper mass can it legitimately be said that light has no mass.
Misconception – Einstein proved that gravity is a curvature in space-time.

Correct Physics – Einstein argued that gravity is the result of viewing nature from a non-inertial frame of reference. He showed that when that doesn’t hold as in the case where tidal forces are present the result is due to space-time curvature. Other physicists objected to the notion that a gravitational field has a relative existence so they chose to interpret tidal forces (i.e. space-time curvature) as determining the presence of a gravitational field. Einstein actually objected to this interpretation.

Misconception – You cannot simultaneously measure both the position and the momentum of a particle.

Correct Physics – This is the wrong phrasing of Heisenberg’s Uncertainty Principle (HUP), which actually states that the position and momentum are not simultaneously determined. This has a very different meaning than what is stated above. Uncertainty is a property of the quantum state and not determined by how measurements are done. No matter how a measurement is taken one cannot change the inherent uncertainty determined by the quantum state of the system.

Misconception – Mass does not depend on velocity.

Correct Physics – This is a statement made by people who choose to use the term mass only to refer to what is known as proper mass aka rest mass. All the statement really means is that the proper mass of a particle does not depend on the particle’s speed.
Misconception – Since a light has no mass it isn’t affected by gravity.

Correct Physics – Physicists recognize three types of mass according to three aspects of the concept of mass. They are
(1) Inertial mass – The ratio of a particle’s momentum to its speed
(2) Passive gravitational mass – The mass on which gravity acts
(3) Active gravitational mass – The source of gravity

Inertial mass is properly defined as the quantity ‘m’ such that the quantity (momentum is conserved. To be precise we say that inertial mass is defined so that momentum is conserved. The equivalence principle, from Einstein’s general theory of relativity, postulates the equality of inertial mass and passive gravitational mass. Since photons have momentum they have inertial mass; since they have inertial mass they have passive gravitational mass; since they have passive gravitational mass they are acted upon by gravity. We can also find the mass of a photon if we know its energy.

Misconception – Gravity is not a force, it’s a curvature in space time.

Correction – Einstein’s general theory of relativity treats the gravitational force on the same footing as inertial forces.

An example of an inertial force is the centrifugal force which is the force felt by an object moving in a curved path that acts outwardly away from the center of rotation. Prior to general relativity inertial forces were viewed as being a result of viewing nature from the wrong frame of reference. It was for this reason that they are more often referred to by the fictitious force, pseudo-force or apparent force. Non-inertial forces can be expressed with a non-zero 4-force. It should be noted that Einstein
viewed inertial forces as being “real.” Einstein also never interpreted gravity to be a curvature in space-time either. Laymen often confuse space-time curvature with the curved path of a particle being deflected in a gravitational field. A more common name for space-time curvature is gravitational tidal gradient, i.e. tidal force. Loosely speaking, gravitational tidal force is the difference in gravitational force in a gravitational field. For an object to experience a tidal force it must have a finite spatial extension. The gravitational force can act on a single point particle. Point particles are not subject to tidal forces but are affected by inertial forces. It is therefore misleading to say that gravity is not a force but merely a curvature in space-time.

The Learning Cycle

This is another method of instruction that has proven successful in addressing students' misconceptions. Lessons are taught in five phases, building from the concrete to the abstract.

To avoid misunderstanding, let’s start by explaining what it isn't: critical thinking is not necessarily being "critical" and negative. In fact, a more accurate term would be evaluative thinking. The result of evaluation can range from positive to negative, from acceptance to rejection or anything in-between. Yes, critical evaluation can produce a glowing recommendation should be used with an attitude of "critical thinking" evaluation are the result of my own critical thinking.

In productive problem solving you generate ideas (by creativity) and evaluate ideas (by criticality). Although creativity occurs first in the process, I think it's best to begin with a foundation of critical thinking. Why? Because wise evaluation, in critical thinking, can prevent
"creativity plus enthusiasm" from converting questionable ideas into unwise action.

Here are two brief definitions of what it is: Critical thinking is "reasonably and reflectively deciding what to believe or do." Critical thinking means making reasoned judgments. In essence, critical thinking is a disciplined manner of thought that a person uses to assess the validity of something: a statement, news story, argument, research, etc.

"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, 1996).

"Most formal definitions characterize critical thinking as the intentional application of rational, higher order thinking skills, such as analysis, synthesis, problem recognition and problem solving, inference, and evaluation"

(Angelo, 1995, p. 6).

"Critical thinking is thinking that assesses itself"

(Center for Critical Thinking, 1996b).

"Critical thinking is the ability to think about one's thinking in such a way as 1. To recognize its strengths and weaknesses and, as a result, 2. To recast the thinking in improved form"

(Center for Critical Thinking, 1996c).
As explained above, critical thinking is essential for effective functioning in the modern world.

Over the last several decades, critical thinking has been discussed and contemplated in educational circles. Many definitions of critical thinking have been offered. In 1991, Pascarella and Terenzini compiled several definitions, stating that critical thinking “typically involves the individual’s ability to do some or all of the following: identify central issues and assumptions in an argument, recognize important relationships, make correct inferences from data, deduce conclusions from information or data provided, interpret whether conclusions are warranted on the basis of the data given, and evaluate evidence or authority (p. 118).”

Critical thinking involves the formation of logical inferences (Simon & Kaplan, 1989). Some scholars and educators erroneously assume critical thinking to be higher order thinking or cognitive processing (Paul, 1994).

According to Elder and Paul (1994), “Critical thinking is best understood as the ability of thinkers to take charge of their own thinking. This requires that they develop sound criteria and standards for analyzing and assessing their own thinking and routinely use those criteria and standards to improve its quality.”

Critical thinking can be set apart from problem solving (Hedges, 1991) in that problem solving is a linear process of evaluation, while critical thinking is a comprehensive set of abilities allowing the inquirer to properly facilitate each stage of the linear problem-solving process. According to Chafee (1988) critical thinking is "our active, purposeful, and organized efforts to make sense of our world by carefully examining our thinking, and the thinking of others, in order to clarify and improve
our understanding” (p.29). According to Halpern (1989) critical thinking is "thinking that is purposeful, reasoned and goal directed. It is the kind of thinking involved, in solving problems, formulating inferences, calculating likelihoods, and making decisions" (p.5). Simply put, critical thinking is the "reasonable and reflective thinking that is focused upon deciding what to believe or do" (Norris & Ennis, 1989, p. 18).

**Misrepresentations about Critical Thinking**

Critical thinking is looked at and viewed in many different ways. To gain a more complete understanding of critical thinking, it is useful to look at what critical thinking “is not.” Critical thinking is not about being superior to someone else. It is different from problem solving, and it is not higher order thinking or cognitive processing. Many scholars engage in, what Richard Paul refers to as “pseudo critical thinking,” which is a form of “intellectual arrogance masked in self-delusion or deception, in which thinking is deeply flawed” (1994, p.14). Other well-meaning educators simply use the term critical thinking in place of other types of information processing that are very similar to, but at the same time different from critical thinking, such as problem solving.

Dr. Lowell Hedges (1991) is one researcher who understood the difference between problem solving and critical thinking. He contended that problem solving is a linear process of evaluation, while critical thinking is an overlying set of abilities that allow the inquirer to properly facilitate each stage of the linear problem-solving process.
Chart of Hedges’ views on critical thinking and problem solving.

Critical Thinking Problem Solving
1. The ability to identify and formulate problems, as well as the ability to solve them.
2. Recognizing a problem situation.
3. The ability to recognize and use inductive reasoning, as well as the ability to solve them.
4. Defining the problem
5. The ability to draw reasonable conclusions from information found in various sources, whether written, spoken, tabular, or graphic, and to defend one’s
6. The ability to comprehend, develops, and uses concepts and generalizations, conclusions rationally.
7. The ability to comprehend, develops, and use concepts and generalizations.
8. Testing hypotheses and gathering data.
9. The ability to distinguish between fact and opinion.
10. Revising hypotheses and testing revised or new hypotheses.
11. Forming a conclusion.

Critical Thinking and Inquiry-based Learning in Education

“Since education is our principal means of preparing students – our future citizens – for an active and responsible life within our technologically-based society, school at all levels should become the focus for the fostering/development of critical thinking” (Costa, 1991). According to Nelson (1994), “Enabling students to think critically is one of the central objectives of liberal and professional education.”

Critical thinking in education calls on students to evaluate their own thought process (Kalman, 2002). Critical thinking accompanies a
movement in education toward inquiry-based or problem-based learning. According to Schamel and Ayres (1992), “students learn best by doing,” or preparing their own questions based on their observations rather than participating in a “predetermined exercise with a far gone conclusion.” Students are fully engaged in learning and cooperative group learning helps students interact with one another (Ahern-Rindell, 1999).

**Critical Thinking and Science Education**

A current theme in Science teaching reform is the emphasis on active, inquiry-based teaching and learning (National Research Council, 1996). Inquiry-based learning is a method of instruction focusing on the student and their ability to design a process for use in solving a problem, requiring higher levels of cognition (Uno, 1999). While inquiry-based learning takes the focus away from memorization of specific scientific concepts, there is supporting evidence that students learn as much “factual” information as they would in a traditional lecture/lab setting (Gabel, 1994). However, inquiry students tend to retain the information longer (Gabel, 1994) and usually experience higher self-efficacy and process skills than students in traditional Science courses (Ebert-May, Brewer, and Allred, 1997).

The case has been made for teaching critical thinking skills in school. Science classrooms provide many opportunities for inquiry-based or problem-based learning. However, in order for this inquiry-based learning to happen, changes must take place in Science classrooms to move away from rote and passive application of learned formulas toward the use of critical thinking as the primary tool of learning (Zoller, Ben-Chaim, and Ron, 2000).
Critical Thinking Skills

The critical thinking skills that were identified by the panel of experts were used in this study because they most closely matched the definition of critical thinking that we have adopted for this study, which was "Critical thinking is a reasoned, purposive, and introspective approach to solving problems or addressing questions with incomplete evidence and information and for which an incontrovertible solution is unlikely" (Rudd, Baker et al. 2000), p. 5) and because subsequent studies have been conducted to validate their usage (Facione 1990; Jones, Hoffman et al. 1994; Jones, Hoffman et al. 1995; Giancarlo 1996; Giancarlo 1996). Facione’s study (1990) concluded that at the very core of critical thinking are interpretation, analysis, evaluation, inference, explanation, and self-regulation. Inference is comprehending and expressing meaning about a wide variety of experiences, beliefs, procedures, rules, etc. Analysis was found to be about identifying the relationship between statements, questions, concepts or descriptions to express beliefs, judgments or reasons. The experts thought that evaluation was about assessing credibility of statements and representations of others as well as assessing the logical strength of statements, descriptions or questions. Inference was found to be the ability to draw reasonable conclusions and/or hypotheses based on facts, judgments, beliefs, principles, concepts or other forms of representation. The experts in the Delphi study found explanation to be about stating and justifying the results of one's reasoning using each of the aforementioned abilities. Self-regulation, the last skill was found to be the ability of an individual to monitor their own personal cognitive activities to make sure that they are engaged in critical thinking. Several studies have been conducted to confirm the Delphi consensus statement. The 1990 Delphi report describing the ideal critical thinker was put to the test by Giancarlo
(1996) using the California-Q sort method, which was a technique derived from the work of Block (1961). A national expert panel concerning critical thinking sorted 100 Q-sort items to achieve a result that would characterize the ideal critical thinker. The results would validate the critical thinking skills identified in the theoretical framework in this study. The following study would secure national recognition of the viability of critical thinking skills. Jones, Hoffman, Moore, Ratcliff, Tibetts, and Click (1995; 1994) further validated the use of critical thinking skills through a 1993/1994 national survey and replication study conducted by the National Center for Higher Education Teaching, Learning and Assessment at The Pennsylvania State University. As a result of this study skills, along with dispositions became recommended outcomes of post-secondary education.

Critical Thinking Dispositions

Critical thinking is dependent upon a person’s disposition to use it (Paul, 1992). Disposition to think critically can be defined as consistent willingness, motivation, inclination and an intention to be engaged in critical thinking while reflecting on significant issues, making decisions and solving problems (Facione et al. 1995, Facione et al. 1997). According to Zoller, Ben-Chaim and Ron (2000), a student’s disposition to think critically is a necessary precondition for critical thinking and greatly affects critical thinking capability. In developing the widely used Watson-Glaser Critical Thinking Appraisal, Glaser (1941) defined critical thinking as the "(1) attitude of being disposed to consider in a thoughtful way the problems and subjects that come within the range of one's experiences, (2) knowledge of the methods of logical inquiry and reasoning and (3) some skill in applying those methods" (p. 5-6).
Later, in 1997, Taube reported statistical and empirical evidence of skills and dispositions, two distinct factors of critical thinking. Experts continue to agree that critical thinking includes the dimensions of skill and disposition (Dewey 1933; Norris and Ennis 1989). In 1990, Facione and his group of experts identified a set of specific skills and sub-skills for the skill dimension and a specific set of attitudes for the disposition dimension (Facione 1990). Facione (2001) developed the CCTDI (California Critical Thinking Disposition Inventory), in order to measure these skills, sub-skills and attitudes. The constructs used are Truth-Seeking, Open-mindedness, Analyticity, Systematicity, Self-confidence, Inquisitiveness, and Maturity (Facione, Facione et al. 2001). The following construct descriptions are from the CCTDI test manual (Facione, Facione, & Giancarlo, 1996).

1. Analyticity targets the disposition of being alert to potentially problematic situations and anticipating possible results or consequences.
2. Self-confidence refers to the level of trust one places in one’s own reasoning process.
3. Inquisitiveness is innate curiousness about acquiring information and which motivates the message recipient to learn more.
4. Maturity addresses cognitive Maturity and mature thinkers are disposed to approach problems, inquiry and decision making realizing that some situations have more than one plausible option and those decisions must sometimes be made without the benefit of having all the relevant information about the situation.
5. Open-mindedness addresses the state of respecting the right of others with differing opinions.
6. Systematicity targets the disposition to being organized, orderly, focused and diligent in seeking information.
7. Truth-seeking describes thinkers who are eager to seek the truth even if
the results do not support one’s own interests or preconceived opinions.
Although Facione’s work has seemingly been the only attempt at
measuring critical thinking dispositions, its validity has been brought into
questions by a study conducted by Moore, Rudd, and Penfield (submitted
for publication). This study examined the reliability of the subscales of
the CCTDI as well as the factor strength of the whole instrument. During
factor analysis, the data obtained in the Moore, Rudd, et al study did not
fit the seven scale structure outlined by Facione and associates (Facione,
Facione, & Giancarlo). Analysis of the seven factor structure resulted in
only 51 of the 75 items on the instrument with factor loadings greater
than .30 and four to 11 items loading on seven factors. The seven factor
structure had a sum of Eigenvalues of 25.33 and explained 27.2% of the
variance.

**Discipline-specific Critical Thinking**

While critical thinking skill and disposition can be defined as
separate entities, both are thought to be open to educational influence,
particularly when meaningfully, contextually bound (Brown 1997).
Critical thinking is a valuable skill that, once learned, can be applied in
many different disciplines; however, researchers have contended that
there is a need to think critically within specific disciplines. According to
Glaser, critical thinking is, in part, “attitude of being disposed to consider
in a thoughtful way the problems and subjects that come within the range
of one's experiences (1941, p. 5-6). Ennis advocates contextual, domain,
or subject specific critical thinking for several reasons. First, background
knowledge is necessary for making justified critical thinking judgments.
Second, critical thinking varies from discipline to discipline and, third, a
full understanding of a discipline requires the ability to think critically in
the discipline (Ennis 1990). (Halliday 2000) argues that critical thinking is to be used in the context of specific disciplines. He quotes Dunne and Morgan from their article in Irish Educational Studies.

"Critical thinking is best developed through an engagement with different areas of knowledge rather than as an autonomous skill to be taught in itself. It is through cutting its teeth on actual topics, themes, an issues and problems as these arise within diverse content domains that thinking can acquire the kind of differentiation subtlety and sense of relevance that help to make it truly critical" (Dunne and Morgan, 1995, p. 115).

According to Guthrie, Alao & Rinehart (1997), there is a need to situate literacy learning, such as critical thinking skills, within content areas in order to drive learning and increase both literacy ability and knowledge in the content area. Finally, Facione (1990) found that "While CT skills themselves transcend specific subjects or disciplines, exercing them successfully in certain contexts demands domain-specific knowledge, some of which may concern specific methods and techniques used to make reasonable judgements in those specific contexts"(p. 5). The success of domain-specific critical thinking has been demonstrated in research. In a study of 254 seventh grade French speaking Science students, researchers found a statistically significant mean gain in pre-test post-test investigation of CCTDI scores (t=4.54, p<.001), suggestive of the fact that critical thinking, indeed can be context specific (Ferguson and Vazquez-Abad 1995).

**Predictors and Correlates of Critical Thinking Skill**

(Facione 1998) reported on several studies (Facione, Facione, & Giancarlo, 1996; Jones, Ratliff, Tibbetts, & Glick, 1994; Giancarlo & Facione, N., 1994; Facione & Facione, 1997) that determined a
significant, but relatively low relationship between critical thinking skills and dispositions. The research indicated that there is a need for both skills and dispositions in curriculum models. Facione describes the disposition toward critical thinking as the "consistent internal motivation to engage problems and make decisions by using critical thinking" (p. 5).

Facione (1998) concluded "educational and professional success required nurturing one's consistent internal motivation to think as well as developing one's thinking skills" (p. 16).

In a study of 193 tenth grade students in the Southwestern United States a positive correlation ($r=.41$) was found between CCTDI scores and CCTST (California Critical Thinking Skills Test) total scores. It was statistically significant at the $p<.05$ level, which might suggest that there is a positive correlation between CT skill and CT disposition. This finding would suggest that critical thinking skill accounts for 16.8% of the variance in critical thinking disposition and vice versa.

In the largest known study to identify relationships between critical thinking skill and disposition, as well as other demographic factors, (Facione and Facione 1997) conducted a five year longitudinal investigation of 7,926 students from 50 different college level programs. Positive correlations were found between overall disposition and strength of critical thinking. Examples of the types of analyses run with the large data set were a sample of 1557 nursing students that showed weak positive correlations ($r=.201$, $p<.001$) and a sample of 793 students who again had similar results ($r=.169$, $p<.001$). These findings would suggest a significant correlation, especially with such a large sample.

The study that looked at correlations between each of the subscales and found significant correlations among all of the subscales, except for the relationships between critical thinking self-confidence and awareness
and the relationship between critical thinking self-confidence and evaluation. These findings indicated that each subscale skill could not be individually correlated with the corresponding disposition. (Rapps, Riegel et al. 2001) conducted a study to test a model of cognitive development which sought to determine which of the four variables, knowledge base, critical thinking skills, critical thinking dispositions, and experience were utilized to predict cognitive development. Critical thinking dispositions contributed to all of the levels of Perry's scheme of intellectual development; dualism, relativism, and commitment, and experience only predicted the commitment stage.

**Skill Building:** Minimal in servicing in critical thinking must be provided for faculty in teacher preparation programs. If faculties are not provided with convenient ways to upgrade their knowledge of critical thinking and how to teach for it, very few will go out of their way to pursue it.

**Overall Conclusions and Implications**

Critical thinking is clearly an honorific phrase in the minds of most teacher educators such that they feel obliged to claim both familiarity with it and commitment to it in their teaching, despite the fact that few have had any in-depth exposure to the research on the concept and most have only a vague understanding of what it is and what is involved in bringing it successfully into instruction. Critical thinking is commonly confused with active involvement in learning (forgetting that active involvement alone is quite compatible with active "mislearning"). A vague appeal to words from Bloom's Taxonomy (analysis, synthesis, evaluation) is often taken to be demonstrative of knowledge of critical thinking. Even faculty in the CSU, which has a formal policy on critical thinking instruction, is apparently largely unfamiliar with the "definition
of critical thinking" and specifications of what minimal conditions for instruction in it are inherent in the policy.

It is clear that virtually all departments represented in the study uncritically assume that instruction in critical thinking takes place--without any effort to verify this assumption. In fact, we found no evidence in these interviews of any systematic efforts that have been made to assess instruction for critical thinking within any of the schools of education studied. What is more, there is little understanding of how to assess it--should schools of education desire to do it. Most disturbingly, since the overwhelming majority assumes that the faculty already understand and emphasize critical thinking in their classes, any "in-house" assessment would doubtless be perceived as a pointless "political" process to be carried out with a minimum of effort (but with a clear sense of how to achieve the politically correct answer). In other words, since professors in schools of education assume that they understand critical thinking and how to teach for it, and that they are already successful in teaching their students both, it follows that it will be exceedingly difficult to produce substantial changes in teacher certification programs in these areas.

It is clear from the results of the study that we are very far from a state of affairs in which critical thinking is a hallmark of instruction in teacher preparation programs. Present instruction is likely to produce teachers who, on the one hand, are confident that they not only understand critical thinking but also know how to teach for it, but who, in point of fact, understand neither. Many will equate critical thinking with mere active involvement or "cooperative learning." Others will believe that some acquaintance with the terms of Bloom's Taxonomy or Howard
Gardner's theory of multiple intelligences is equivalent to understanding critical thinking. Some will equate it with an emphasis on learning styles or with concept maps or some other tool or facet or dimension of learning.

Others will equate the whole of critical thinking with some component part of it. Some will therefore emphasize multiple points of view (and take that to be the whole of it). Some will emphasize recognizing one's assumptions. Some will emphasize questioning information sources. Some will emphasize analyzing concepts. But very few will have a comprehensive sense of the whole or a realistic idea of how to cultivate it while teaching the content of a subject or discipline.

Using the criteria of the California State Universities and Colleges as an alternative reference point, it is clear that, based on the information we have gathered, the overwhelming number of those certified to teach have little understanding of how to teach so that students will understand "the relationship of language to logic,(or have) the ability to analyze, criticize, and advocate ideas, to reason inductively and deductively, and to reach factual or judgmental conclusions based on sound inferences drawn from unambiguous statements of knowledge or belief....(or acquire) the ability to distinguish fact from judgment, belief from knowledge, and skills in elementary inductive and deductive processes, including an understanding of the formal and informal fallacies of language and thought."

Finally, given the information gathered in this study, it is highly likely that most of those certified to teach have, given present instruction, little understanding of what reasoning is, what assumptions are, what
inferences are, what implications are, or what it is to reason with intellectual discipline within a subject field (historically, biologically, psychologically,...).

It appears likely that we are now certifying teachers who not only have little understanding of critical thinking or how to teach for it but also wrongly and confidently think they do. The end result is that California classrooms are places in which both teachers and students lack explicit knowledge of how to reason in a disciplined way about serious subjects and questions. In the absence of that understanding, one can expect a drifting toward intellectual relativism (i.e. toward the view that all answers sincerely believed and defended are equally good since, as far as they can see, there is no final way to intellectually assess competing answers other than by degree of active involvement in their defense). Subjectivity of response, subjectivity of grading, intellectual undisciplined answers will in all likelihood be unconsciously encouraged. Open-mindedness will be confused with the willingness to accept everyone's answer to a complex question as equally "right" (for them).

Given the facts revealed in this study, it is unlikely that students preparing to teach are being instructed in the basic structures of reasoning. Students studying history, Biology, and mathematics will not recognize that historians, biologists, and mathematicians equally make assumptions, develop specialized concepts, reason to conclusions, make interpretations of data, trace implications and consequences, define problems, concerns, and issues, and think within a disciplinary frame of reference or point of view. Students studying English, Physics, and Chemistry will not recognize that thinking clearly, accurately, and precisely; thinking deeply, broadly, and logically; are equally important intellectual criteria in every subject. Students will continue to lack any
insight into the fact that moral issues and problems require as much disciplined reasoning and clarity of definition as does reasoning in any other domain. Students will graduate, in short, without any plausible semblance of intellectual perspective and discipline.

If we are interested in teachers certified in California having a reasonable grounding in the rudiments of critical thinking based on a rich, substantive concept of it, or at least a minimalist, baseline concept, then we have a major task facing us, not the least of which is persuading the majority of the faculty that they do not already know what they confidently assume that they do know.

**Characteristics of Critical Thinkers**

For a quick overview, read Characteristics of Critical Thinking which begins with "What is Critical Thinking?" and continues with: Characteristics of Critical Thinking, Why teach Critical Thinking?, and Teaching Strategies to help promote Critical Thinking Skills. Linda Elder and Richard Paul describe Valuable Intellectual Traits (Intellectual Humility, Courage, Empathy, Integrity, Perseverance, Faith In Reason, and Fair-mindedness) and Universal Intellectual Standards (Clarity, Accuracy, Precision, Relevance, Depth, Breadth, and Logic). (also on posters)

For a more comprehensive overview, use 35 Dimensions of Critical Thought as a launching pad to read 35 pages with brief, clear descriptions of Affective Strategies, Cognitive Strategies (Macro-Abilities), and Cognitive Strategies (Micro-Skills).

An effective thinker must be willing to think and able to think. These requirements — for disposition (be willing) and skill (be able) —
are described in the pages above, and with more detail in a series of papers by Peter Facione, Noreen Facione, Carol Giancarlo, and Joanne Gainen. I suggest The Motivation to Think in Working and Learning and Professional Judgment and the Disposition Toward Critical Thinking — or you can read the abstracts to see what looks interesting.

**Why should we teach Critical Thinking?**

In an essay that "takes a Socratic approach to defining critical thinking and identifying its value in one's personal, professional, educational, and civic life," Peter Facione (a dean at Santa Clara University) discusses "what and why" in Critical Thinking: What It Is and Why It Counts and concludes with a consensus statement (of experts in the field) about critical thinking and the ideal critical thinker:

"We understand critical thinking to be purposeful, self-regulatory judgment which results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations upon which that judgment is based. [Since this includes almost all types of logical reasoning,] CT is essential as a tool of inquiry. As such, CT is a liberating force in education and a powerful resource in one's personal and civic life. While not synonymous with good thinking, CT is a pervasive and self-rectifying human phenomenon. The ideal critical thinker is habitually inquisitive, well-informed, trustful of reason, open-minded, flexible, fair-minded in evaluation, honest in facing personal biases, prudent in making judgments, willing to reconsider, clear about issues, orderly in complex matters, diligent in seeking relevant information, reasonable in the selection of criteria, focused in inquiry, and persistent in seeking results which are as precise as the subject and
the circumstances of inquiry permit. Thus, educating good critical thinkers means working toward this ideal. It combines developing CT skills with nurturing those dispositions which consistently yield useful insights and which are the basis of a rational and democratic society."

Education in critical thinking offers an alternative to a drift toward postmodern relativism, by emphasizing that we can "distinguish between facts and opinions or personal feelings, judgments and inferences, inductive and deductive arguments, and the objective and subjective."

{MCC General Education Initiatives} Critical thinking encourages us to recognize that our "rationally justifiable confidence" in a claim can span a wide range, from feelings to fact and everything in between. Three Categories of Questions explains why, because students don't recognize questions involving "reasoned judgment" (which are neither fact nor opinion), they "fail to see the difference between offering legitimate reasons and evidence in support of a view and simply asserting the view as true."

**TEACHING Critical Thinking — Activities & Strategies**

Dany Adams explains how, "because the scientific method is a formalization of critical thinking, it can be used as a simple model that removes critical thinking from the realm of the intuitive and puts it at the center of a straightforward, easily implemented, teaching strategy," in Critical Thinking and Scientific Method.

ERIC Digests offers excellent introductory summary/overviews for teaching critical thinking in schools at all levels, from K-12 through higher education — How Can We Teach Critical Thinking? & Promoting Critical Thinking in the Classroom & Strategies for Teaching Critical Thinking — plus methods for teaching critical thinking in the contexts of
environmental education & literature & television & adult ESL. {All except "adult ESL" were written between 1989 and 1994, so they're not up-to-date, but most principles for "teaching critical thinking" were discovered/invented before 1989 and are still relevant today. } And ERIC has a wide range of resources, letting you search for research & other information about thinking skills (critical thinking, evaluative thinking, decision making, ...) and much more.

The evaluation of thinking skills is a challenge. Accurate evaluation of a thinking skill — or even defining precisely what the "skill" is, and how we can observe and measure it — is much more difficult than evaluating knowledge. Some educators have accepted the challenge, and Insight Assessment describes options for evaluation of critical thinking.

The Center for Critical Thinking (led by Richard Paul) offers a links-page for critical thinking education — scroll down their page to "Higher Education Strategies & Samples" and "K-12 Strategies & Samples" and "For Students"; and they describe research about critical thinking in colleges with links to "Effect of a Model for Critical Thinking..." and "The Effect of Richard Paul's Universal Elements..." and the full Executive Summary for a study of 56 universities (public & private) to "Determine Faculty Emphasis on Critical Thinking in Instruction." Of course, education also occurs outside schools, and most thinking occurs outside the classroom in everyday life and business (a workshop) and other areas of life.

**The Role of Critical Thinking in Education and Life**

All proponents of thinking skills (critical, creative,...) emphasize the relevance of thinking for many aspects of life, not just those usually
associated with "thinking." For example, the Critical Thinking Community says, "Critical thinking is the art of taking charge of your own mind. Its value is simple: if we can take charge of our own minds, we can take charge of our lives."

"Critical thinking is not an isolated goal unrelated to other important goals in education. Rather, it is a seminal goal which, done well, simultaneously facilitates a rainbow of other ends. It is best conceived, therefore, as the hub around which all other educational ends cluster. For example, as students learn to think more critically, they become more proficient at historical, scientific, and mathematical thinking. Finally, they develop skills, abilities, and values crucial to success in everyday life.

Recent research suggests that critical thinking is not typically an intrinsic part of instruction at any level. Students come without training in it, while faculty tend to take it for granted as an automatic by-product of their teaching. Yet without critical thinking systematically designed into instruction, learning is transitory and superficial."

The Logic of Critical Thinking

The essence of critical thinking is logic, and logical evaluation — by using reality checks and quality checks — is the essence of Scientific Method and Design Method. On the other end of the logic spectrum, we see a variety of Logical Fallacies that include circular reasoning and strawman arguments.
The Ethics of Critical Thinking

Peter Facione describes a limitation that occurs with all types of thinking:

A person can be good at critical thinking, meaning that the person can have the appropriate dispositions and be adept at the cognitive processes, while still not being a good (in the moral sense) critical thinker. For example, a person can be adept at developing arguments and then, unethically, use this skill to mislead and exploit a gullible person, perpetrate a fraud, or deliberately confuse and confound, and frustrate a project.

The experts were faced with an interesting problem. Some, a minority, would prefer to think that critical thinking, by its very nature, is inconsistent with the kinds of unethical and deliberately counterproductive examples given. They find it hard to imagine a person who was good at critical thinking not also being good in the broader personal and social sense. In other words, if a person were "really" a "good critical thinker" in the procedural sense and if the person had all the appropriate dispositions, then the person simply would not do those kinds of exploitive and aggravating things.

The large majority, however, hold the opposite judgment. They are firm in the view that good critical thinking has nothing to do with any given set of ethical values or social mores. The majority of experts maintain that critical thinking conceived of as we have described it above, is, regrettably, not inconsistent with its unethical use. A tool, an approach to situations, these can go either way, ethically speaking, depending on the character, integrity, and principles of the persons who possess them. So, in the final analysis the majority of experts maintained that "it is an
inappropriate use of the term to deny that someone is engaged in critical thinking on the grounds that one disapproves ethically of what the person is doing. What critical thinking means, why it is of value, and the ethics of its use are best regarded as three distinct concerns." Richard Paul describes two beneficial dispositions that are encouraged (but not guaranteed) by critical thinking education:

"Fair-minded thinkers take into account the interests of everyone affected by the problem and proposed solutions. They are more committed to finding the best solution than to getting their way." And a critical thinker "has confidence that, in the long run, one's own higher interests and those of humankind at large will be best served by giving the freest play to reason,... despite the deep-seated obstacles in the native character of the human mind and in society as we know it."

Yes, reason is useful, it is noble and desirable, and it should be highly valued and carefully developed. But we should keep things in perspective, regarding what reason can accomplish. Probably most of us will agree with Paul (about the value of critical thinking) but also with the majority of experts, who conclude that becoming skilled at critical thinking does not guarantee that this powerful tool will always be used for the benefit of others.

Critical thinking is an important and vital topic in modern education. All educators are interested in teaching critical thinking to their students. Many academic departments hope that its professors and instructors will become informed about the strategy of teaching critical thinking skills, identify areas in one's courses as the proper place to emphasize and teach critical thinking, and develop and use some problems in exams that test students' critical thinking skills. This critical
thinking manual has been prepared to inform and aid you to accomplish these things, and it has been kept brief and straightforward so that all faculty members will have the time and opportunity to read it and follow the suggestions it contains.

**Purpose and Rationale of Teaching Critical Thinking**

The purpose of specifically teaching critical thinking in the Sciences or any other discipline is to improve the thinking skills of students and thus better prepare them to succeed in the world. But, you may ask, don't we automatically teach critical thinking when we teach our subjects, especially mathematics and Science, the two disciplines which supposedly epitomize correct and logical thinking? The answer, sadly, is often no. Please consider these two quotations:

"It is strange that we expect students to learn, yet seldom teach them anything about learning." Donald Norman, 1980.

"We should be teaching students how to think. Instead, we are teaching them what to think." Clement and Lochhead, 1980.

Perhaps you can now see the problem. All education consists of transmitting to student’s two different things: (1) the subject matter or discipline content of the course ("what to think"), and (2) the correct way to understand and evaluate this subject matter ("how to think"). We do an excellent job of transmitting the content of our respective academic disciplines, but we often fail to teach students how to think effectively about this subject matter, that is, how to properly understand and evaluate it. This second ability is termed critical thinking. All educational disciplines have reported the difficulty of imparting critical thinking...
skills. In 1983, in its landmark report A Nation at Risk, the National Commission on Excellence in Education warned:

A final rationale for critical thinking is explained by William T. Daly (1990) in a short article, "Developing Critical Thinking Skills." He says that "the critical thinking movement in the U.S. has been bolstered and sustained by the business community's need to compete in a global economy. The general skill levels needed in the work force are going up while the skill levels of potential employees are going down. As a result, this particular educational reform movement will remain crucial to the education of the work force and the economy's performance in the global arena. This economic pressure to teach critical thinking skills will fall on educational institutions because these skills, for the most part, are rarely taught or reinforced outside formal educational institutions. Unfortunately, at the moment, they are also rarely taught inside educational institutions."

Critical thinking means correct thinking in the pursuit of relevant and reliable knowledge about the world. Another way to describe it is reasonable, reflective, responsible, and skillful thinking that is focused on deciding what to believe or do. A person who thinks critically can ask appropriate questions, gather relevant information, efficiently and creatively sort through this information, reason logically from this information, and come to reliable and trustworthy conclusions about the world that enable one to live and act successfully in it. Critical thinking is not being able to process information well enough to know to stop for red lights or whether you received the correct change at the supermarket. Such low-order thinking, critical and useful though it may be, is sufficient only for personal survival; most individuals master this. True critical thinking is higher-order thinking, enabling a person to, for example,
responsibly judge between political candidates, serve on a murder trial jury, evaluate society's need for nuclear power plants, and assess the consequences of global warming. Critical thinking enables an individual to be a responsible citizen who contributes to society, and not be merely a consumer of society's distractions.

Children are not born with the power to think critically, nor do they develop this ability naturally beyond survival-level thinking. Critical thinking is a learned ability that must be taught. Most individuals never learn it. Critical thinking cannot be taught reliably to students by peers or by most parents. Trained and knowledgeable instructors are necessary to impart the proper information and skills. Math and Science instructors have precisely this information and these skills. Why?

Critical thinking can be described as the scientific method applied by ordinary people to the ordinary world. This is true because critical thinking mimics the well-known method of scientific investigation: a question is identified, a hypothesis formulated, relevant data sought and gathered, the hypothesis is logically tested and evaluated, and reliable conclusions are drawn from the result. All of the skills of scientific investigation are matched by critical thinking, which is therefore nothing more than scientific method used in everyday life rather than in specifically scientific disciplines or endeavors. Critical thinking is scientific thinking. Many books and papers describing critical thinking present it's goals and methods as identical or similar to the goals and methods of Science. A scientifically-literate person, such as a math or Science instructor, has learned to think critically to achieve that level of scientific awareness. But any individual with an advanced degree in any university discipline has almost certainly learned the techniques of critical thinking.
Critical thinking is the ability to think for one's self and reliably and responsibly make those decisions that affect one's life. Critical thinking is also critical inquiry, so such critical thinkers investigate problems, ask questions, pose new answers that challenge the status quo, discover new information that can be used for good or ill, question authorities and traditional beliefs, challenge received dogmas and doctrines, and often end up possessing power in society greater than their numbers. It may be that a workable society or culture can tolerate only a small number of critical thinkers, that learning, internalizing, and practicing scientific and critical thinking is discouraged. Most people are followers of authority: most do not question, are not curious, and do not challenge authority figures who claim special knowledge or insight. Most people, therefore, do not think for themselves, but rely on others to think for them. Most people indulge in wishful, hopeful, and emotional thinking, believing that what they believe is true because they wish it, hope it, or feel it to be true. Most people, therefore, do not think critically.

Critical thinking has many components. Life can be described as a sequence of problems that each individual must solve for one's self. Critical thinking skills are nothing more than problem solving skills that result in reliable knowledge. Humans constantly process information. Critical thinking is the practice of processing this information in the most skillful, accurate, and rigorous manner possible, in such a way that it leads to the most reliable, logical, and trustworthy conclusions, upon which one can make responsible decisions about one's life, behavior, and actions with full knowledge of assumptions and consequences of those decisions.
Raymond S. Nickerson (1987), an authority on critical thinking, characterizes a good critical thinker in terms of knowledge, abilities, attitudes, and habitual ways of behaving.

**Characteristics of such a thinker**

1. uses evidence skillfully and impartially
2. Organizes thoughts and articulates them concisely and coherently
3. Distinguishes between logically valid and invalid inferences
4. suspends judgment in the absence of sufficient evidence to support a decision
5. understands the difference between reasoning and rationalizing
6. attempts to anticipate the probable consequences of alternative actions
7. understands the idea of degrees of belief
8. sees similarities and analogies that are not superficially apparent
9. can learn independently and has an abiding interest in doing so
10. applies problem-solving techniques in domains other than those in which learned.
11. can structure informally represented problems in such a way that formal techniques, such as mathematics, can be used to solve them
12. can strip a verbal argument of irrelevancies and phrase it in its essential terms.
13. habitually questions one's own views and attempts to understand both the assumptions that are critical to those views and the implications of the views
14. is sensitive to the difference between the validity of a belief and the intensity with which it is held
15. is aware of the fact that one's understanding is always limited, often much more so than would be apparent to one with a non-inquiring attitude.

16. recognizes the fallibility of one's own opinions, the probability of bias in those opinions, and the danger of weighting evidence according to personal preferences.

**Relationship of Critical Thinking to the Scientific Method**

Because of the identification of critical thinking as scientific thinking, it is reasonable to conclude that math and Science courses are a good place to learn critical thinking by learning the scientific method; unfortunately, this is not always true. Good scientists who conduct Science must practice critical thinking, and good Science teachers usually teach it, but few ordinary individuals learn the scientific method, even those who successfully take a number of Science classes in high school and college. This is because, as discussed above, Science in the United States is often poorly taught as a fact-based discipline rather than as a way of knowing or method of discovery. As incredible as it may seem, studies reveal that 3% of the U.S. population is scientifically literate, down from 5% about twenty years ago. Thus, it does not appear that Science alone will teach critical thinking to the masses. In fact, critical thinking programs are almost always designed by social scientists and directed toward improving thinking in the humanities and social studies, but the same can be accomplished with math and Science courses. Properly taught university courses should teach a student critical thinking in addition to the disciplinary content of the course.

It is useful to ask why the scientific method--now recognized, in its guise of critical thinking, as so important to modern education that
hundreds of critical thinking programs exist in thousands of schools across the nation--is so valuable for an individual to learn and practice. The reason is because the scientific method is the most powerful method ever invented by humans to obtain relevant and reliable knowledge about nature. Indeed, it is the only method humans have of discovering reliable knowledge (knowledge that has a high probability of being true). Another name for this type of knowledge is justified true belief (belief that is probably true because it has been obtained and justified by a reliable method). Nobel Prize-winner Sir Peter Medawar claimed that, "In terms of fulfillment of declared intentions, Science is incomparably the most successful enterprise human beings have ever engaged upon." Other methods of gaining knowledge--such as those using revelation, authority, artistic and moral insight, philosophical speculation, hopeful and wishful thinking, and other subjective and authoritarian means--have historically resulted in irrelevant and unreliable knowledge, and they are no better today. These nonscientific methods of discovering knowledge, however, are more popular than scientific methods despite their repeated failures in obtaining reliable knowledge. There are many reasons for this, but two of the most important are that nonscientific methods are (1) more congenial to emotional and hopeful human nature, and (2) are easier to learn and practice than scientific methods. Despite these reasons, however, the value and power of possessing reliable knowledge--as contrasted with the usual unreliable, misleading, irrelevant, inaccurate, wishful, hopeful, intuitive, and speculative knowledge most humans contend with--have caused modern government, business, and education leaders to place the scientific endeavor in high regard, and caused them to promote teaching the scientific method and its popular manifestation: critical thinking.
Humans are conditioned from birth to follow authority figures and not to question their pronouncements. Such conditioning is done by parents and teachers using a wide variety of positive and negative reinforcement techniques. Most individuals reach adulthood in this conditioned form. The result of such conditioning is the antithesis of both scientific investigation and critical thinking: individuals lack both curiosity and the skills to perform independent inquiry to discover reliable knowledge. Individuals who think critically can think for themselves: they can identify problems, gather relevant information, analyze information in a proper way, and come to reliable conclusions by themselves, without relying on others to do this for them. This is also the goal of Science education. Critical thinking allows one to face and comprehend objective reality by gaining reliable knowledge about the world. This, in turn, allows one to better earn a living, achieve success in life, better solve life's problems, and be reconciled to existence, mortality, and the universe. If a person is happier possessing reliable knowledge and living in objective reality, rather than living in ignorance and possessing false or unreliable beliefs, this is as good a reason as any for teaching and learning critical thinking.

 Formal Critical Thinking Programs

There are two ways to teach critical thinking in the classroom. The first method, and the one we will find endorsed in this manual, is also the easiest, least time-consuming, and the least expensive. This method is to simply modify one's teaching and testing methods slightly to enhance critical thinking among one's students. This method is explained in the following two sections.
The second method--more difficult, time-consuming, and expensive--is briefly described now. This method makes use of formal critical thinking exercises, programs, and materials that have been prepared by specialists and can be purchased for immediate use by the teacher or instructor. These materials are the dominant means by which critical thinking is now being taught in primary and secondary education. For a single classroom, school, or school district, such formal critical thinking materials cost hundreds to thousands of dollars. The fact that critical thinking programs exist today is a sad commentary on the decline of education in the United States, for students apparently once learned critical thinking in our country without such materials.

Dozens of formal critical thinking programs exist. Here are just three that arrived unsolicited in my faculty mailbox:

First, the "CORT Thinking Program" by Dr. Edward de Bono, is a set of 60 "thinking lessons" that promise to "succeed in motivating students of all ages and abilities to: think--and develop creative solutions to problems--both inside and outside the classroom, improve the quantity and quality of their creative writing, and see themselves as active thinkers, and therefore able to hold a better self image of themselves and have confidence in their own ability to succeed."

Second, the "Strategies for Teaching Critical Thinking across the Curriculum" from Education Testing Service consists of a two-phase professional development program for secondary-level educators that will enable them to "integrate the teaching of thinking skills into their instructional program, and train teachers in their schools and/or districts to do the same." Phase I teaches "introduction to thinking skills, concept formation, finding patterns, making inferences, formulating and testing
hypotheses, and understanding and constructing meaning." Phase II teaches the teachers to train other teachers.

The third program, from Teacher's Press, asks "Are you concerned when American teenagers lack logical thinking skill, equate influence with tricks and bribery, are unable to evaluate the reliability of data?" They have prepared high school course materials that actively address these concerns. For example, the description of their unit on "A Study of Logical Fallacies" states that, "Teaching critical thinking skills has long been accepted as a major goal of most teachers. Most probably say that they want to develop in their students a trusting, but questioning, world outlook. Most want students to actively investigate the world in a structured, scientific way--as opposed to blind acceptance of tradition, authority or folk wisdom."

Course Areas in Which to Emphasize Critical Thinking

The prior sections of this manual were written to describe critical thinking, to inform you about the pressing need to promote it among students, and to encourage you to make it part of your course curriculum and teaching method. Now you will learn where and how to do this in your own courses. Critical thinking can be presented or emphasized in all classroom areas: lecture, homework, term papers, and exams. We will examine each in turn. Some slight extra effort on the part of the instructor will be necessary, but the effort will be worthwhile because the results are so valuable for the student. Remember, as you teach critical thinking; teach also why it is worthwhile.
Critical thinking can be taught during:

1. **Lectures** You may of course directly teach critical thinking principles to your students during lecture, but this is neither required nor advisable. Stay with your subject matter, but present this is such a way that students will be encouraged to think critically about it. This is accomplished during lecture by questioning the students in ways that require that they not only understand the material, but can analyze it and apply it to new situations.

2. **Laboratories** Students inevitably practice critical thinking during laboratories in Science class, because they are learning the scientific method.

3. **Homework** Both traditional reading homework and special written problem sets or questions can be used to enhance critical thinking. Homework presents many opportunities to encourage critical thinking.

4. **Quantitative Exercises** Mathematical exercises and quantitative word problems teach problem solving skills that can be used in everyday life. This obviously enhances critical thinking.

5. **Term Papers** The best way to teach critical thinking is to require that students write. Writing forces students to organize their thoughts, contemplate their topic, evaluate their data in a logical fashion, and present their conclusions in a persuasive manner. Good writing is the epitome of good critical thinking.

6. **Exams** Exam questions can be devised which promote critical thinking rather than rote memorization. This is true for both essay question exams and multiple-choice exams.
SKILLS RELATED TO CRITICAL THINKING

Across subject areas and levels, educational research has identified several discrete skills related to an overall ability for critical thinking. These are:

Finding analogies and other kinds of relationships between pieces of information

Determining the relevance and validity of information that could be used for structuring and solving problems

Finding and evaluating solutions or alternative ways of treating problems

Just as there are similarities among the definitions of critical thinking across subject areas and levels, there are several generally recognized "hallmarks" of teaching for critical thinking (see, for example, Beyer, 1985; Costa, 1985). These include:

Promoting interaction among students as they learn - Learning in a group setting often helps each member achieve more.

Asking open-ended questions that do not assume the "one right answer" - Critical thinking is often exemplified best when the problems are inherently ill-defined and do not have a "right" answer. Open-ended questions also encourage students to think and respond creatively, without fear of giving the "wrong" answer.

Allowing sufficient time for students to reflect on the questions asked or problems posed - Critical thinking seldom involves snap judgments;
therefore, posing questions and allowing adequate time before soliciting responses helps students understand that they are expected to deliberate and to ponder, and that the immediate response is not always the best response.

Teaching for transfer - The skills for critical thinking should "travel well." They generally will do so only if teachers provide opportunities for students to see how a newly acquired skill can apply to other situations and to the student's own experience.

**FINDING PROBLEMS**

Many students and teachers alike have lamented that the format of problems in the classroom (particularly in math and Science) bears little resemblance to the way problems look in real life. In fact, one of the most important practical thinking skills one can acquire knows how to identify a problem. The Finding Problems strategy is a way of framing tasks so that students use skills similar to those needed for the ill-defined problems they will encounter in life. Tasks developed with this strategy are sufficiently defined as to be solvable, but do not state explicitly which variable or aspect of the problem will constitute or enable a solution. Consider the following Physics problem (adapted from Harvie, 1987):

"Brian, all 72 kg of him, bungee-jumps from a 100-m tower toward the river below. He falls 35 m before the bungee cord starts to stretch. This cord can stretch 40% of its length and has a breaking strength of 7000 N. Will this become a "free fall" for Brian, or will he "bounce back"?
Consider an alternate version of this problem, in which the last sentence is replaced by the following: "When the bungee cord has reached its maximum length, does the tension exceed the cord's breaking strength?" Several aspects of the first version make it more effective for encouraging students to think rather than simply to look for the appropriate quantities to "plug in" to a formula.

The first version does not specify what must be calculated; therefore, it requires students to decide for themselves just what the problem is and how their knowledge of Physics can be used to solve it. Teachers can help students learn to solve problems of this type by first providing them with a set of general questions, such as: How are the objects and situations in the problem similar to any objects or situations that were discussed in Physics? Which variables are already in Physics terms and which can be converted to Physics terms? Are all of the pieces of information in the problem relevant to its solution?

Problem-finding is an excellent group activity, particularly if two or more groups work on the same task independently and then come together to compare strategies. In this way, each student has the benefit of exposure to several ways of solving the problem.

ENHANCING THE ENVIRONMENT (after Keefe & Walberg, 1992)

Critical thinking in the classroom is facilitated by a physical and intellectual environment that encourages a spirit of discovery. Regarding the physical layout of the classroom, two suggestions can be offered. First, if seating is arranged so that students share the "stage" with the teacher and all can see and interact with each other, this helps to minimize the passive, receptive mode many students
adopt when all are facing the teacher. Second, visual aids in the classroom can encourage ongoing attention to critical thought processes, e.g., posting signs that say, "Why do I think that?" "Is it fact or opinion?" "How are these two things alike?" "What would happen if...?" Suggestions below each question can remind students how they should go about answering them. Most importantly, as the students move through the curriculum in a given subject, their attention can be directed periodically to the signs as appropriate. In this way, the signs emphasize the idea of transfer by showing that many of the same thinking strategies and skills apply to different topics and problems.

"We understand critical thinking to be purposeful, self-regulatory judgment which results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations upon which that judgment is based. CT is essential as a tool of inquiry. As such, CT is a liberating force in education and a powerful resource in one's personal and civic life. While not synonymous with good thinking, CT is a pervasive and self-rectifying human phenomenon. The ideal critical thinker is habitually inquisitive, well-informed, trustful of reason, open-minded, flexible, fair-minded in evaluation, honest in facing personal biases, prudent in making judgments, willing to reconsider, clear about issues, orderly in complex matters, diligent in seeking relevant information, reasonable in the selection of criteria, focused in inquiry, and persistent in seeking results which are as precise as the subject and the circumstances of inquiry permit. Thus, educating good critical thinkers means working toward this ideal. It combines developing CT skills with nurturing those dispositions which consistently yield useful insights and which are the basis of a rational and democratic society."
Education in critical thinking offers an alternative to a drift toward postmodern relativism, by emphasizing that we can "distinguish between facts and opinions or personal feelings, judgments and inferences, inductive and deductive arguments, and the objective and subjective." {MCC General Education Initiatives} Critical thinking encourages us to recognize that our "rationally justifiable confidence" in a claim can span a wide range, from feelings to fact and everything in between. Three Categories of Questions explains why, because students don't recognize questions involving "reasoned judgment" (which are neither fact nor opinion), they "fail to see the difference between offering legitimate reasons and evidence in support of a view and simply asserting the view as true."

All proponents of thinking skills emphasize the relevance of thinking for many aspects of life, not just those usually associated with "thinking." For example, the Critical Thinking Community says, "Critical thinking is the art of taking charge of your own mind. Its value is simple: if we can take charge of our own minds, we can take charge of our lives."

"Critical thinking is not an isolated goal unrelated to other important goals in education. Rather, it is a seminal goal which, done well, simultaneously facilitates a rainbow of other ends. It is best conceived, therefore, as the hub around which all other educational ends cluster. For example, as students learn to think more critically, they become more proficient at historical, scientific, and mathematical thinking. Finally, they develop skills, abilities, and values crucial to success in everyday life."
Recent research suggests that critical thinking is not typically an intrinsic part of instruction at any level. Students come without training in it, while faculty tends to take it for granted as an automatic by-product of their teaching. Yet without critical thinking systematically designed into instruction, learning is transitory and superficial."

**Peter Facione describes a limitation that occurs with all types of thinking:**

A person can be good at critical thinking, meaning that the person can have the appropriate dispositions and be adept at the cognitive processes, while still not being a good (in the moral sense) critical thinker. For example, a person can be adept at developing arguments and then, unethically, use this skill to mislead and exploit a gullible person, perpetrate a fraud, or deliberately confuse and confound, and frustrate a project.

The experts were faced with an interesting problem. Some, a minority, would prefer to think that critical thinking, by its very nature, is inconsistent with the kinds of unethical and deliberately counterproductive examples given. They find it hard to imagine a person who was good at critical thinking not also being good in the broader personal and social sense.

The large majority, however, hold the opposite judgment. They are firm in the view that good critical thinking has nothing to do with any given set of ethical values or social mores. The majority of experts maintain that critical thinking conceived of as we have described it above, is, regrettably, not inconsistent with its unethical use. A tool, an approach to situations, these can go either way, ethically speaking, depending on
the character, integrity, and principles of the persons who possess them. So, in the final analysis the majority of experts maintained that "it is an inappropriate use of the term to deny that someone is engaged in critical thinking on the grounds that one disapproves ethically of what the person is doing. What critical thinking means, why it is of value, and the ethics of its use are best regarded as three distinct concerns."

Richard Paul describes two beneficial dispositions that are encouraged (but not guaranteed) by critical thinking education:

"Fair minded thinkers take into account the interests of everyone affected by the problem and proposed solutions. They are more committed to finding the best solution than to getting their way." And a critical thinker "has confidence that, in the long run, one's own higher interests and those of humankind at large will be best served by giving the freest play to reason,... despite the deep-seated obstacles in the native character of the human mind and in society as we know it."

When teachers become advocates of quality thinking and learning, students are regularly required to:

1) State and explain goals and purposes,

2) clarify the questions they need to answer and the problems they need to solve,

3) Gather and organize information and data,

4) Explicitly assess the meaning and significance of information you give them,

5) Demonstrate that they understand concepts,
6) Identify assumptions,

7) consider implications and consequences,

8) Examine things from more than one point of view,

9) State what they say clearly,

10) Test and check for accuracy,

11) Stick to questions, issues, or problems; and not wander in their thinking,

12) Express themselves precisely and exactly,

13) Deal with complexities in problems and issues,

14) Consider the point of view of others,

15) Express their thinking logically,

16) Distinguish significant matters from insignificant ones,

And as a result of such instruction, the students (in general):

1) Learn content at a deeper and more permanent level

2) Are better able to explain and apply what they learn,

3) Are better able to connect what they are learning in one class with what they are learning in other classes,

4) Ask more and better questions in class,

5) Understand the textbook better,
6) Follow directions better,

7) Understand more of what you present in class,

8) Write better,

9) Apply more of what they are learning to their everyday life,

10) Become more motivated learners in general,

11) Become progressively easier to teach.

Yes, reason is useful, it is noble and desirable, and it should be highly valued and carefully developed. But we should keep things in perspective, regarding what reason can accomplish. The majority of experts, who conclude that becoming skilled at critical thinking, does not guarantee that this powerful tool will always be used for the benefit of others.

**Raymond S. Nickerson (1987), an authority on critical thinking,** characterizes a good critical thinker in terms of knowledge, abilities, attitudes, and habitual ways of behaving. Here are some of the characteristics of such a thinker:

- uses evidence skillfully and impartially
- organizes thoughts and articulates them concisely and coherently
- distinguishes between logically valid and invalid inferences
• suspends judgment in the absence of sufficient evidence to support a decision

• understands the difference between reasoning and rationalizing

• attempts to anticipate the probable consequences of alternative actions

• understands the idea of degrees of belief

• sees similarities and analogies that are not superficially apparent

• can learn independently and has an abiding interest in doing so

• applies problem-solving techniques in domains other than those in which learned

• can structure informally represented problems in such a way that formal techniques, such as mathematics, can be used to solve them

• can strip a verbal argument of irrelevancies and phrase it in its essential terms

• habitually questions one's own views and attempts to understand both the assumptions that are critical to those views and the implications of the views
• is sensitive to the difference between the validity of a belief and the intensity with which it is held

• is aware of the fact that one's understanding is always limited, often much more so than would be apparent to one with a non inquiring attitude

• recognizes the fallibility of one's own opinions, the probability of bias in those opinions, and the danger of weighting evidence according to personal preferences

Paul, Binker, Jensen, and Kreklau (1990) have developed a list of 35 dimensions of critical thought:

"A. Affective Strategies

S-1 thinking independently

S-2 developing insight into egocentricity or socio centricity

S-3 exercising fair mindedness

S-4 exploring thoughts underlying feelings and feelings underlying thoughts

S-5 developing intellectual humility and suspending judgment

S-6 developing intellectual courage

S-7 developing intellectual good faith or integrity

S-8 developing intellectual perseverance
S-9 developing confidence in reason

B. Cognitive Strategies--Macro-Abilities

S-10 refining generalizations and avoiding oversimplifications

S-11 comparing analogous situations: transferring insights to new contexts

S-12 developing one's perspective: creating or exploring beliefs, arguments, or theories

S-13 clarifying issues, conclusions, or beliefs

S-14 clarifying and analyzing the meanings of words or phrases

S-15 developing criteria for evaluation: clarifying values and standards

S-16 evaluating the credibility of sources of information

S-17 questioning deeply: raising and pursuing root or significant questions

S-18 analyzing or evaluating arguments, interpretations, beliefs, or theories

S-19 generating or assessing solutions

S-20 analyzing or evaluating actions or policies

S-21 reading critically: clarifying or critiquing texts

S-22 listening critically: the art of silent dialogue

S-23 making interdisciplinary connections
S-24 practicing Socratic discussion: clarifying and questioning beliefs, theories, or perspectives

S-25 reasoning dialogically: comparing perspectives, interpretations, or theories

S-26 reasoning dialectically: evaluating perspectives, interpretations, or theories

C. Cognitive Strategies--Micro-Skills

S-27 comparing and contrasting ideals with actual practice

S-28 thinking precisely about thinking: using critical vocabulary

S-29 noting significant similarities and differences

S-30 examining or evaluating assumptions

S-31 distinguishing relevant from irrelevant facts

S-32 making plausible inferences, predictions, or interpretations

S-33 evaluating evidence and alleged facts

S-34 recognizing contradictions

S-35 exploring implications and consequences"
AFFECTIVE STRATEGIES

S-1 Thinking Independently
Principle: Critical thinking is independent thinking, thinking for oneself. Many of our beliefs are acquired at an early age, when we have a strong tendency to form beliefs for irrational reasons (because we want to believe, because we are praised or rewarded for believing). Critical thinkers use critical skills and insights to reveal and reject beliefs that are irrational.

In forming new beliefs, critical thinkers do not passively accept the beliefs of others; rather, they try to figure things out for themselves, reject unjustified authorities, and recognize the contributions of genuine authorities. They thoughtfully form principles of thought and action; they do not mindlessly accept those presented to them. Nor are they unduly influenced by the language of another. If they find that a set of categories or distinctions is more appropriate than that used by another, they will use it. Recognizing that categories serve human purposes, they use those categories which best serve their purpose at the time. They are not limited by accepted ways of doing things. They evaluate both goals and how to achieve them. They do not accept as true, or reject as false, beliefs they do not understand. They are not easily manipulated. Independent thinkers strive to incorporate all known relevant knowledge and insight into their thought and behavior. They strive to determine for themselves when information is relevant, when to apply a concept, or when to make use of a skill. They are self-monitoring: they catch their own mistakes; they don't need to be told what to do every step of the way.

S-2 Developing Insight into Egocentricity or Sociocentricity
Principle: Egocentricity means confusing what we see and think with reality. When under the influence of egocentricity, we think that the way
we see things is exactly the way things are. Egocentricity manifests itself as an inability or unwillingness to consider others' points of view, a refusal to accept ideas or facts which would prevent us from getting what we want (or think we want).

In its extreme forms, it is characterized by a need to be right about everything, a lack of interest in consistency and clarity, an all or nothing attitude ("I am 100% right; you are 100% wrong."), and a lack of self-consciousness of one's own thought processes. The egocentric individual is more concerned with the appearance of truth, fairness, and fair-mindedness, than with actually being correct, fair, or fair-minded. Egocentricity is the opposite of critical thought. It is common in adults as well as in children.

As people are socialized, egocentricity partly evolves into sociocentricity. Egocentric tendencies extend to their groups. The individual goes from "I am right!" to "We are right!" To put this way, people find that they can often best satisfy their egocentric desires through a group. "Group think" results when people egocentrically attach themselves to a group. One can see this in both children and adults: My daddy is better than your daddy! My school (religion, country, race, etc.) is better than yours. Uncritical thinkers often confuse loyalty with always supporting and agreeing, even when the other person or the group is wrong. If egocentricity and sociocentricity are the disease, self-awareness is the cure. We need to become aware of our own tendency to confuse our view with "The Truth". People can often recognize when someone else is egocentric. Most of us can identify the sociocentricity of members of opposing groups. Yet when we ourselves are thinking egocentrically or sociocentrically, it seems right to us (at least at the time).
Our belief in our own rightness is easier to maintain because we ignore the faults in our thinking. We automatically hide our egocentricity from ourselves. We fail to notice when our behavior contradicts our self-image. We base our reasoning on false assumptions we are unaware of making. We fail to make relevant distinctions (of which we are otherwise aware and able to make) when making them prevents us from getting what we want. We deny or conveniently "forget" facts that do not support our conclusions. We often misunderstand or distort what others say.

The solution, then, is to reflect on our reasoning and behavior; to make our beliefs explicit, critique them, and, when they are false, stop making them; to apply the same concepts in the same ways to ourselves and others; to consider every relevant fact, and to make our conclusions consistent with the evidence; and to listen carefully and open-mindedly to others. We can change egocentric tendencies when we see them for what they are: irrational and unjust. The development of children's awareness of their egocentric and sociocentric patterns of thought is a crucial part of education in critical thinking. This development will be modest at first but can grow considerably over time.

**S-3 Exercising Fair-mindedness**

Principle: To think critically, we must be able to consider the strengths and weaknesses of opposing points of view; to imaginatively put ourselves in the place of others in order to genuinely understand them; to overcome our egocentric tendency to identify truth with our immediate perceptions or long-standing thought or belief.

This trait is linked to the ability to accurately reconstruct the viewpoints and reasoning of others and to reason from premises, assumptions, and ideas other than our own. This trait also requires the willingness to remember occasions when we were wrong in the past.
despite an intense conviction that we were right, as well as the ability to imagine our being similarly deceived in a case at hand. Critical thinkers realize the unfairness of judging unfamiliar ideas until they fully understand them. The world consists of many societies and peoples with many different points of view and ways of thinking. To develop as reasonable persons, we need to enter into and think within the frameworks and ideas of different peoples and societies. We cannot truly understand the world if we think about it only from one viewpoint, as Americans, as Italians, or as Soviets. Furthermore, critical thinkers recognize that their behavior affects others, and so consider their behavior from the perspective of those others.

S-4 Exploring Thoughts Underlying Feelings and Feelings Underlying Thoughts
Principle: Although it is common to separate thought and feeling as though they were independent, opposing forces in the human mind, the truth is that virtually all human feelings are based on some level of thought and virtually all thought generative of some level of feeling. To think with self-understanding and insight, we must come to terms with the intimate connections between thought and feeling, reason and emotion.

Critical thinkers realize that their feelings are their response (but not the only possible, or even necessarily the most reasonable response) to a situation. They know that their feelings would be different if they had a different understanding or interpretation of the situation. They recognize that thoughts and feelings, far from being different kinds of "things", are two aspects of their responses. Uncritical thinkers see little or no relationship between their feelings and their thoughts, and so escape responsibility for their thoughts, feelings, and actions. Their own feelings
often seem unintelligible to them. When we feel sad or depressed, it is often because we are interpreting our situation in an overly negative or pessimistic light. We may be forgetting to consider positive aspects of our lives.

We can better understand our feelings by asking ourselves, "How have I come to feel this way? How am I looking at the situation? To what conclusion have I come? What is my evidence? What assumptions am I making? What inferences am I making? Are they sound inferences? Do my conclusions make sense? Are there other ways to interpret this situation?" We can learn to seek patterns in our assumptions, and so begin to see the unity behind our separate emotions. Understanding ourselves is the first step toward self-control and self-improvement. This self-understanding requires that we understand our feelings and emotions in relation to our thoughts, ideas, and interpretations of the world.

**S-5 Developing Intellectual Humility and Suspending Judgment**

Principle: Critical thinkers recognize the limits of their knowledge. They are sensitive to circumstances in which their native egocentricity is likely to function self-deceptively; they are sensitive to bias, prejudice, and limitations of their views. Intellectual humility is based on the recognition that one should not claim more than one actually knows. It does not imply spinelessness or submissiveness.

It implies the lack of intellectual pretentiousness, arrogance, or conceit. It implies insight into the foundations of one's beliefs: knowing what evidence one has how one has come to believe what further evidence one might look for or examine. Thus, critical thinkers distinguish what they know from what they don't know. They are not afraid of saying "I don't know" when they are not in a position to be sure. They can make this distinction because they habitually ask themselves,
"How could one know whether or not this is true?" To say "In this case I must suspend judgment until I find out x and y", does not make them anxious or uncomfortable. They are willing to rethink conclusions in the light of new knowledge. They qualify their claims appropriately.

In exposing children to concepts within a field of knowledge, we can help them see how all concepts depend on other, more basic concepts and how each field is based on fundamental assumptions which need to be examined, understood, and justified. The class should often explore the connections between specific details and basic concepts or principles. We can help children discover experiences in their own lives which help support or justify what a text says. We should always be willing to entertain student doubts about what a text says. Judgment

**S-6 Developing Intellectual Courage**

Principle: To think independently and fairly, one must feel the need to face and fairly deal with unpopular ideas, beliefs, or viewpoints. The courage to do so arises when we see that ideas considered dangerous or absurd are sometimes rationally justified (in whole or in part) and that conclusions or beliefs inculcated in us are sometimes false or misleading.

To determine for ourselves which is which, we must not passively and uncritically accept what we have "learned". We need courage to admit the truth in some ideas considered dangerous and absurd, and the distortion or falsity in some ideas strongly held in our social group. It will take courage to be true to our own thinking, for honestly questioning our deeply held beliefs can be difficult and sometimes frightening, and the penalties for non-conformity are often severe. Judgment

**S-7 Developing Intellectual Good Faith or Integrity**

Principle: Critical thinkers recognize the need to be true to their own thought, to be consistent in the intellectual standards they apply, to hold
themselves to the same rigorous standards of evidence and proof to which they hold others, to practice what they advocate for others, and to honestly admit discrepancies and inconsistencies in their own thought and action. They believe most strongly what has been justified by their own thought and analyzed experience.

They have a commitment to bringing the self they are and the self they want to be together. People in general are often inconsistent in their application of standards once their ego is involved positively or negatively. For instance, when people like us, we tend to over-estimate their positive characteristics; when they dislike us, we tend to underrate them.

**S-8 Developing Intellectual Perseverance**

Principle: Becoming a more critical thinker is not easy. It takes time and effort. Critical thinking is reflective and recursive; that is, we often think back to previous problems to re-consider or re-analyze them. Critical thinkers are willing to pursue intellectual insights and truths in spite of difficulties, obstacles, and frustrations.

They recognize the need to struggle with confusion and unsettled questions over time in order to achieve deeper understanding and insight. They recognize that significant change requires patience and hard work. Important issues often require extended thought, research, and struggle. Considering a new view takes time. Yet people are often impatient to "get on with it" when they most need to slow down and think carefully. People rarely define issues or problems clearly; concepts are often left vague; related issues are not sorted out, etc. When people don't understand a problem or situation, their reactions and solutions often compound the original problem. Children need to gain insight into the need for intellectual perseverance.
S-9 Developing Confidence in Reason

Principle: The rational person recognizes the power of reason and the value of disciplining thinking in accordance with rational standards. Virtually all of the progress that has been made in Science and human knowledge testifies to this power, and so to the reasonability of having confidence in reason.

To develop this faith in reason is to come to see that ultimately one's own higher interests and those of humankind at large will best be served by giving the freest play to reason, by encouraging people to come to their own conclusions through a process of developing their own rational faculties. It is to reject force and trickery as standard ways of changing another's mind. It is to believe that, with proper encouragement and cultivation, people can develop the ability to think for themselves, to form reasonable points of view, draw reasonable conclusions, think clearly and logically, persuade each other by reason and, ultimately, become reasonable persons, despite the deep-seated obstacles in the native character of the human mind and in society as we know it.

This confidence is essential to building a democracy in which people come to genuine rule, rather than being manipulated by the mass media, special interests, or by the inner prejudices, fears, and irrationalities that so easily and commonly dominate human minds. You should note that the act of faith we are recommending is not blind faith, but should be tested in everyday experiences and academic work. In other words, we should have confidence in reason because reason works. Confidence in reason does not deny the reality of intuition; rather, it provides a way of distinguishing intuition from prejudice. When we know the source of our thinking and keep our minds open to new reason and evidence, we will be more likely to correct our prejudiced thought. At the
heart of this principle of faith in reason is the desire to make sense of the world and the expectation that sense can be made. Texts often don't make sense to children, sometimes because what they say doesn't make sense; more often because children aren't given time to make sense out of what they are told.

Being continually called upon to "master" what seems nonsensical undermines the feeling that one can make sense of the world. Many children, rushed through mountains of material, give up on this early. ("If I try to make sense of this, I'll never finish. Trying to really understand just slows me down. Nobody expects me to make sense of this; they just want me to do it.")

**Cognitive Strategies - Macro-Abilities**

**S-10 Refining Generalizations and Avoiding Oversimplifications**

Principle: It is natural to seek to simplify problems and experiences to make them easier to deal with. Everyone does this. However, the uncritical thinker often oversimplifies and as a result misrepresents problems and experiences.

What should be recognized as complex, intricate, ambiguous, or subtle is viewed as simple, elementary, clear, and obvious. For example, it is typically an oversimplification to view people or groups as all good or all bad, actions as always right or always wrong, one contributing factor as the cause, etc., and yet such beliefs are common.

Critical thinkers try to find simplifying patterns and solutions, but not by misrepresentation or distortion. Seeing the difference between useful simplifications and misleading oversimplifications is important to critical thinking. Critical thinkers scrutinize generalizations, probe for possible exceptions, and then use appropriate qualifications. Critical
thinkers are not only clear, but also exact and precise. One of the strongest tendencies of the egocentric, uncritical mind is to see things in terms of black and white, "all right" and "all wrong". Hence, beliefs which should be held with varying degrees of certainty are held as certain. Critical thinkers are sensitive to this problem. They understand the important relationship of evidence to belief and so qualify their statements accordingly. The tentativeness of many of their beliefs is characterized by the appropriate use of such qualifiers as 'highly likely', 'probably', 'not very likely', 'highly unlikely', 'often', 'usually', 'seldom', 'I doubt', 'I suspect', 'most', 'many', and 'some'.

S-11 Comparing Analogous Situations: Transferring Insights to New Contexts

Principle: An idea's power is limited by our ability to use it. Critical thinkers' ability to use ideas mindfully enhances their ability to transfer ideas critically. They practice using ideas and insights by appropriately applying them to new situations. This allows them to organize materials and experiences in different ways, to compare and contrast alternative labels, to integrate their understanding of different situations, and to find useful ways to think about new situations.

Every time we use an insight or principle, we increase our understanding of both the insight and the situation to which we have applied it. True education provides for more than one way to organize material. For example, history can be organized in our minds by geography, chronology, or by such phenomena as repeated patterns, common situations, analogous "stories", and so on. The truly educated person is not trapped by one organizing principle, but can take knowledge apart and put it together many different ways. Each way of organizing knowledge has some benefit.
S-12 Developing One's Perspective: Creating or Exploring Beliefs, Arguments, or Theories

Principle: The world is not given to us sliced up into categories with pre-assigned labels on them. There are always many ways to "divide up" and so experience the world. How we do so is essential to our thinking and behavior. Uncritical thinkers assume that their perspective on things is the only correct one. Selfish critical thinkers manipulate the perspectives of others to gain advantage for themselves.

Fair-minded critical thinkers learn to recognize that their own ways of thinking and that of all other perspectives are some combination of insight and error. They learn to develop their points of view through a critical analysis of their experience. They learn to question commonly accepted ways of understanding things and avoid uncritically accepting the viewpoints of their peers or society. They know what their perspectives are and can talk insightfully about them. To do this, they must create and explore their own beliefs, their own reasoning, and their own theories.

S-13 Clarifying Issues, Conclusions, or Beliefs

Principle: The more completely, clearly, and accurately an issue or statement is formulated, the easier and more helpful the discussion of its settlement or verification. Given a clear statement of an issue, and prior to evaluating conclusions or solutions, it is important to recognize what is required to settle it. And before we can agree or disagree with a claim, we must understand it clearly.

It makes no sense to say "I don't know what you mean, but I deny it, whatever it is." Critical thinkers recognize problematic claims, concepts, and standards of evaluation, making sure that understanding precedes judgment. They routinely distinguish facts from interpretations,
opinions, judgments, or theories. They can then raise those questions most appropriate to understanding and evaluating each.

**S-14 Clarifying and Analyzing the Meanings of Words or Phrases**

Principle: Critical, independent thinking requires clarity of thought. A clear thinker understands concepts and knows what kind of evidence is required to justify applying a word or phrase to a situation. The ability to supply a definition is not proof of understanding. One must be able to supply clear, obvious examples and use the concept appropriately. In contrast, for an unclear thinker, words float through the mind unattached to clear, specific, concrete cases. Distinct concepts are confused.

Often the only criterion for the application of a term is that the case in question "seems like" an example. Irrelevant associations are confused with what are necessary parts of the concept (e.g., "Love involves flowers and candlelight.") Unclear thinkers lack independence of thought because they lack the ability to analyze a concept, and so critique its use.

**S-15 Developing Criteria for Evaluation: Clarifying Values and Standards**

Principle: Critical thinkers realize that expressing mere preference does not substitute for evaluating something. Awareness of the process or components of evaluating facilitates thoughtful and fair-minded evaluation. This process requires developing and using criteria or standards of evaluation, or making standards or criteria explicit.

Critical thinkers are aware of the values on which they base their judgments. They have clarified them and understand why they are values. When developing criteria, critical thinkers should understand the object and purpose of the evaluation, and what function the thing being evaluated is supposed to serve. Critical thinkers take into consideration different points of view when attempting to evaluate something.
S-16 Evaluating the Credibility of Sources of Information
Principle: Critical thinkers recognize the importance of using reliable sources of information. They give less weight to sources which either lack a track record of honesty, are not in a position to know, or have a vested interest in the issue. Critical thinkers recognize when there is more than one reasonable position to be taken on an issue; they compare alternative sources of information, noting areas of agreement; they analyze questions to determine whether or not the source is in a position to know; and they gather more information when sources disagree.

They recognize obstacles to gathering accurate and pertinent information. They realize that preconception, for example, influences observation—that we often see only what we expect to see and fail to notice things we aren't looking for.

S-17 Questioning Deeply: Raising and Pursuing Root or Significant Questions
Principle: Critical thinkers can pursue an issue in depth, covering various aspects in an extended process of thought or discussion. When reading a passage, they look for issues and concepts underlying the claims expressed. They come to their own understanding of the details they learn, placing them in the larger framework of the subject and their overall perspectives. They contemplate the significant issues and questions underlying subjects or problems studied. They can move between basic underlying ideas and specific details.

When pursuing a line of thought, they are not continually dragged off the subject. They use important issues to organize their thought and are not bound by the organization given by another. Each of the various subject areas has been developed to clarify and settle questions peculiar
to it. The teacher can use such questions to organize and unify details covered in each subject.

Perhaps more important are basic questions everyone faces about what people are like, the nature of right and wrong, how we know things, and so on. Both general and subject-specific basic questions should be repeatedly raised and used as a framework for organizing details children are learning.

**S-18 Analyzing or Evaluating Arguments, Interpretations, Beliefs, or Theories**

Principle: Rather than carelessly agreeing or disagreeing with a conclusion based on their preconceptions of what is true, critical thinkers use analytic tools to understand the reasoning behind it and determine its relative strengths and weaknesses. When analyzing arguments, critical thinkers recognize the importance of asking for reasons and considering other views.

They are especially sensitive to possible strengths of arguments that they disagree with, recognizing the tendency to ignore, oversimplify, distort, or otherwise unfairly dismiss them. Critical thinkers analyze questions and place conflicting arguments, interpretations, and theories in opposition to one another, as a means of highlighting key concepts, assumptions, implications, etc. When giving or being given an interpretation, critical thinkers, recognizing the difference between evidence and interpretation, explore the assumptions on which interpretations are based and propose and evaluate alternative interpretations for their relative strength. Autonomous thinkers consider competing theories and develop their own theories.
S-19 Generating or Assessing Solutions
Principle: Critical problem-solvers use everything available to them to find the best solution they can. They evaluate solutions, not independently of, but in relation to one another (since 'best' implies a comparison). They take the time to formulate problems clearly, accurately, and fairly, rather than offering a sloppy, half-baked, or self-serving description ("Susie's mean!" "This isn't going well, how can we do it better?") and then immediately leaping to solutions. They examine the causes of the problem at length. They reflect on such questions as, "What makes some solutions better than others? What does the solution to this problem require? What solutions have been tried for this and similar problems? With what results?" But alternative solutions are often not given; they must be generated or thought up. Critical thinkers must be creative thinkers as well, generating possible solutions in order to find the best one. Very often a problem persists, not because we can't tell which available solution is best, but because the best solution has not yet been made available-no one has thought of it yet.

Therefore, although critical thinkers use all available information relevant to their problems, including solutions others have tried in similar situations, they are flexible and imaginative, willing to try any good idea whether it has been done before or not. Fair-minded thinkers take into account the interests of everyone affected by the problem and proposed solutions. They are more committed to finding the best solution than to getting their way. They approach problems realistically.

S-20 Analyzing or Evaluating Actions and Policies
Principle: To develop one's perspective, one must analyze actions and policies and evaluate them. Good judgment is best developed through practice: judging behavior, explaining and justifying those judgments,
hearing alternative judgments and their justifications, and assessing judgments. When evaluating the behavior of themselves and others, critical thinkers are aware of the standards they use, so that these, too, can become objects of evaluation.

Critical thinkers examine the consequences of actions and recognize these as fundamental to the standards for assessing behavior and policy. Critical thinkers base their evaluations of behavior on assumptions which they have reasoned through. They can articulate and rationally apply principles.

S-21 Reading Critically: Clarifying or Critiquing Texts

Principle: Critical thinkers read with a healthy skepticism. But they do not doubt or deny until they understand. They clarify before they judge. Since they expect intelligibility from what they read, they check and double-check their understanding as they read. They do not mindlessly accept nonsense. Critical readers ask themselves questions as they read, wonder about the implications of, reasons for, examples of, and meaning and truth of the material.

They do not approach written material as a collection of sentences, but as a whole, trying out various interpretations until one fits all of the work, rather than ignoring or distorting what doesn't fit their interpretation. They realize that everyone is capable of making mistakes and being wrong, including authors of textbooks. They also realize that, since everyone has a point of view, everyone sometimes leaves out some relevant information. No two authors would write the same book or write from exactly the same perspective. Therefore, critical readers recognize that reading a book is reading one limited perspective on a subject and that more can be learned by considering other perspectives.
S-22 Listening Critically: The Art of Silent Dialogue

Principle: Critical thinkers realize that listening can be done passively and uncritically or actively and critically. They know that it is easy to misunderstand what is said by another and hard to integrate another's thinking into one's own. Compare speaking and listening. When we speak, we need only keep track of our own ideas, arranging them in some order, expressing thoughts with which we are intimately familiar: our own.

But listening is more complex. We must take the words of another and translate them into ideas that make sense to us. We have not had the experiences of the speaker. We are not on the inside of his or her point of view. When we listen to others, we can't anticipate, as they can themselves, where their thoughts are leading them. We must continually interpret what others say within the confines of our experiences. We must find a way to enter into their points of view, shift our minds to follow their train of thought. Consequently, we need to learn how to listen actively and critically. We need to recognize that listening is an art involving skills that we can develop only with time and practice. We must realize, for example, that to listen and learn from what we are hearing, we need to learn to ask key questions that enable us to locate ourselves in the thought of another: "I'm not sure I understand you when you say..., could you explain that further?" "Could you give me an example or illustration of this?" "Would you also say ...?" "Let me see if I understand you. What you are saying is... Is that right?" "How do you respond to this objection?"

Critical readers ask questions as they read and use those questions to orient themselves to what an author is saying. Critical listeners ask questions as they listen to orient themselves to what a speaker is saying:
"Why does she say that? What examples could I give to illustrate that point? What is the main point? How does this detail relate to the main point? That one? Is he using this word as I would, or somewhat differently?" These highly skilled and activated processes are crucial to learning. We need to heighten student awareness of and practice in them as often as we can.

S-23 Making Interdisciplinary Connections

Principle: Although in some ways it is convenient to divide knowledge up into disciplines, the divisions are not absolute. Critical thinkers do not allow the somewhat arbitrary distinctions between academic subjects to control their thinking. When considering issues which transcend subjects (and most real-life issues do), they bring relevant concepts, knowledge, and insights from many subjects to the analysis.

They make use of insights from one subject to inform their understanding of other subjects. There are always connections between subjects. To understand, say, reasons for the American Revolution (historical question), insights from technology, geography, economics, and philosophy can be fruitfully applied.

S-24 Practicing Socratic Discussion: Clarifying and Questioning Beliefs, Theories, or Perspectives

Principle: Critical thinkers are nothing if not questioners. The ability to question and probe deeply, to get down rooting ideas, to get beneath the mere appearance of things, is at the very heart of the activity. And, as questioners, they have many different kinds of questions and moves available and can follow up their questions appropriately.

They can use questioning techniques, not to make others look stupid, but to learn what they think, help them develop their ideas, or as a prelude to evaluating them. When confronted with a new idea, they want
to understand it, to relate it to their experience, and to determine its implications, consequences, and value. They can fruitfully uncover the structure of their own and others' perspectives. Probing questions are the tools by which these goals are reached. Furthermore, critical thinkers are comfortable being questioned. They don't become offended, confused, or intimidated. They welcome good questions as an opportunity to develop a line of thought.

**S-25 Reasoning Dialogically: Comparing Perspectives, Interpretations, or Theories**

Principle: Dialogical thinking refers to thinking that involves a dialogue or extended exchange between different points of view. Whenever we consider concepts or issues deeply, we naturally explore their connections to other ideas and issues within different points of view.

Critical thinkers need to be able to engage in fruitful, exploratory dialogue, proposing ideas, probing their roots, considering subject matter insights and evidence, testing ideas, and moving between various points of view. When we think, we often engage in dialogue, either inwardly or aloud with others. We need to integrate critical thinking skills into that dialogue so that it is as useful as possible. Socratic questioning is one form of dialogical thinking.

**S-26 Reasoning Dialectically: Evaluating Perspectives, Interpretations, or Theories**

Principle: Dialectical thinking refers to dialogical thinking conducted in order to test the strengths and weaknesses of opposing points of view. Court trials and debates are dialectical in intention. They pit idea against idea, reasoning against counter-reasoning in order to get at the truth of a matter. As soon as we begin to explore ideas, we find that some clash or are inconsistent with others.
If we are to integrate our thinking, we need to assess which of the conflicting ideas we will provisionally accept and which we shall provisionally reject, or which parts of the views are strong and which weak, or how the views can be reconciled. Children need to develop dialectical reasoning skills, so that their thinking not only moves comfortably between divergent points of view or lines of thought, but also makes some assessments in light of the relative strengths and weaknesses of the evidence or reasoning presented. Hence, when thinking dialectically, critical thinkers can use critical micro-skills appropriately.

**Cognitive Strategies - Micro-Skills**

**S-27 Comparing and Contrasting Ideals with Actual Practice**
Principle: Self-improvement and social improvement are presupposed values of critical thinking. Critical thinking, therefore, requires an effort to see ourselves and others accurately. This requires recognizing gaps between ideals and practice. The fair-minded thinker values truth and consistency and so works to minimize these gaps.

The confusion of facts with ideals prevents us from moving closer to achieving our ideals. A critical education strives to highlight discrepancies between facts and ideals, and proposes and evaluates methods for minimizing them. This strategy is intimately connected with "developing intellectual good faith".

**S-28 Thinking Precisely About Thinking: Using Critical Vocabulary**
Principle: An essential requirement of critical thinking is the ability to think about thinking, to engage in what is sometimes called "metacognition". One possible definition of critical thinking is the art of thinking about your thinking while you're thinking in order to make your thinking better: more clear, more accurate, fairer.
It is precisely at the level of "thinking about thinking" that most critical thinking stands in contrast to uncritical thinking. Critical thinkers can analyze thought—take it apart and put it together again. For the uncritical thinker, thoughts are "just there". "I think what I think, don't ask me why." The analytical vocabulary in the English language (such terms as 'assume', 'infer', 'conclude', 'criterion', 'point of view', 'relevance', 'issue', 'elaborate', 'ambiguous', 'objection', 'support', 'bias', 'justify', 'perspective', 'contradiction', 'consistent', 'credibility', 'evidence', 'interpret', 'distinguish') enables us to think more precisely about our thinking. We are in a better position to assess reasoning (our own, as well as that of others) when we can use analytic vocabulary with accuracy and ease.

S-29 Noting Significant Similarities and Differences
Principle: Critical thinkers strive to treat similar things similarly and different things differently. Uncritical thinkers, on the other hand, often don't see significant similarities and differences. Things superficially similar are often significantly different. Things superficially different are often essentially the same.

Only through practice can we become sensitized to significant similarities and differences. As we develop this sensitivity, it influences how we experience, how we describe, how we categorize, and how we reason about things. We become more careful and discriminating in our use of words and phrases. We hesitate before we accept this or that analogy or comparison. We recognize the purposes of the comparisons we make. We recognize that purposes govern the act of comparing and determine its scope and limits.

The hierarchy of categories biologists, for instance, use to classify living things reflects biological judgment regarding which kinds of
similarities and differences between species are the most important biologically, that is, which distinctions shed the most light on how each organism is structured and lives. To the zoologist, the similarities between whales and horses are considered more important than their similarities to fish. The differences between whales and fish are considered more significant than differences between whales and horses. These distinctions suit the biologists' purposes.

**S-30 Examining or Evaluating Assumptions**

Principle: We are in a better position to evaluate any reasoning or behavior when all of the elements of that reasoning or behavior are made explicit. We base both our reasoning and our behavior on beliefs we take for granted. We are often unaware of these assumptions. Only by recognizing them can we evaluate them.

Critical thinkers have a passion for truth and for accepting the strongest reasoning. Thus, they have the intellectual courage to seek out and reject false assumptions. They realize that everyone makes some questionable assumptions. They are willing to question, and have others question, even their own most cherished assumptions. They consider alternative assumptions. They base their acceptance or rejection of assumptions on their rational scrutiny of them. They hold questionable assumptions with an appropriate degree of tentativeness. Independent thinkers evaluate assumptions for them, and do not simply accept the assumptions of others, even those assumptions made by everyone they know.

**S-31 Distinguishing Relevant From Irrelevant Facts**

Principle: To think critically, we must be able to tell the difference between those facts which are relevant to an issue and those which are not. Critical thinkers focus their attention on relevant facts and do not let
irrelevant considerations affect their conclusions. Whether or not something is relevant is often unclear; relevance must often be argued. Furthermore, a fact is only relevant or irrelevant in relation to an issue. Information relevant to one problem may not be relevant to another.

**S-32 Making Plausible Inferences, Predictions, or Interpretations**

Principle: Thinking critically involves the ability to reach sound conclusions based on observation and information. Critical thinkers distinguish their observations from their conclusions. They look beyond the facts, to see what those facts imply. They know what the concepts they use imply.

They also distinguish cases in which they can only guess from cases in which they can safely conclude. Critical thinkers recognize their tendency to make inferences that support their own egocentric or sociocentric world views and are therefore especially careful to evaluate inferences they make when their interests or desires are involved. Remember, every interpretation is based on inference, and we interpret every situation we are in.

**S-33 Giving Reasons and Evaluating Evidence and Alleged Facts**

Principle: Critical thinkers can take their reasoning apart in order to examine and evaluate its components. They know on what evidence they base their conclusions. They realize that un-stated, unknown reasons can be neither communicated nor critiqued. They are comfortable being asked to give reasons; they don't find requests for reasons intimidating, confusing, or insulting.

They can insightfully discuss evidence relevant to the issue or conclusions they consider. Not everything offered as evidence should be accepted. Evidence and factual claims should be scrutinized and
evaluated. Evidence can be complete or incomplete, acceptable, questionable, or false.

**S-34 Recognizing Contradictions**

Principle: Consistency is a fundamental—some would say the defining—ideal of critical thinkers. They strive to remove contradictions from their beliefs, and are wary of contradictions in others. As would-be fair-minded thinkers they strive to judge like cases in a like manner.

Perhaps the most difficult form of consistency to achieve is that between word and deed. Self-serving double standards are one of the most common problems in human life. Children are in some sense aware of the importance of consistency. ("Why don't I get to do what they get to do?") They are frustrated by double standards, yet are given little help in getting insight into them and dealing with them.

Critical thinkers can pinpoint specifically where opposing arguments or views contradict each other, distinguishing the contradictions from compatible beliefs, thus focusing their analyses of conflicting views.

**S-35 Exploring Implications and Consequences**

Principle: Critical thinkers can take statements, recognize their implications—what follows from them—and develop a fuller, more complete understanding of their meaning. They realize that to accept a statement one must also accept its implications. They can explore both implications and consequences at length. When considering beliefs that relate to actions or policies, critical thinkers assess the consequences of acting on those beliefs.

Because of the identification of critical thinking as scientific thinking, it is reasonable to conclude that math and Science courses are a
good place to learn critical thinking by learning the scientific method; unfortunately, this is not always true. Good scientists who conduct Science must practice critical thinking, and good Science teachers usually teach it, but few ordinary individuals learn the scientific method, even those who successfully take a number of Science classes in high school and college.

**Discovering the Parts of Thinking**

What are the basic features of thinking that students need to know to effectively take charge of their thinking intellectually, with respect to any content? First, they must come to realize that whenever humans reason, they have no choice but to use certain elements, without which their thinking would be intellectually unintelligible. Consider. Thinking is inevitably driven by the questions we seek to answer, and those questions we seek to answer for some purpose. To answer questions, we need information which is in fact meaningful to us only if we interpret it (i.e., by making inferences). Our inferences, in turn, are based on assumptions and require that we use ideas or concepts to organize the information in some way from some point of view. Last but not least, our thinking not only begins somewhere intellectually (in certain assumptions), it also goes somewhere---that is, has implications and consequences.

Thus whenever we reason through any problem, issue, or content we are well advised to take command of these intellectual structures: purpose, question, information, inferences, assumptions, concepts, point of view, and implications. By explicitly teaching students how to take command of the elements of reasoning we not only help them take command of their thinking in a general way; we also provide a vehicle
which effectively enables them to critically think through the content of their classes, seeing connections between all of what they are learning. Of course, we are not implying that elementary school teachers would introduce all of these ideas simultaneously. Not at all. This vocabulary for talking about thinking needs to be learned slowly and progressively. And the process is the perfectly natural one of helping students to think better in context. For example, children come to school with their own goals and purposes and we as teachers have ours. For school to work, children have to enter into goals and purposes that they don’t come to school with.

Young children do not come to school with the goal of learning numbers and letters, arithmetic, spelling, and reading. But they, like us, accomplish more when they know what they are trying to accomplish. The general goal of "figuring things out" is the essential goal intellectually. To become a good learner we have to learn how to figure things out: first numbers and letters and simple stories, and then eventually history, and novels and mathematical formulas. Whatever the "content" to be learned is, they need to learn to approach it in the spirit of "I can figure this out," "I can use my mind and thinking to understand this."

One way to begin to teach content as a mode of thinking is to recognize the fact that all content areas presuppose not only a particular purposes, but those purposes are connected to organized ways of figuring things out. If students understand the purpose of history, the purpose of literature, the purpose of government, etc., they can begin to learn that there are different things which we as learner try to figure out. Furthermore, they learn that when we want to figure something out, we have to ask particular questions about it. Hence, all subjects presuppose certain fundamental questions which guide thinking within a content area.
From the earliest stages of parenting and teaching, we can emphasize with our children what we want them to figure out. We can focus instruction on key fundamental questions and make those questions explicit. When information is required, we can elicit student help in assembling that information. When it is appropriate to take the step of interpreting information, we can help students make their inferences explicit. When students make questionable inferences, we can call that to their attention and ask them what other inferences might be made. If they are making a questionable assumption, we can help them recognize that. We can emphasize the importance of their thinking through implications and consequences. We can introduce diverse point of view and make explicit we are doing that. We can help them to role play different ways of looking at things (using different characters in stories, etc.). There are many, many ways--almost endlessly different ways--to encourage students to discover and take command of their thinking. The central point is this, there are distinct advantages to helping students to discover thinking and begin to take charge of it. Let look at this in a broad and general way.

**The Advantages of Critical Thinking**

When teachers become advocates of quality thinking and learning, in keeping with this stage theory, they teach in such a way that students are regularly required to:

1) State and explain goals and purposes,

2) Clarify the questions they need to answer and the problems they need to solve,
3) Gather and organize information and data,

4) Explicitly assess the meaning and significance of information you give them,

5) Demonstrate that they understand concepts,

6) Identify assumptions,

7) Consider implications and consequences,

8) Examine things from more than one point of view,

9) State what they say clearly,

10) Test and check for accuracy,

11) Stick to questions, issues, or problems; and not wander in their thinking,

12) Express themselves precisely and exactly,

13) Deal with complexities in problems and issues,

14) Consider the point of view of others,

15) Express their thinking logically,

16) Distinguish significant matters from insignificant ones,

And as a result of such instruction, the students (in general):

1) Learn content at a deeper and more permanent level

2) are better able to explain and apply what they learn,
3) are better able to connect what they are learning in one class with what they are learning in other classes,

4) Ask more and better questions in class,

5) understand the textbook better,

6) follow directions better,

7) understand more of what you present in class,

8) write better,

9) apply more of what they are learning to their everyday life,

10) Become more motivated learners in general,

11) become progressively easier to teach.

There are many ways to teach content so that students progress as thinkers. However if we are to do so, we must explicitly focus on the mind intellectually and grasp the stages that students must progress through. We and our students must recognize that we all develop incrementally as thinkers, and that the progress of any one of us is directly dependent on our level of intellectual knowledge and commitment. Put another way, if I am to develop my critical thinking ability I must both "discover" my thinking and must intellectually take charge of it. To do this I must make a deep commitment to this end.

Precisely because the human mind left to its own, pursues that which is immediately easy, that which is comfortable, and that which serves its selfish interests. At the same time, it naturally resists that which is
difficult to understand, that which involves complexity, that which requires entering the thinking and predicaments of others.

For these reasons, it is crucial that we as teachers and educators discover our own "thinking," the thinking we do in the classroom and outside the classroom, the thinking that gets us into trouble and the thinking that enables us to grow. As educators we must treat thinking--quality thinking--as our highest priority. It is the fundamental determinant of the quality of our lives. It is the fundamental determinant of the quality of the lives of our students. We are at some stage in our development as thinkers. Our students are at some stage in the development of theirs. When we learn together as developing thinkers, when we all of us seek to raise our thinking to the next level, and then to the next after that, everyone benefits, and schooling then becomes what it was meant to be, a place to discover the power of lifelong learning. This should be a central goal for all our students--irrespective of their favored mode of intelligence or learning style. It is in all of our interest to accept the challenge: to begin, to practice, to advance as thinkers.

Misconceptions are also referred to as preconceived notions, non scientific beliefs, mixed conceptions or conceptual misunderstandings. Which are responsible for incorrect ideas of concepts.

The mental processes, strategies and representations people use to solve problems, make decisions and learn new concepts is critical thinking.

Hence researcher thinks to check the relationship between misconceptions and critical thinking skills.
Statement of the Problem:

RELATIONSHIP BETWEEN MISCONCEPTIONS OF SECONDARY SCHOOL STUDENTS IN PHYSICS AND THEIR CRITICAL THINKING SKILLS – A STUDY

Definitions of the terms used in the statement of the problem:

Concept-

Conceptual Definition:

An idea or representation of the common element or attribute by which groups or classes may be distinguished, a thought, an opinion, an idea or a mental image.

(Good C. V.)

Operational definition:

For the purpose of this study concept is an idea, rule, formula, units, conversions and experiments involved in Physics content of Science and Technology – 1 textbook of secondary schools prescribed by the state government of Maharashtra. The concepts in this study are Matter, Density, States of Matter, Change in states, Evaporation, Condensation, sublimation, Absorption of Heat, Elements, Compounds, Mixtures, Elements electronic configuration, Discovery of Neutron, Atomic number, Atomic mass number, Distribution of electron in orbits, Motion, displacement and Velocity, Uniform and Non uniform motion, Straight line motion, Uniform circular motion, Force and motion, Balanced and Unbalanced forces, Types of inertia, First Second and third Newtons law of motion, Law of conservation of momentum, Gravitation, Newtons laws of Gravitation, Gravitational force of earth, Thrust, Pressure in fluids, Pressure applied by gas, Pressure by liquid, Archimedes Principle, Work, Energy, Types of Energy, Law of conservation of energy, Power, Nature of Sound, Production of Sound,
Propagation of sound, Sound waves, Longitudinal and Transverse waves, features of sound waves, Velocity of Sound, capability of human ears, Reflection of Sound, Echo, Reverberation, sonar are considered.

**Misconceptions**

Conceptual definition:

Misconceptions might also be referred to as preconceived notions, non-scientific beliefs, naive theories, mixed conceptions, or conceptual misunderstandings.

Operational definition:

For the purpose of this study, secondary school student’s misunderstandings about the basic concepts in Physics are identified by the researcher. E.g. Mass does not depend on velocity, Carbon dioxide cant occupies a space, Ice melts in water is freezing, The amount of matter in substance is weight, There is no bonding in atoms and molecules of a pure substance are considered.

**Physics**

Conceptual definition:

The branch of physical Science that is concerned with matter and energy, including the study of phenomenon associated with mechanics, heat, wave motion, sound, electricity, magnetism, light and atomic and nuclear structure. (Good C.V.)

Operational definition:

For the purpose of this study it is Subject involved at the secondary school level specially in the curriculum i.e. Physics
Critical thinking –
Conceptual definition:

Critical thinking as the intentional application of rational, higher order thinking skills, such as analysis, synthesis, problem recognition and problem solving, inference, and evaluation"

(Angelo, 1995, p. 6).

Operational definition:

For the purpose of this study critical thinking skills named as exercising fair mindedness, making interdisciplinary connections, developing confidence in reason, comparing analogous situations, credibility of sources of information, analyzing or evaluating arguments, interpretations, beliefs or theories, generating or assessing solutions, analyzing or evaluating actions or policies, comparing and contrasting ideals with actual practice, noting significant similarities and differences, distinguishing relevant from irrelevant facts, recognizing contradictions, thinking independently, developing insight into egocentricity or sociocentricity, clarifying issues, conclusions or beliefs, examining or evaluating assumptions, refining generalizations and avoid oversimplifications of secondary school students are studied.
Relation –

Conceptual definition:

Law or a principle whereby effect is given to an act done at one time as if it had been done at a previous time.

Operational definition:

A logical or natural association between misconceptions and Physics concepts is considered.

Objectives of the study:

1. To analyze the Physics content included in Science and Technology syllabus at secondary school level.

2. To diagnose IX students misconceptions in the subject Physics.

3. To study the critical thinking skills of secondary school students.

4. To study the relationship between misconceptions in Physics and critical thinking skills of IX standard students.

5. To develop remedial program on diagnosed Physics misconceptions.

6. To study the effectiveness of remedial program on diagnosed Physics misconceptions.

ASSUMPTIONS:

1. Students have misconceptions in Science about some concepts.

2. Critical thinking skills can be developed through Science learning.
3. There is relationship between misconceptions and critical thinking skills.

**Null Hypothesis**

1. There is no significant relationship between misconceptions in Physics with critical thinking skills of IX standard students.

2. There is no significant relationship between misconceptions in Physics with critical thinking skills in Boys and Girls of IX standard in urban area.

3. There is no significant relationship between misconceptions in Physics with critical thinking skills of Boys and Girls of IX standard in rural area.

4. There is no significant relationship between misconceptions in Physics with critical thinking skills of Boys of IX standard in Urban and rural area.

5. There is no significant relationship between misconceptions in Physics with critical thinking skills in Girls of IX standard in Urban and rural area.

6. There is no significant difference between pretest scores of experimental and control group of IX standard students in rural area.

7. There is no significant difference between posttest scores of experimental and control group of IX standard students in rural area.

8. There is no significant difference between pretest scores of experimental and control group of IX standard students in urban area.
9. There is no significant difference between posttest scores of experimental and control group of IX standard students in urban area.

10. There is no significant difference between pretest and posttest scores of control group in rural area.

11. There is no significant difference between pretest and posttest scores of control group in urban area.

12. There is no significant difference between pretest and posttest scores of experimental group in rural area.

13. There is no significant difference between pretest and posttest scores of experimental group in urban area.

14. There is no significant difference between posttest scores of boys and girls of control group in urban area.

15. There is no significant difference between posttest scores of boys and girls of experimental group in urban area.

16. There is no significant difference between posttest scores of boys and girls of control group in rural area.

17. There is no significant difference between posttest scores of boys and girls of experimental group in rural area.

18. There is no significant difference between posttest scores of boys in control group of urban and rural area.

19. There is no significant difference between posttest scores of boys in experimental group of urban and rural area.
20. There is no significant difference between posttest scores of girls in control group of urban and rural area.

21. There is no significant difference between posttest scores of girls in experimental group of urban and rural area.

**Delimitations**

This study is delimited to

1. Secondary school level syllabus of Physics from Science and Technology – I prescribed by state government of Maharashtra
2. Secondary school students in Marathi Medium.
3. Certain concepts which have misconceptions in Science from 9th standard.
4. Schools in Kolhapur district.

**SCOPE OF THE STUDY**

In support of scope of the study Whitney says- “It will provide information concerning, who, what, where and how many. To define a problem means to put a fence around it to separate it, by careful distinction from like questions, found in related situations of need.”

The study will cover institutions conducting secondary schools in Kolhapur city of Kolhapur district.

In this researcher will deal with the selected concepts such as Energy, Motion, heat, temperature, clouds, Evolution, Gas, Rain, Stars, Galaxy, Solar System, Gravitational Force, Electrons, Atoms etc.

The Study will give one way to reduce the misconception in Science and student can think critically which results in to better achievement.
SIGNIFICANCE OF THE RESEARCH

Science is a foundation of higher education hence it is obvious that the teaching of Science at secondary level has beyond doubt importance. If no significant plans are taken to ensure the perfection in teaching Science it will create problems for the students in the future education. Since secondary education is base of higher education it carries great importance.

By conducting experiments In the secondary education system if positive results are achieved. If we avoid misconceptions in Science then the learning process will get more faster which is the need of this era. This will encourage the student in self learning process. It will help student to get rid of unwanted fear of the subject in his mind and misconception about the subject.

Due to misconceptions about concepts in Science teachers imparting wrong information. Due to this they have many problems in present knowledge society. If they get correct information then only they will use correct knowledge to create their future.

In fact when critical thinking suggest many ways to one problem they have no any problem in grasping scientific concepts.

Through research a decision maker can quickly get a summary of current scenario which improves his information base for making sound decision affecting future operations of the organization. Research is useful to accelerate the decision making power and alone it can make possible the identification of the determinant.

The human resource development uses research effectively for its more important activity namely manpower planning. The main task of the academician is to enrich reservoir of knowledge by doing research.
The teacher also faces different problems in selection and use of proper teaching aid, teaching tools and teaching methods for different topics in Science.

Result of this study will be useful to the teachers of Secondary Schools, B.Ed. trainees, Teacher educators, parents, authors and educationist.

Researcher believe using critical thinking skills is an important life skill for the gifted and talented learner. Too often these students do not stretch themselves; rather they used their advanced vocabularies to camouflage what they don’t understand. They need to be able to cite reasons to support their thinking. Understanding and developing intellectual standards is a moral quality he want his students to exhibit he do not want them to be selfish in their thought.