CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

In this chapter, the discussion is organized to review past studies related to the brainstorming technique, creative thinking and critical thinking skills in science education. It starts with the brainstorming technique, which includes different techniques of brainstorming, brainstorming for productivity (idea generation), brainstorming for creative thinking and brainstorming for critical thinking as well as student's perception of brainstorming technique. The next two sections provide a description of the literature on creativity and creative thinking, and critical thinking. The last two sections will provide a review of thinking skills, particularly in relation to creativity, critical thinking and problem-solving, and will end with a review of the learning process and problem solving.

2.1 Brainstorming Technique

Osborn (1953) introduced brainstorming as a technique for solving problems. However, researchers have suggested a variety of definitions for the brainstorming technique, such as use of the brain, which represents the leadership center and control in humans when exposed to the stimulus or multiple stimuli that provoke the human senses, which is linked to the brain intrinsically and morally in a very precise manner (Coombs, 2001). Son (2001) defined brainstorming as a one of the discussion methods, which encourages members of the group to generate the largest possible number of diverse and innovative ideas spontaneously in an open climate and not limited to critical launch ideas that represent solutions to the problem and then choose the right ones (Son, 2001).

After the researcher reviewed definitions of brainstorming it was found that all past researchers appear to be in agreement on the basic principle, that brainstorming technique is for enhancing thinking and to stimulate learners' mind to generate ideas to solve problems.

The brainstorming technique can be said to be based on three principles. The use of these principles would help to free the thinking abilities inherent in groups. These principles are:

i. Collaboration. A group of learners thinking together is superior to a single learner thinking of his or her own. Osborn advocated that "individuals operating in a brainstorming group suggest twice as many ideas as individuals working on their own."
ii. Deferred judgment. Eliminate the past immediate judgment for generated ideas, and gradually accumulate a pool of high quality and original ideas, which are subsequently filtered.
iii. Quantity breeds quality. Increase the number of ideas generated, the greater the probability of achieving a more qualitative set of ideas after filtering (Stroebe, et al., 2010).

In the present study, the researcher was committed to these principles during the implementation of the brainstorming technique among the second grade intermediate students in physics. In the next section, different techniques of brainstorming technique would be reviewed.

2.1.1 Different Techniques of Brainstorming

The brainstorming technique can be implemented in a number of different ways as follows:

1. Negative (or reverse) brainstorming: The group thinks up opposites of the desired ideas. Reverse brainstorming is intended to open fresh perspectives and allow students to attack the original problem from a new point of view.
2. Group passing technique: Each person in a circular group writes down one idea, and then passes the piece of paper to the next person, who adds some thoughts. This continues until everybody gets his or her original piece of paper back. By this time, it is likely that the group will have extensively elaborated on each idea. This technique takes longer, but it allows individuals time to think deeply about the problem.
3. Team idea mapping method: The team idea mapping method is based on association. The benefit of this method is that it ensures a large volume of different ideas. It does also allow a broader perspective of the variety of ideas. The process begins with a well-defined topic. Each participant brainstorms individually, then all the ideas are merged onto one large idea map. During this merge phase, participants may discover a common understanding of the issues as they share the meanings behind their ideas. During this sharing, new ideas may arise by the association, and they are added to the map as well. Once all the ideas are captured, the group can prioritize and/or take action.
4. Online brainstorming (electronic brainstorming): It is conducted in the same way as traditional brainstorming the only difference is the absence of physical or visual presence. It typically supported by an Electronic Meeting System (EMS)

participants share a list of ideas over a network, ideas are entered independently. Contributions become immediately visible to all and are typically synonymized to encourage openness and reduce personal prejudice. Electronic brainstorming facilitates the coordination of a large group of participants in a session (Gallupe et al., 1992).

5. Directed brainstorming: Is a variation of electronic brainstorming. It can be performed manually or with the computer. In this method, the criteria and conditions for evaluating an excellent idea is known before the session is conducted. The participants are given a sheet of paper (if manually done) or an electronic form. The brainstorming question (problem) is then communicated. The candidates are given a respond time, once the respond time is over the papers are swapped to other member's conduction the brainstorming. The other participant will evaluate the idea and try to improve the idea based on the initial criteria. The swapping process is continued for at least three to four consecutive rounds. In the laboratory, directed brainstorming has been found to almost triple the productivity of groups over electronic brainstorming (Santanen, Briggs, & Vreede, 2004).
6. Group brainstorming: Osborn (1953) proposed groups of around 12 participants. Participants are encouraged to provide wild and unexpected answers. Ideas receive no criticism or discussion. The group simply provides ideas that might lead to a solution and apply no analytical judgment as to the feasibility. The judgments are reserved for a later date. Group brainstorming tends to produce fewer ideas (as time is spent developing ideas in depth); less ideas quality and can lead to the suppression of creative.

7. Individual brainstorming: In this type, brainstorming is done independently. The most common method of executing individual brainstorming is through free speaking, free writing, and spider web (Maheshwai, et al., 2003), but tends not to develop the ideas as effectively, perhaps as individuals on their own run up against problems they cannot solve.

In the present study, the researcher prepared a brainstorming technique approach which involves a mixture of individual and group brainstorming techniques as an optimal procedure to avoid the impact of various inhibitory processes (blocking, free riding, evaluation) and that which requires less facilitation and time (Brodbeck & Greitemeyer, 2000; Brown & Paulus, 2002; Paulus & Paulus, 1997; Starko, 2009).

2.1.2 Brainstorming for Productivity (Idea Generation)

Idea generation in the learning process is considered as the foundation for stimulating students' active thinking and engagement with other members within the group who may help them to see the problem from a different perspective. Moreover, generating more and best ideas would lead to better problem-solving and learning (Wang, et al., 2011). Thomas Edison said that "To have a great idea, have a lot of them." Osborn (1953) claimed that more ideas can be produced by a group than by the corresponding number of separately working individuals. Osborn reasoned that performance would be enhanced in brainstorming groups because individuals would be freed from self-criticism and the criticism of others if the rules of brainstorming were followed. Additionally, any novel ideas suggested by one group member could possibly lead to more novel or original ideas by other group members (Lamm & Trommsdorff, 1973; Osten, 1992).

Taylor, Berry, and Block, (1958) were first to test Osborn's claim and developed and utilized individual group "nominal groups" in their study which included two groups (a group of four persons interacting and a nominal group) to allow for a statistical comparison between results of the each group utilizing the four brainstorming rules recommended by Osborn (1953) (see p5). Thus, the researchers instructed both group types to generate ideas on three different tasks that were similar to the kinds of prompts given in the Torrance Tests of Creative Thinking (TTCT), (tourism problems, extra thumb and teachers).

The results revealed that interacting groups generated fewer ideas than nominal groups, and the number of high-quality responses was superior for the nominal groups over the interacting groups (Taylor, et al., 1958). In a review of the brainstorming literature, Diehl and Stroebe, (1987) found that the performance of nominal groups' showed superior group brainstorming. These results are contrary to Osborn's assumptions (Diehl & Stroebe, 1987; Gallupe, Bastianutti, & Cooper, 1991; Goldenberg & Wiley, 2011; Lamm & Trommsdorff, 1973).

In the years that followed, the nominal group gained popularity among group performance researchers. Most of the later empirical studies focused more on comparing nominal group productivity (Isaksen, 1998). Typical results were similar to Taylor and his colleagues' finding that interacting groups generated fewer ideas than nominal groups. This superiority of nominal groups in terms of the number of generated ideas relative to their interacting group counterparts has been termed "productivity loss" or "process loss" (Goldenberg & Wiley, 2011; Steiner, 1972). Diehl and Stroebe (1987) explained three major processes of productivity loss in the brainstorming group may not help students acquire domain knowledge effectively in science education (Wang, Li, et al., 2006). These processes are as illustrated in Figure 2.1.

a) Evaluation apprehension;

b) Free riding; and

c) Production blocking.

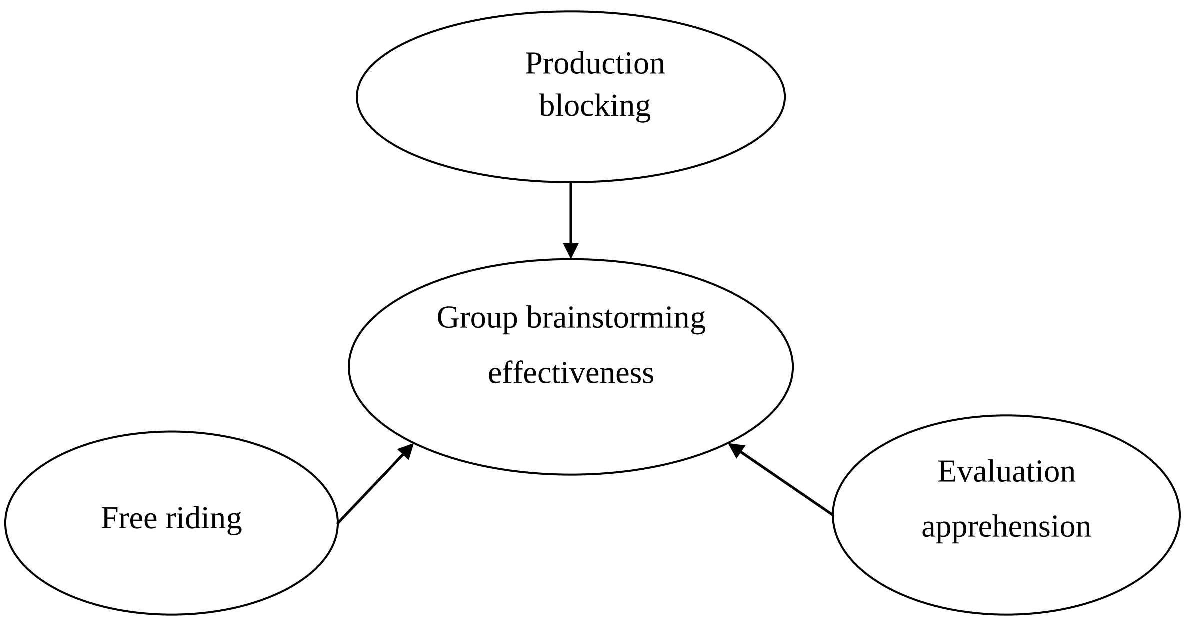

Figure 2.1 Influencing factors of group brainstorming effectiveness

a) Evaluation apprehension

Diehl and Stroebe (1987) found that evaluation apprehension occurs when group members become apprehensive about submitting ideas to the group because they feel that other group members will evaluate and/or criticize those ideas. The result of evaluation apprehension is that:

i. Participants produce fewer sides on controversial than controversial topics, and when believing that they would be observed rather than not observed;
ii. Group members may withhold some ideas because they feel are unsafe, and they worry what others will think;
iii. Participants want to be liked, to fit in, to avoid embarrassment. They don't want them to be unduly evaluated or criticized, and
iv. The most unusual ideas will not be expressed because the speaker risks ridicule**.**

b) Free riding (social loafing)

Diehl and Stroebe (1987) assessed whether the productivity loss of interactive brainstorming groups was indeed due to free riding, the results suggested that free riding was responsible for part of the productivity loss of interactive brainstorming groups. Social loafing may inhibit the number of ideas generated that leads to reduced group performance because individuals in groups do not feel as responsible for producing ideas, so they exert less effort. The overall result is reduced performance on tasks that require the additive efforts of all group members.

c) Production blocking

Lamm and Trommsdorff, (1973) determined that production blocking is a major cause of the productivity loss in brainstorming groups. The reason for the lower productivity is a lack of speaking time as the group members will not talk while another individual is talking and only one group member speaks at times. Diehl and Stroebe's (1987) tested this hypothesis by three experimental conditions (blocking, communication), (blocking, no communication) and (no blocking, no communication) with four participants groups of the same gender. Diehl and Stroebe's (1987) findings were:

i. Bottleneck occurs because everyone in a group cannot speak at the same time;
ii. People forget ideas while waiting for their turn to speak, many ideas are never expressed;
iii. Impossible to generate new ideas while remembering a current idea and waiting to share it; and
iv. More ideas were produced when subjects could immediately present their ideas as they occurred, compared to waiting their turn.

Diehl and Stroebe (1987) identified production blocking as a major cause of the productivity loss in brainstorming groups. Other researchers have theorized that there are additional factors that affect group performance on idea generation. Nijstad and his colleagues (2003) tested the effect of cognitive interference on production blocking in two experiments and found that the production blocking interferes with idea generation. When group members wait for their turn to express the ideas, delays arise between the generation and articulation of ideas. The duration of delays affects the cluster length, whereas the lack of predictability of delays influences the number of clusters. There are two different processes which explain the effect of delays, as illustrated in Figure 2.2.

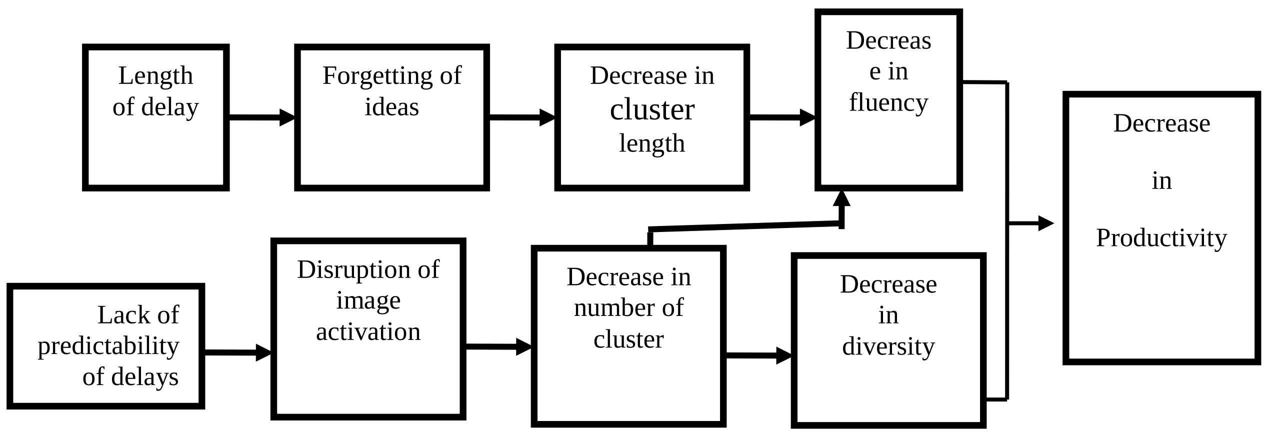

Figure 2.2: The two-stage theory of production blocking from (Nijstad, Stroebe, & Lodewijkx, 2003)

From the large number of empirical studies which were focused on productive loss and comparison between interactive and nominal groups the differences between individual and group brainstorming in terms of performance are as shown in Table 2.1.

Table 2.1**:** Differences between individual and group brainstorming

	Individual	**Group**
1. Range of ideas	Wide	Narrow
2. Development of ideas	Shallow	Deep
3. Freedom of expression	More	Less
4. Quality of ideas	High	Low
5. Communicate	Weak	Strong

Table 2.1 compared between individual and group brainstorming performance. For example, if an individual were brainstorming, the ideas generated would not be very developed because there is a limit to the depth of their knowledge. In contrast, in group brainstorming, the ideas could be more fully developed because what one person in the group does not know, another might. For developing ideas, during brainstorming sessions one novel idea suggested by one group member could possibly lead to more novel or original ideas by other group members. In individual brainstorming, members enjoy the flexibility of learning at their own pace. They can set their own time and place and work accordingly. Students tend to be more creative at certain times and places. This is absent in group brainstorming where people should follow set timelines and place. In addition, for freedom of expression, some group members may feel shy to share their crazy or weird ideas. On the other hand, individual brainstorming allows participants to put down all their

ideas without hesitation or fear of mockery. If a group brainstorming session is poorly organized, it can quickly sidetrack the discussion. The group members, especially the reserved and the quiet, can get blocked off and they cannot be at their creative best and express their ideas. Individuals do not suffer this constraint when they brainstorm on their own. As for the quality of ideas in group thinking sessions, some may feel that their ideas are not as good or valuable as those expressed by other members of the group. Thus, some ideas can be lost this way. Nonetheless, it can be concluded that individual brainstorming may miss certain benefits of shared experience and expertise in group brainstorming and vice versa (Diehl & Stroebe, 1987; Gallupe, et al., 1991; Isaksen, 1998; Lamm & Trommsdorff, 1973; Osten, 1992; Paulus & Yang, 2000; Stroebe, et al., 2010).

Researchers have found that to reduce the gap of production loss between individual and group brainstorming, teachers must follow these three processes as shown in Figure 2.3.

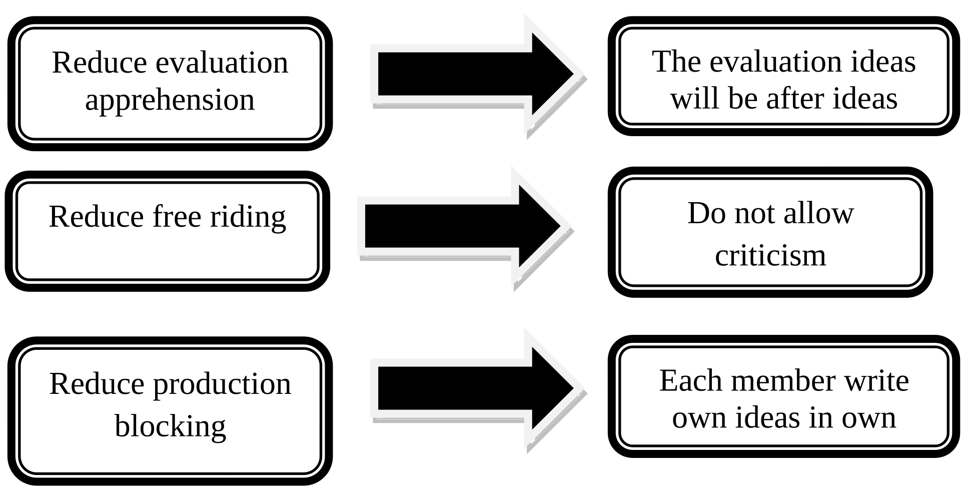

Figure 2.3: Three processes to reduce production loss in group brainstorming

2.1.3 Brainstorming for Creative Thinking

Although brainstorming is known as a technique for enhancing creativity most of the researchers have focused more on quantitative measures of group performance when compared to individual and group brainstorming (Stroebe, et al., 2010). Moreover, it is used widely in industry, government, business and to a limited degree in the field of education, especially in physics education (DeHaan, 2009; Paulus & Paulus, 1997; Scott, et al. 2004; Wood, 1970).

However, brainstorming is described in education as a beneficial technique used to stimulate and enhance learning for students (Paulus & Paulus, 1997) (United State of America) in science education and fostering creativity in physics (Wang, et al., 2011, Cheng, 2011) (China) because any type of stimulation enhances particular cognitive structures (relevant domain knowledge) in the mind of students for deep mental exploration for creative idea generation (Stroebe, et al., 2010). The most important function of the brainstorming technique for students is to practice the flexibility, fluency, risk taking, elaboration and other skills, which are associated with creativity (Starko, 2009). The brainstorming technique has lead to valuable instructional and learning opportunities in science education as it helps students to apply unknown procedures in solving a problem.

In contrast, the main purpose of brainstorming is to let students generate ideas or options for solving a problem by themselves (Wang, Li, et al., 2006). Butler and Kline, (1998) (United State of America) found that brainstorming is an effective technique for facilitating intellectual fluency. Thus, these help students to generate creative solutions.

Cheng, (2011) found that in addition to creativity enhancement, brainstorming improves students' abilities, such as novel and innovative thinking, challenging and risk-taking attitudes, metacognitive, and help students to better understanding of science knowledge and positive attitudes towards science learning.

In physics learning, brainstorming encourages students to express ideas in simplest and quickest ways due to the instructions of brainstorming which has no wrong answers and any reasonable answers are accepted (Cheng, 2004). In contrast Holubová, (2010) (Czech Republic) found that physics teachers (in – service teachers and pre- graduated teachers) have never practiced the brainstorming technique in the physics classroom. Therefore, there is a need to enhance teacher training by using brainstorming technique in physics learning.

In this study, the researcher used a modified brainstorming technique to try and enhance creative thinking among secondary second grade physics students in an Iraqi Saba school.

2.1.4 Brainstorming for Critical Thinking

According to the literature reviewed, empirical studies related to the utilisation of the brainstorming technique in the enhancement of critical thinking in science education are few and limited.

Critical thinking through the brainstorming technique enhances when students working in groups begin to evaluate each idea generated using the agreed-upon criteria, students discuss whether or not their proposed ideas were likely to solve the problem and decide which should be rejected, while others can be modified to make them more powerful and appropriate to solve the problem (Case, 2005; Mased & Yamin, 2012). Ho, (1998) found that ideas generated through a brainstorming technique becomes more effective and feasible when group members have evaluated and judged it.

Schneider, (2002) asserted that brainstorming is an effective technique to develop and enhance critical thinking skills for students in science. It helps student's activation of thinking to explore new options instead of receiving information from a teacher. Furthermore, Maitah, et al., (2011) (Jordan) found that the brainstorming method requires learners to recall their previous experience, and practise different mental and intellectual skills, such as knowledge acquisition skill, social skills, organizational skills, collaborative skills, and particularly critical-thinking skills, while there are no such opportunities for those who learn by traditional methods. Harbi, (2002) (Kingdom of Saudi Arabia) identified that brainstorming is a useful method for developing critical thinking and there is positive and direct statistically significant relationship between critical thinking and achievement when using the brainstorming technique among biology students in secondary school.

A researcher found that brainstorming proved effective in the enhancement of creative thinking in many empirical studies; likewise, researchers concluded that a creative learner is a critical thinker because creative and critical are related (see section 2.4). Rabari, et al., (2011) (Kenya) asserted that the correlation between creative thinking and critical thinking are strong in physics teaching. From these points, in this study, the researcher of the present study examined the brainstorming technique for enhancing critical thinking in physics for secondary Iraqi students.

2.1.5 Students' Perception of Brainstorming Technique

Perception is important in a teaching and learning situation as it reinforces teachers' decision-making on how to handle classroom situations. Researchers have shown that perception plays an important part in teaching. Research on brainstorming techniques have focused on what students perceived about learning outcomes, and what they valued and preferred in the brainstorming learning processes.

In fact, studies have found that the results were not "one-sided", and included both negative and positive perceptions of learning via the brainstorming technique in physics learning (Cheng, 2004, 2011; Holubová, 2010). Studies that report positive findings for brainstorming technique are presented first, followed by those that reported negative findings.

Most literature suggests that students' perception towards the brainstorming technique is positive in learning physics. Physics lessons during brainstorming have more activities and fewer rote learning, more practices, more student participation, more chances to interact with classmates and more self-initiated. Gaining more knowledge, better understanding and opportunities to explore science in daily-life and discover newer ideas (Cheng, 2011). Burdett, (2003) reported students see brainstorming as helping them to activate prior knowledge and made them move from not knowing to relating things and feeling that the mind is opening up to new ideas and making connections. Furthermore, brainstorming gives the opportunity to learn new things from peers that know and gain different perspectives that they would never have thought of and others appreciate their ideas.

Students have indicated that the brainstorming interactive technique as both interesting and useful. Students felt satisfied and interested in the brainstorming process that makes learning enjoyable. Students felt that through brainstorming, they could reflect upon virtues such as kindness or truthfulness and which might take moral courage. Students took the initiative to discuss with classmates and ask questions as well as to mentally think it over, and acquire a better understanding of the topic and love physics more(Finney, 2008).

Moreover, the brainstorming process not only serves as an effective way to create a comprehensive list of ideas, but also allows students to see the process of thinking in action, and made students think more deeply about problems (Davis, 1986). Hobson, (2001) suggested that brainstorming is an interactive technique for complex abstract subjects. For example, students who were studying global warming found the topic significantly more interesting and relevant because the brainstorming technique kept the class actively thinking by helping students to break out of their patterned way of thinking and to look at things in a new way. Moreover, students indicated improvements in their science learning, especially which related to creative science development. Students also found that the class was relaxed and not under great pressure as in the usual classes.

However, not all students have positive perceptions towards the brainstorming learning experience. Problems faced by students have been reported. Students felt that the brainstorming activities are difficult, are not so simple and demanding, especially at the beginning. Furthermore, many students have given feedback that the working time in lessons is not enough. Students' also seem to fear criticism and ridicule from their classmates on their ideas (Holubová, 2010).

In this study, the researcher has prepared a set of questions to assess brainstorming characteristics from the students' perspective (see APPENDIX D).

2.1.6 Methodology Utilised in Previous Studies

Through a thorough analysis of methodologies used in previous studies, the researcher found that different types of research methodologies have been used for investigating the brainstorming technique. However, three types of research methods: quantitative, qualitative and mixed method approaches are the common methods used in the previous studies. Most previous studies followed the quantitative approach to assess causality and reach generalizable conclusions through explore the effectiveness of brainstorming technique in teaching and learning (Alaatari, 2006; Harbi, 2002; Maitah, et al., 2011; Mohammed, 2010). On the other hand, other studies followed the qualitative approach to provide an in-depth understanding of phenomena through the students’ perspectives (Holubová, 2010; Kohn & Smith, 2010; Wang, Rosé, Li, & Chang, 2006). The researcher found in the literature review that only Cheng (2004, 2011) utilized mixed methods approach (quantitative and qualitative) to examine the effectiveness of brainstorming technique on enhancing creativity in physics. The researcher was unable to find any phenomenological studies undertaken in the Arabian countries in general and in Iraq in particular that utilized a mixed method approach to examine the role of brainstorming technique in enhancing the creative and critical thinking skills in physics.

Therefore, in this study, the researcher used both quantitative and quantitative data collection techniques to investigate and explore the role of brainstorming technique in enhancing creative and critical thinking among second-grade intermediate student in physics. The goal of utilizing both techniques in this study is to draw from the strengths and minimize the weaknesses of both approaches (Johnson & Onwuegbuzie, 2004). Furthermore, The two types of data collected allowed for triangulation (Olsen, 2004).

2.2 Creativity and Creative Thinking

There is no consensus on the definition of creativity in the literature (BacanlI, DombaycI, Demir, & Tarhan, 2011). Therefore, there is a diversity of creativity definitions. Torrance, (1966) defined creativity as: a process of becoming sensitive to a problem, deficiencies, gaps in knowledge, missing elements, disharmonies, and so on; identifying the difficulty; searching for solutions, making guesses, or formulating a hypothesis about these deficiencies; testing and retesting these hypotheses and possibly modifying and retesting them; and finally communicating the results (p.6). Furthermore, creativity has been described as "the ability to solve problems and fashion products and to raise new questions" (Gardner, 1993); Cropley, (2001) characterized creativity by 'novelty, effectiveness and ethicality'.

Davis, (1992) documents four "Ps" for understanding creativity: person, product, process and press (i.e., environment or climate). Meanwhile, Harris, (1998) saw creativity from three aspects as: an ability, an attitude and a process and described these aspects as follows:

i. An ability

Creativity is the ability to imagine or invent something new. Creativity is not the ability to create out of nothing, but the ability to generate new ideas by combining, changing, or reapplying existing ideas. Some creative ideas are astonishing and brilliant, while others are just simple, good, practical ideas that no one seems to have thought of yet (Harris, 1998).

ii. An attitude

Creativity is also an attitude: the ability to accept change and newness, a willingness to play with ideas and possibilities, a flexibility of outlook, the habit of enjoying the good, while looking for ways to improve it. We are socialized into accepting only a small number of permitted or normal things, like chocolate-covered strawberries, for example. The creative person realizes that there are other possibilities, like peanut butter and banana sandwiches, or chocolate-covered prunes. .(Harris, 1998)

iii. A process

Creative students work hard and continually to improve ideas and solutions, by making gradual alterations and refinements to their works.

However, in a summary of scientific research into creativity, Mumford, (2003) reached a general agreement that “creativity involves the production of novel, useful products” p. 110. In the context of this study, creativity is the ability of secondary (second-grade) Iraqi

Physics students to generate the largest number of ideas characterized by diversity and originality in physics.

2.2.1 Creative Thinking Skills

Creative thinking skills are essential for success in learning and success in life (Fisher, 2006a). Guilford, (1950) proposed creativity as the ability to produce a new idea into existence via divergent thinking or arrive at many solutions to a problem, and offer three dimensions to describe creativity as illustrated in figure 2.4:

i. Fluency: ability to generate lots of ideas, which loosens up the creative wheels. The first step to problem solving or any creative endeavor is having as many ideas as possible to choose from, play with, research, or evaluate. Fluency is classified as associational fluency, ideational fluency, expressional fluency and figural fluency. ((Kim, 2005; Okere, 1986)

ii. Flexibility: ability to look at a question or topic from multiple perspectives. In science, flexible students think of different types of variables that may impact a phenomenon (Meador, 2003), discover whole new areas of possibility, including different interpretations of scientific data (Shively, 2011). Flexibility is classified as spontaneous and adaptive flexibility (Kim, 2005; Okere, 1986).

iii. Originality: is the crux of creativity. This means generating unique or unusual products, unexpected ideas. It is the most fragile dimension of creativity in school settings oriented to correct “answers." However, originality may emerge from unlikely juxtapositions, similar to flexibility prompts (Meador, 2003).

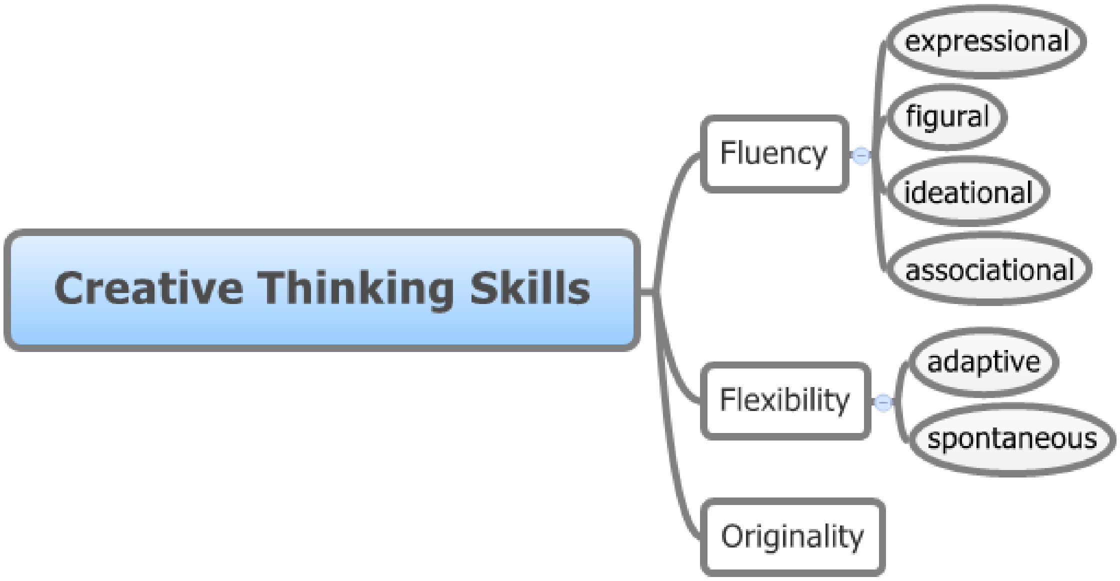

Figure 2.4 Creative Thinking Skills

Each creative skill works as a part of the total creative process, for example, fluency becomes meaningless if none of the ideas is original. Flexibility also leads to originality. Not one of these alone represents creative thinking. Therefore, teachers are cautioned to let their efforts become fragmented pieces of the creative problem that result in the development of isolated skills (Meador, 1997). Focusing on fluency, flexibility and originality skills gives teachers and students an effective shortcut to enhancing creativity together (Shively, 2011).

2.2.2 Characterizations of a Creative Thinker

Teachers should be aware of the characteristics of creative students as this will enable teachers to see the potential of each student (Kim, 2005). Claxton, Edwards, and Scale-Constantinou, (2006) grouped the characteristics or dispositions which are most supportive of creativity into six as illustrated in Figure 2.5. Taken together, they form the acronym CREATE. CREATE serves to make the general point that 'being creative' is more than being able to do 'mind maps' and brainstorming.

Figure 2.5 Characterization of creative thinkers

Curiosity: a creative person seem has an appetite for questioning that sometimes borders on the obsessive, though more likely the questioning disposition manifests most strongly in their particular domain of creative expertise (Claxton & Lucas, 2004).

Resilience: genuine creativity is complicated not quick and easy. It is not all fun and it is certainly not the case that 'anything goes'. Whether the sense of creative satisfaction derives from meeting an external challenge or from an inner need to capture and express something through an artwork, creative people have a strong feeling for what is 'right' which often prevents them from accepting easier solutions. The sense of 'quality', and of the tolerance for effort and frustration that the commitment to quality entails, is essential to creativity. That ability to tolerate confusion and frustration, to relish a challenge, and not to give up prematurely, has to be a core attribute of creative people (Pirsig, 1974).

Experimenting: Creative people like tampering with opinions, materials, ideas, actions and possibilities. Though their projects are dear to them, they have a playful approach to solutions, and are always search for new angles and views.

Attentiveness: Discoveries of experimenting cannot be gathered and put to good use. Creative people seem to have a propensity for intense, effortless concentration. They are able to let themselves go into their experience (or into their imagined worlds) whole heartedly, and become rapt, engrossed and absorbed (Melcher & Schooler, 1996).

Thoughtfulness: How people make use of the private rooms and resources of their own minds strongly influences their creativity. There are several forms of inward 'thoughtfulness' that are all involved. Pondering over questions and possibilities is one. Thinking carefully and methodically is another. Being sensitive to that inner sense of rightness is another. Allowing and enjoying the semi-autonomous play of images and metaphors that happens in states of reverie, having an attitude of respectful skepticism' towards hunches; knowing when to keep trying to figure something out, and when to give up and relax – being a skilful orchestrator of your own states of mind and mental modes (Martindale, 1999).

Environment-setting: Finally, creative people seem to know that their physical and social environment can make a big difference, and that they need different kinds of setting, support (or challenge) at different points. As far as possible, they regulate their social world so that it supports the kind of thinking that they need to do. They also seem to surround themselves with people who are going to support their creativity – whether emotionally, intellectually or practically. They know how to use the rhythms of time to balance different kinds of thinking. Their daily rhythms allow for both hard work and reverie; they know the worth of breaks and holidays. They know the places and the times of the day that seem conducive to the muse (Claxton 1997, Claxton & Lucas, 2004).

2.2.3 Procedures of Creative Thinking

Creative thinking is a complex process evolving from factors, including personality, motivation, circumstance, and divergent and convergent thinking (Meador, 1997). The mental processes involve creative thinking are difficult to describe Fisher, (2002) determinate set of mental processes is at work.

The creative process is consistent with the result from cognition research. DeHaan, (2009) sees creativity as a multi-component process and that there are two stages to the creative process include associative and analytical. In the associative stage, thinking is defocused, suggestive, and revealing remote, intuitive, or subtle connections between items that may be correlated, or may not, and are usually not causally related. In the analytical stage, thought is focused and evaluative, more conducive to analyzing relationships of cause and effect for a review of other cognitive aspects of creativity (DeHaan, 2009). Many of the researchers developed models to clarify the creative process, such as Wallas, (1926) who presented one of the first models of the creative process consisting of four stages, as illustrated in Figure 2.6.

1. Preparation: collecting background information and focusing on the problem;
2. Incubation: laying the problem aside for a time;
3. Illumination: the moment when a new idea finally emerges, and

4. Verification: develop a plan to implement and test ideas.

The process of creative thinking requires a complex combination of elements that include cognitive flexibility, memory control, inhibitory control, and analogical thinking, enabling the mind to free-range and analogize, as well as to focus and test (DeHaan, 2009) it is the interplay among the cognitive and affective processes that underlie inventiveness and the ability to find novel solutions to a problem. These creative processes help foster creativity development and providing opportunities to be creative (Jeffrey & Craft, 2004).

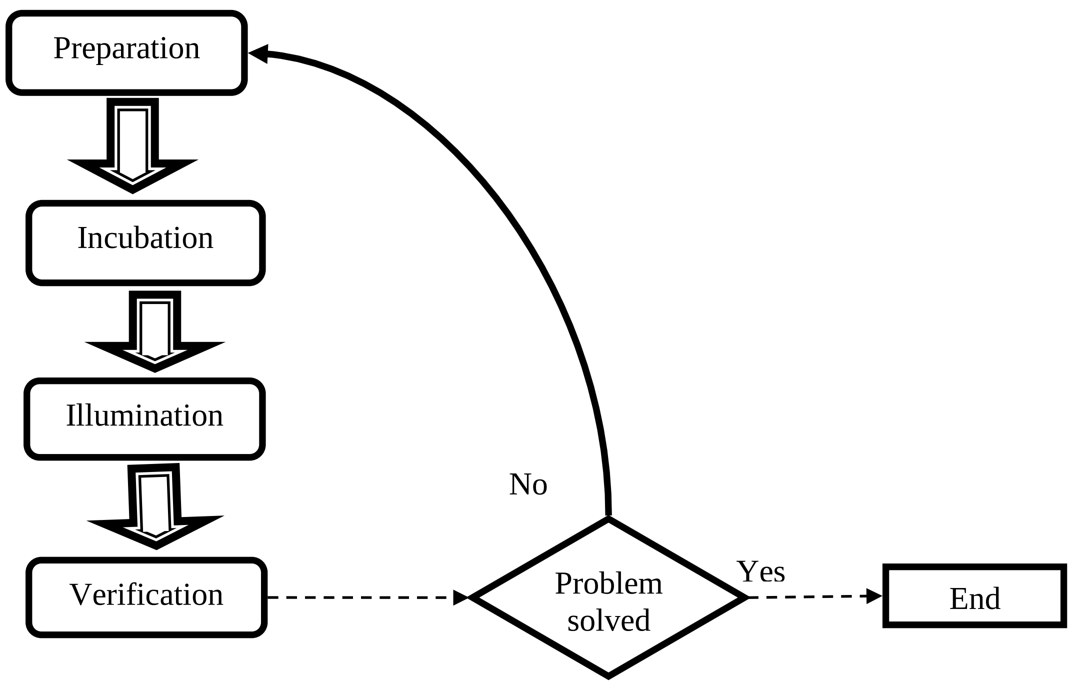

Figure 2.6: Creative thinking process

The researchers have demonstrated that the cognitive processes underlying creativity and learning are essentially identical. They both involve the emergence of the new in the mind of the student (Sawyer, 2011).

In the context of this study, brainstorming is described as a creative thinking process which stimulates the cognitive creativity of learners to generate a largest set of physics ideas to solve a problem and give the opportunity to practice creative thinking skills (fluency, flexibility and originality).

2.2.4 Creativity Studies in Science Education

Creativity researchers have been studying these topics since the 1950s. However, this research has had surprisingly little impact on schools (Sawyer, 2011). Moreover, empirical research to study the development of creativity in regular science lessons in Asian and Arabian countries are still lacking (Cheng, 2011; Dagher & BouJaoude, 2011). Perhaps as was put forward years earlier by (Okere, 1986), this situation could give the impression that educational experiences in many of the Asian and Arabian schools are not enhancing creativity in physics

Typically, students are required in physics lessons to describe physics phenomena, calculate quantities, and conduct an experiment which is carefully pre-specified as to their procedures and outcomes by teachers and textbook. In such a situation, these activities are unlikely to foster creativity in contrast that it hinders creativity (Diakidoy & Constantinou, 2001). Creativity is supported, deliberate, and meaningful while still connected to the curriculum, not teaching separate lessons or developing new materials (Shively, 2011). Schools should offer an opportunity for students in science lessons to develop creativity to the benefit of their future lives, by enhancing pre-service science teachers in the development of their classroom skills and practice (Kind & Kind, 2007; Simsek & Kıyıcı, 2010). However, most teacher education programmes don't mention creativity at all.

Unfortunately, a teacher does not exercise creative thinking during the science lessons due to a lack of depth of understanding necessary to make contributions to the field and make outstanding grades in science due to their ability to memorize and retain information (Meador, 2003). Teachers thought that using methods to enhance creativity in physics lessons would lead to being behind the yearly teaching schedule, harm student's examination result, wasting student's time and out of the teacher or student's capacity (Cheng, 2004).

However, science education ought to aim at helping students to be a creative and critical thinkers and not just limit itself to delivering basic scientific information and narrow skills of laboratory and the experimental scientific method (Swartz, Fischer, & Parks, 1998). There are huge risks of de-killing teachers and encouraging conformity and passivity in some. Education systems and school leaders have been working against creating a successful future (Morris, 2008).

In contrast, teaching creative thinking has a positive effect on learning achievement of students, teaching methods, curricular arrangement, and personal experience (Jeng, et al., 2010). In the science classroom, especially in physics, teaching creativity helps students to improve conceptions, attitudes, abilities and behaviours in creative science development. In addition teaching creativity encourages students to think wider and border, appreciate creative ideas, developing curiosity, confidence and self-initiation in science learning (Cheng, 2011).

2.2.5 The Challenge of Eenhaning Creative Thinking in Science Education

Creativity is central to improving the functioning and development of society (Fisher, 2002). However, there are obstacles to teaching creativity which makes it difficult to enhance creativity for students in science (Simsek & Kıyıcı, 2010). These obstacles have been classified in many ways by different authors. Sawyer, (2011) for example, categorized the obstacles of creativity into external forces such as institutional, administrative, and political challenges and internal forces represent the four top-down structures.

i. Curriculum: Fisher, (2002); Koh, (2002); Simsek and Kıyıcı, (2010) are in agreement with Sawyer, that the main obstacle to creativity is a too heavily a prescribed curriculum. The curriculum should give students opportunities to enhance creative thinking skills. Reducing the content of the curriculum will increase the time available to infuse the teaching of thinking skills in the classroom.

ii. Assessments: Science tests do not assess whether students have pre-existing misconceptions nor do they assess problem solving or thinking skills. Assessment and testing should be designed to encompass creative thinking skills. Instead of only testing student's ability to recall information.

iii. Learning goals: The goal of learning now is enhancing students' abilities to learn, apply and process knowledge.

iv. Teacher practices: Teacher should be a higher-trained professional. The role of teachers is to scaffold and facilitate collaborative knowledge building. Science education research that explores the appropriate role of guiding scaffolds in the unavoidably unpredictable and emergent process of creative learning.

The top three blocks to creativity within the classroom according to Cropley, (1992) are success orientation, sanction against question and external evaluation. Alencar, Fleith, and Martinez, (2003) added four factors that most likely block expression of students creativity, named inhibition/shyness, lack of time/opportunity, lack of motivation and social repressions. Another obstacle to creativity is feeling over-stressed. Learners need the stimulus of a challenge (Fisher, 2002). On the other hand, the teacher can encourage students' creativity by giving students more time as a whole so that the students can unhurriedly explore; create an inviting and exciting classroom environment; provide an abundant supply of interesting and useful materials and resources; create a classroom climate where students feel that there is acceptance of their mistakes; risk-taking; innovation and uniqueness; along with a certain amount of mess, noise, and freedom (Edwards & Springate, 1995).

2.2.6 Tests for Measuring Creative Thinking Skills

To enhance creativity, there must be measurable indicators to evaluate how much students have gained from learning. Okere (1986) found that creativity is measurable in physics education. The formal psychometric measurement of creativity is usually considered to have begun with Guilford, (1950). Guilford's group constructed several tests to measure creativity in 1967 such as:

i. Plot Titles: where participants are given the plot of a story and asked to write original titles;
ii. Quick Responses: is a word-association test scored for uncommonness;

iii. Figure Concepts: where participants were given simple drawings of objects and individuals and asked to find qualities or features that are common by two or more drawings; these were scored for uncommonness;

iv. Unusual Uses: is finding unusual uses for common everyday objects such as bricks;

v. Remote Associations: where participants are asked to find a word between two given words, and

vi. Remote Consequences: where participants are asked to generate a list of consequences of unexpected events (e.g. loss of gravity).

Building on Guilford's work, Torrance developed the Torrance Tests of Creative Thinking (TTCT) in1966. They involved simple tests of divergent thinking and other problem-solving skills, which were used to assess three mental characteristics: fluency, flexibility and originality for a student. The TTCT test has been modified four times since its original version. Torrance's research and the development of the TTCT have provided the groundwork for the idea that creative levels can be measured and then increased through teaching and practice (Kim, 2006; McIntyre, Hite, & Rickard, 2003; Scott, et al., 2004). Moreover, the Wallach Kogan creativity test (Wallach & Kogan, 1965) is a still an useful test to measure creativity for students. In a recent study Carson, Peterson, and Higgins, (2005) developed a new self-report measure, the Creative Achievement Questionnaire (CAQ) that assesses achievement across 10 domains of creativity. The CAQ test has been shown to be reliable and valid when compared to other measures of creativity and to independent evaluation of creative output.

In science education, there are several creative thinking tests that have been designed, for instance, (Hu & Adey, 2002; Pekmez, Aktamis, & Taskin, 2009). In physics education, the number of such available creative thinking tests in the context of a specific domain, particularly in the context of learning physics unfortunately is extremely inadequate. The researcher of the present study believes that she can take advantage of the previous tests and features of physics in the development of a test appropriate to physics to measure the three skills that the present study aims to study.

2.2.7 Teaching Approaches Reported to Promote Creative Thinking

At the present time, there is an international trend to develop creative thinking in science lessons (Cheng, 2011). However, strategies to promote creative thinking in science are not widely known or used. Teachers still teach science through lectures and textbooks that are dominated by facts and algorithmic processing rather than by concepts, principles, and evidence based ways of thinking (DeHaan, 2009).

Therefore, it is important to investigate which instructional strategies facilitate learning thinking skills and syllabus content simultaneously, and it is based on the idea that academic study offers many chances to enhance and practice mental operations for students at a certain educational stage (Lizarraga, et al., 2010). Researchers recommended that there are deliberate instructional strategies for promoting creative thinking in the science classroom. Sternberg, Williams, Small, and Thomas, (1998) presented twenty-four tips for teachers to enhance creativity. Among them, the following techniques might apply to a science classroom (DeHaan, 2009):

i. Model Creativity: The most powerful technique to develop creativity. Students develop creativity when teachers model creative thinking;

ii. Question Assumptions: Make questioning a part of the daily classroom exchange. It is more important for students to learn what questions to ask-and how to ask them than to learn the answers. Students should know how to formulate good questions and evaluate rather than simply answer them;

iii. Encourage Idea Generation: Students need to be encouraged in generating many ideas, regardless of whether some are silly or unrelated by providing an environment free of criticism;

iv. Cross-Fertilize Ideas: this technique motivates students who aren't interested in subjects taught in abstraction and give students' opportunities to think across disciplines. Teachers should avoid compartmentalization and stop teaching in subject area boxes: math box, the social studies box, and the science box. Creative ideas and insights often result from integrating material across subject areas, not from memorizing and reciting material. Teachers should allow their students to identify their best and worst academic area, then ask them to come up with project ideas in their weak area;

v. Imagine Other Viewpoints: students broaden their perspective by learning to see the world from a different point of view, and that experience enhances creative thinking and contributions; and

vi. Build Self-Efficacy: All students have the ability to be creative and to experience the joy associated with making something new, but teachers must give them a strong base for creativity.

Kind and Kind, (2007) focused on introducing inquiry-based science into classrooms. The core of the approach ‘Inquiry based science’ is to present students with real-world problems and data, and to allow them to formulate hypotheses, design experiments, gather data, and marshal evidence in support or against the hypotheses. Learning is more creative when learning activities mimic the real-world creative processes of scientists.

Cheng, (2011) and Starko, (2009) identified that teaching of divergent thinking and idea generation strategies, for example using brainstorming, mind-mapping, creative dramatics, and creative problem solving technique (CPS) are popular strategies to enhance creative thinking in science education. Fisher (2006) suggested six strategies for enhancing creative thinking among students which can be applied to a wide range of curriculum areas and involves using imagination; generating questions, ideas and outcomes; experimenting with alternatives; being original; expanding on what they know or say and exercising their judgment. Cheng (2004) presented a set of strategies for enhancing creative thinking in physics learning which includes, mind-mapping; brainstorming; free questioning; open discovery, open inquiry; problem solving and metaphors. Dass, (2004) asserted that to promote creativity in science classrooms, useful creative thinking strategies must be used, which includes, visualization, divergent thinking, open-ended questioning, consideration of alternative viewpoints, generation of unusual ideas and metaphors, novelty, solving problems and puzzles, designing devices and machines, and multiple modes of communicating results. Mumford, (2003) mentioned the new methods applied for studying creativity such as the historiometric approach, the case study approach, systems model as well as the cognitive and computer modeling.

In a recent review Cheng, (2011) developed five different kinds of creative science learning activities as instructional strategies for infusing creativity into science subjects, namely, discovery, understanding, presentation, application and transformation of science knowledge.

In summary, in this study, the researcher used brainstorming as a teaching technique for enhancing creative thinking because brainstorming is supported by three strong components in learning, namely, motivation, cognitive processing and cooperative learning. Additionally, the process of brainstorming stimulates the cognitive creativity of students.

2.3 Critical Thinking

Critical thinking is a rich concept that has been developing throughout the past 2500 years. Critical thinking concept is rooted in three academic disciplines namely philosophy, behavioral psychology and cognitive psychological. Therefore, a definition of critical thinking is quite different among these three schools. However, definitions for critical thinking that have emerged in the field of education include:

i. "the mental processes, strategies, and representation's people use to solve problems, make decisions, and learn new concepts" (Sternberg, 1986, p. 3);

ii. "the use of those cognitive skills or strategies that increase the probability of a desirable outcome" (Halpern, 1998, p.450) ;

iii. "seeing both sides of an issue, being open to new evidence that disconfirms your ideas, reasoning dispassionately, demanding that claims be backed by evidence, deducing and inferring conclusions from available facts, solving problems, and so forth" (Willingham, 2008, p. 8), and

iv. "the art of analyzing and evaluating thinking with a view to improving it" (Paul & Elder, 2008, p. 4).

It appears that the definition of literature for critical thinking has numerous similarities in that critical thinking is a mental process that uses logical and analytical methods to reach solutions and evidence given to evaluate the proposed ideas. A more detailed description is discussed below.

2.3.1 Core Critical Thinking Skills

The key to successful learning is critical thinking skills (Miri, David, & Uri, 2007). Numerous lists of critical thinking skills have been proposed, perhaps due to perhaps the multiplicity of definitions and interpretation of theories interpreted as explained above. The researcher has reviewed the categories provided by past researchers who are considered pioneers in the study of critical thinking which is as follows:

1. Watson and Glaser (1980) classified critical thinking as the five skills (inference, recognizing assumption, deduction, interpretation, evaluating arguments);
2. Halpern (1997) classified critical thinking as the five skills (verbal inference, analysis of arguments, hypothesis testing, using probability and not Uncertainty, decision-making and problem-solving);

3. Facione (1998) classified critical thinking as the six skills (interpretation, analysis, evaluation, inference, explanation, self-organizing);
4. Beye (1999) classified critical thinking as the ten skills (distinguish between facts and allegations, distinction between objective evidence and random ability to determine the credibility of news and opinion, verify the authenticity of the source of the news, discrimination vague allegations and evidence of objectivity, ability to determine the degree of bias of others, ability to distinguish logical fallacies. distinguish the assumptions contained in the text of the phenomenon, identify inconsistencies during the inference process, determine the strength of the proof or evidence), and
5. Ennis (2004) classified critical thinking as the six skills (focus to a particular question, analyze the arguments and evidence, judge the credibility of the source of the information and data, avoid impulsivity in sentencing, determine the criteria for the credibility of the source of the information, discovery of inaccuracies or errors).

However, close analysis of the above classifications reveals similarities in semantics (Meador, 1997). In the present study the researcher followed the classification of Watson and Glaser (1980) of critical thinking skills which most researchers have related to the science in general and physics in particular (AbuMhadi, 2011).

Watson and Glaser (1980) see critical thinking as a mixture of attitudes, knowledge, and skills. In addition to thinking critically, a learner must be able to:

i. Define problems;
ii. Choose valid information to solve the problem;
iii. Employ and apply knowledge in new setting, and

iv. Evaluate inference.

Watson and Glaser (1980) defined five critical thinking skills for solving a problem. These skills are:

i. Inference: Discriminating among degrees of truth or falsity of inferences drawn from given data;
ii. Recognizing assumptions: Recognizing unstated assumptions or presuppositions in given statements or assertions;
iii. Deduction: Determining whether certain conclusions necessarily follow from information in given statements or premises;
iv. Interpretation: Weighing evidence and deciding if generalizations or conclusions based on the given data are warranted, and
v. Evaluating of arguments: Distinguishing between arguments that are strong and relevant and those that are weak or irrelevant to a particular issue.

Critical thinking skills are supported by four important aspects in learning which include metacognition (thinking about thinking), motivation, collaboration and creativity. Metacognition supports critical thinking in that students are able to evaluate their own thought processes, arguments and reasoning. All these skills are necessary for self-regulated learning. Motivation supports critical thinking in that students when faced with challenging or interesting learning activities and assessment tasks may spark students' motivation and they start to think critically. Students who possess critical thinking dispositions, include, characteristics such as willingness to entertain other's viewpoints, and make good collaborators and therefore opportunities for collaboration must be provided to promote critical thinking among students. Finally, creativity requires the ability of critical thinking to evaluate intellectual products, and critical thinking requires the open-mindedness and flexibility which are abilities of creative thinking (Lai, 2011).

Recently, researchers have begun to investigate the relationship between the disposition to think critically and critical thinking skills. Many believe that in order to enhance critical thinking skills, the disposition to think critically must be nurtured as well, as illustrated in Figure 2.7.

Figure 2.7 Relationship between disposition and critical thinking skills

Although the critical thinking skills and dispositions are listed separately, they are integrated in the actual process of teaching (Ennis, 1985; Facione, 1990). Facione, (1990) argues that cognitive skills are not sufficient as students are more than thinking machines. This disposition can be described as habits of mind or attitudes. Researchers tend to identify similar sets of dispositions associated with critical thinking which includes:

i. Inquisitiveness;
ii. open-mindedness;

iii. flexibility;

iv. the propensity to seek reasons;

v. fair-mindedness;

vi. Try to be well-informed, and

vii. Respect for and willingness to entertain diverse view points (Bailin, Case, Coombs, & Daniels, 1999; Ennis, 1985; Facione, 1998; Halpern, 1998).

2.3.2 Characterizations of a Critical Thinker

Facione, (1990) describes the ideal critical thinker is habitually inquisitive, well informed, trustful of reason, 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 an inquiry permit. Wade, (1995) identifies eight characteristics of critical thinking which involves: asking questions, defining a problem, examining evidence, analyzing assumptions and biases, avoiding emotional reasoning, avoiding oversimplification, considering other interpretations, and tolerating ambiguity. Dealing with ambiguity is also seen by Strohm and Baukus, (1995) as an important part of critical thinking, "Ambiguity and doubt serve a critical-thinking function and are a necessary and even a productive part of the process" (p. 56).

Another characteristic of critical thinking identified by many sources is metacongition. Metacongition is thinking about one's own thinking. More specifically, metacognition is being aware of one's thinking as one performs specific tasks and then using this awareness to control what one is doing" (Jones & Ratcliff, 1993, p. 10).

Beyer, (1995) elaborately explains essential aspects of critical thinking. These are:

i. Dispositions: Critical thinkers are skeptical, open-minded, value fair-mindedness, respect evidence and reasoning, respect clarity and precision, look at different points of view, and will change positions when reason leads them to do so;

ii. Criteria: In helping students to think critically, to make thoughtful assessment or reasoned judgment, there is a need for an appropriate set of criteria or conditions that must be met for something to be judged as believable. Although the argument can be made that each subject area has different criteria, some standards apply to all subjects. "An assertion must be based on relevant, accurate facts; based on credible sources; precise; unbiased; free from logical fallacies; logically consistent; and strongly reasoned" (Beyer, 1995, p. 12). These criteria are important for the teaching-learning process in a science class;

iii. Argument**:** Is a statement or proposition with supporting evidence. Critical thinking involves identifying, evaluating, and constructing arguments;

iv. Reasoning**:** The ability to infer a conclusion from one or multiple premises. To do so requires examining logical relationships among statements or data;

v. Point of View: The way one views the world, which shapes one's construction of meaning. In a search for understanding, critical thinkers view phenomena from many different points of view, and

vi. Procedures for Applying Criteria: Other types of thinking use a general procedure. Critical thinking makes use of many procedures. These procedures include asking questions, making judgments, and identifying assumptions.

2.3.3 Procedures of Critical Thinking

All literature on critical thinking in science education has conceptualized critical thinking in terms of procedure as mental processes or series of procedural steps. This is based on literature on cognitive development. Bailin, (2002) and Brookfield, (1987) advocated that processes of critical thinking include the whole processes of identifying and challenging assumptions, imagining and explore alternatives, examination of information, looking at the epistemological, reflection skepticism, experiential, political perspectives of the source information and reasoning to come up with solutions. Furthermore, Kurfiss, (1988) identified five cognitive processes to motivate students to think critically namely:

i. Stimulate student’s curiosity by using problems as organizing principle for instruction, familiar examples, inquiry methods and link new information with student's background knowledge to enhance student's understanding, organizing and accessibility or declarative knowledge;
ii. Directing the students into when and how to utilize what they are learning such as use practice, modeling and feedback to teach reasoning skills relevant to the subject of study;
iii. Describe and construct metacognitive student's exercises and assessments;
iv. Raise and discuss beliefs about the nature of what is to be learned and provide experiences to overcome students‘ misconceptions and prior knowledge about any related matter; and
v. Use social and cognitive strategies to improve and motivation to learn.

Bailin, et al., (1999) proposed three components to help teachers in teaching critical thinking, which is slightly similar with the procedures put forward by Kurfiss (1988):

i. Engaging students in dealing with tasks that call for reasoned judgment or assessment;
ii. Helping them develop intellectual resources for dealing with these tasks; and
iii. Providing an environment in which critical thinking is valued and students are encouraged and supported in their attempts to think critically and engage in critical discussion.

However, the literature on the procedures of critical thinking is actually varied and different (Marrapodi & Education, 2003). Bailin (2002) asserted that no specification in terms of procedures is sufficient to describe the critical thinking in science education. Some researchers view critical thinking as a generic set of skills or processes to be developed independent of content and context (Case, 2005).

However, there are sets of procedures which are necessary for all critical thinking such as controlling an experiment or verifying a result in science. These cases involve participating in a specific procedures, which have inbuilt criteria in order to carry them out. This is consistent with the process of brainstorming technique especially in the step ‘evaluation of ideas’.

2.3.4 Empirical Studies for Critical Thinking in Science Education

Several researchers argue that critical thinking is an invaluable component in science education, particularly at secondary schools (Gunn, et al., 2008; Hargreaves & Grenfell, 2003; Rodrigues & Oliveira, 2008) and educators such as John Dewey and Karl Pearson urged that science be taught in order to infuse critical thinking (Hobson, 2001).

Nevertheless, studies point out that science classrooms (including physics) are still strongly depended on a transmissive approach demanding the memorization of physics equations, principles and laws or the performance of mere exercises based on a practice and drill approach. This method of learning physics is boring and uninteresting for students and does not enhance critical thinking and does not meet the actual requirements of society and of the new trends of physics curricula (Bailin, 2002; Dagher & BouJaoude, 2011; Gunn, et al., 2008; Hargreaves & Grenfell, 2003; Rodrigues & Oliveira, 2008; Sulaiman, 2011; Vieira, Tenreiro-Vieira, & Martins, 2011; Zohar & Tamir, 1993). Brookfield (1987) asserted that critical thinking is removed from the school classroom. Skills of critical thinking are seldom explicitly taught to students during the lessons (Kurfiss, 1988). Moreover, many of the experts fear that some of the students' experiences in school are actually harmful to the development and cultivation of strong critical thinking (Facione, 1998).

Therefore, the science education community urgently needs to be aware of the importance that critical thinking has in science learning and needs to find ways to support teachers and help students to make meaning of scientific knowledge (Rodrigues & Oliveira, 2008). Students are regarded not as passive recipients of information, but researchers who are required to discover knowledge, skills, and strategies that are personally meaningful and compatible with prior knowledge representations (Gunn, et al., 2008). To foster critical thinking in science the teacher must focus on “critical challenge” such as reasons rather than rules; procedures on conceptual tools; reasoning in specific contexts; and a focus on the group as well as individual reasoning (Bailin, 2002). In all these cases, students go beyond locating facts or reporting what they know but be able to judge or assess possible options (Case, 2005).

Rodrigues and Oliveira, (2008) demonstrated that good performance in physics required critical thinking. Therefore, to help students in critical thinking, there are five types of intellectual resources involved: background knowledge; criteria for judgment; critical thinking vocabulary; thinking strategies and habits of mind (Case, 2005).

2.3.5 The Challenge of Enhancing Critical Thinking in Science Education

The literature in science education claims that there are a number of challenges and difficulties in the fostering of critical thinking. First, many of the efforts to encourage critical thinking in science based on misconceptions about the nature of critical thinking are particularly in terms of processes, skills and separation of critical thinking and knowledge (Bailin, 2000). Moreover, teachers do not have a clear idea about critical thinking because the meaning of critical thinking attributed to the different contexts (Vieira, et al., 2011) and unwillingness to allow sufficient thinking time for students (Rodrigues & Oliveira, 2008). Second, the biggest obstacle in science education is students’ previous misconceptions. Furthermore, science texts suffer from serious flaws, which give students false and misleading ideas about science (Paul, Willsen & Binker, 1993) .

In addition to the two factors mentioned above there are other reasons which influence the enhancement of critical thinking among students. Critical thinking is one type among a plethora of thinking skills and there will never be adequate time devoted to it. Critical thinking is ranked as 'higher-order thinking', which presumably requires mastery of 'lower order thinking' before it can be introduced to students.

However, the evidence suggests that many students were incapable of reaching higher-order thinking, and therefore classroom activities are relegated to simple tasks like reading and repeating. Furthermore, critical thinking skills are separated from the content, especially in secondary schools, where the teaching of critical thinking is generally divorced from the teaching of subject matter because in many classrooms, curriculum content is the priority (Case, 2005).

Maitah, et al., (2011) summarized a number of obstacles that can lead to the failure of the critical thinking development process:

i. Low level of motivation for learning;
ii. Low level of perseverance, discussion activities and ambition by the students;
iii. Lack of the attention of the students inside the classroom, which generates dispersion in focus;
iv. Lack of arrangements and courses that students of educational colleges received prior to their appointment as qualified teachers in schools to teach thinking, and
v. Misunderstanding of the requirements of critical thinking skills and how to explain the skills and apply it by both the teacher and student.

Therefore, the science education community urgently needs awareness of the importance that critical thinking has in teaching science and needs to find ways to help teachers in accomplishing this target (Rodrigues & Oliveira, 2008).

2.3.6 Tests for Measuring Critical Thinking Skills

Measuring critical thinking skills is a complex issue (Abrami, et al., 2008). However, researchers in education have employed several tests that purport to measure critical thinking skills. The purpose of this section is not to provide an exhaustive review of all the available tests, but rather to illustrate some of the principles underlying these tests and how they relate across the range of tests available. The emphasis will be upon tests at the secondary school level.

Abrami, et al., (2008) classified critical thinking tests to five categories:

i. Tests by Watson and Glaser, (1980), and Ennis, (1985, 2009);
ii. Secondary source measures: researchers adopted tests from other sources with or without modifications or developed (standardized or substandard) tests to meet the requirement of their research setting;
iii. Tests developed by teachers: teachers develop critical thinking skills for students through interview questions, open-ended questions, and essay type of tasks;
iv. Tests developed by researchers: this category refers to nonstandard measures researchers develop to use in a particular study.

v. Tests developed by researchers: researchers who are teachers or instructors develop tests to measure critical thinking skills such as Zohar and Tamir, (1993) and Critical Thinking Test by Fisher (1996).

In the present study, the researcher developed the test based upon a number of existing critical thinking tests in science education (Alwani, 1999; Burns, Okey, & Wise, 1985; Monica, 2005; OECD, 2000; Watson & Glaser, 1980) to measure the five skills (inference, recognizing assumptions, deductions, interpretations and evaluating arguments) which the present study aims to enhance among secondary Iraqi Physics students.

2.3.7 Instructional Strategies Used to Promote Critical Thinking

In order to promote students' critical thinking in science classrooms, teachers must use effective instructional strategies for learning to go beyond the rote memorization of formulae matched to simple problem types (Narode, 1987). Some of the methods hinder critical thinking rather than enhance it (Pithers & Soden, 2000).

Therefore, there are several efforts focused on effective instructional strategies on the development and enhancement of critical thinking skills and disposition (Abrami et al, 2008). Researchers have recommended that to enhance the critical thinking skills, particular instructional strategies can be used, such as explicit teaching, modeling, cooperative or collaborative learning and constructivist techniques (Lia, 2011). Many researchers have noted that explicit instruction help teachers to enhance critical thinking skills among students in science education (Abrami, et al., 2008; Gunn, et al., 2008;

Halpern, 2007; Huitt, 1998). Both students and teachers benefit from explicit instruction. By providing cognitive scaffolds that help students to activate higher thinking skills and scientific inquiry, students are focused to synthesize, analyze, reflect, skill and reason. In addition, Halpern (2007) and Faccion (2011) recommend that critical thinking need to develop the dispositions for difficult thinking and learning, to increase the probability of transcontextual transfer through direct learning activities, and to make metacognitive monitoring explicit and declared.

Modeling is another strategy recommended by several critical thinking researchers (Duron, et al., 2006; Huitt, 1998; Sale & Cheah, 2011). Huitt (1998) also claimed that the more appropriate teaching method to encourage critical thinking is modeling and /or personal experience. Teachers need to model critical thinking skills for students (Sale & Cheah, 2011). Duron, Limbach, and Waugh (2006) developed modeling that can be implemented in virtually any teaching or training setting to effectively move learners toward critical thinking.

Many researchers have recommended that using collaborative or cooperative learning enhances critical thinking (Abrami, et al., 2008; Gokhale, 1995; Heyman, 2008; Huitt, 1998; Narode, 1987; Nelson, 1994; Ngeow, 1998). Collaborative learning defined as "An instructional method in which students work in groups toward a common academic goal" (Gokhale, 1995, p. 2).

Collaborative learning has a positive effect on learning in general and for developing and enhancing critical thinking, in particular (Abrami et al, 2008, Heyman, 2008; Ngeow, 1998, Gokhale, 1995, Nelson, 1994). Collaborative learning is rooted in theories of Piaget and Vygotsky, which emphasize the value of social interaction for improving cognitive development when students interact with one another (Dillenbourg, Baker, Blaye, & O'Malley, 1995). On one hand, collaborative learning promotes dialogical interchange and reflexivity among students, encourage students to share alternative viewpoints, support each other's inquiry processes, and develop critical thinking skills (Ngeow, 1998). On the other hand, collaborative learning must be scaffolded. Nelson (1994) points out that the scaffolding process involves three steps. First, preparation which provides students with a common background on which to collaborate such as a common assigned presentation in class. Second, cognitive structuring which provides students with questions that prompt them towards more sophisticated thinking than they would on their own. Finally, the collaborative process should be structured via specifying students’ roles and gets all the members of a group to participate meaningfully.

Finally, a constructivist learning strategy is an effective strategy to promote critical thinking. One foundational premise of constructivism is that learners have to construct their own knowledge individually and collectively.

In summary, all these instructional strategies will enhance students to devise the questions, propose solutions, seek information (Pithers & Soden, 2000) and link between different kinds of phenomena based upon the laws of physics. Thus, students will practice critical thinking skills in the process (Paul, Willsen & Binker, 1993).

In this study, the researcher has used the brainstorming technique, which includes cooperative and collaborative learning and cognitive effects for helping the learner to activate critical thinking to solve physics problem and make decisions.

2.4 Research Combining both Creative and Critical Thinking

Enhancing higher thinking skills in physics (Mestre, Dufresne, Gerace, Hardiman, & Tougher, 1992) and in science education (Rabari, et al., 2011) is an important aim for educational systems. Therefore, many researchers have made connections between critical thinking and creativity (Aizikovitsh-Udi & Amit, 2011; Bailin, 2002; Barak & Dori, 2009; Bonk & Smith, 1998; Cotton, 1991; Fisher, 2002; Forrester, 2008; Glassner & Schwarz, 2007; Harris, 1998; Koh, 2002; Marrapodi & Education, 2003; Paul & Elder, 2008; Rabari, et al., 2011; Sulaiman, 2011; Swartz, et al., 1998) Glassner&Schwarz,2006.

All these researchers have typically agreed that students need both creative and critical thinking in the process of solving the problem because first, students must analyze the problem; then generate possible solutions; next choose and implement the best solution; and finally, evaluate the effectiveness of the solution. In this manner, creative thinking comes before critical thinking and then resonates back to it (BacanlI, et al., 2011).

Therefore, creativity or critically thinking alone is not sufficient because they complement each other. A process of thinking that skillfully combines creative and critical thinking could be called "productive" thinking (Rusbult, 1997). Stimulating student’s intellectual work develops the intellect as both a creator and evaluator: as a creator that evaluates and as an evaluator who creates. The result is fitness of mind, and comprehensive intellectual excellence (Paul & Elder, 2008). Learning becomes much more meaningful, interesting and effective when students are given the opportunity to be creative and critical by exercising their thinking abilities. Schools should focus not on knowledge alone but also on teaching and practicing creative and critical thinking skills (Forrester, 2008).

Creative and critical thinking skills involve and affect both teachers and learners as they are brought together into sharing the responsibility for effective learning. Critical thinking supports as well as follows creative thinking because once the focus has been widened by creative thinking, then critical thinking serves to evaluate ideas, which can be accomplished by narrowing the focus again to catalogue ideas and identify the most reasonable ones, or those most likely to succeed. Creative thinking is one aspect of the development of critical thinking (Brookfield, 1987).

Likewise, teaching critical thinking leads to the development of creative thinking (Koh, 2002) It seems that creative thinking has aspects of critical thinking, and critical thinking has aspects of creativity. Paul and Elder (2006) note that “critical thinking without creativity is reduced to mere skepticism and negativity, and creativity without critical thought is reduced to mere novelty” (p. 35). This means that critical and creative thinking are intimately related, each without the other is of limited use (Paul & Elder, 2008). Dehaan (2009) stated that the creative process requires both divergent and convergent thinking.

In contrast, all these agreements of the strong relationship between creative and critical thinking in research literature there is a gap where the experimental studies have rarely focused on ties between creative and critical thinking. Fisher, (2002); Glassner & Schwarz, (2007); Harris, (1998) for example, have differentiated between critical thinking, which is analytic, convergent, vertical probability, judgmental, involves hypothesis testing, giving objective answers, left brained, closed linear, reasoning, logical, and creative thinking which is generative, divergent, lateral, possibility, suspended judgment, hypothesis forming, subjective answers, right brained, open-ended, associative, speculating, and intuitive. This comparison did indeed provide an opportunity for a deep analysis of the ties between critical and creative thinking.

This present research intends to investigate the enhancing of both creative and critical thinking in physics learning.

2.5 Creative and Critical Thinking Related to the Cognitive Domain of Bloom's Taxonomy

According to Bloom's Taxonomy of Educational Objectives (1956), creative and critical thinking skills fall under the highest level of cognitive domain: analyzing, creating, and evaluating as illustrated in Figure 2.8. Analyzing (the ability to separate materials into component parts so that its organizational structure may be understood), creating (the ability to put ideas together in new ways, to innovate and think creatively) and evaluating (the ability to judge the worth of ideas against stated criteria by reviewing and asserting evidence, then making appropriate judgments another aspect of critical thinking) (Bloom, Englehart, Furst, & Krathwohl, 1956). Processes that required more mental effort than simple remembering and recall. Higher thinking skills are sometimes known as higher-order thinking skills or protective thinking skills, which include creative and critical thinking (Meador, 1997). Both evaluating and creating depend on analyzing; evaluating requires a comparison while creating requires re-arranging (Forrester, 2008).

Creative and critical thinking have three dimensions: the analytic, the evaluative, and the creative, these three dimensions cannot be separated from each other and must be involved if the other two are to be effective (Paul & Elder, 2008). It is important for science teachers to associate between upper levels (analysis, create, and evaluation) and the process that underlies the "purposeful, self-regulatory judgment that drives problem-solving and decision-making". Lamb, (2003) equates evaluation with critical thinking and synthesis with creative thinking (Huitt, 1998). Creative thinking is designed to create, and critical thinking is designed to evaluate. To think creatively and critically, we have to use both sides of brain and understand many aspects of basic knowledge first. Both skills are extremely important for achievement and success in the world today. Therefore, teachers should build these skills in students because each has value, and when used in conjunction, creates a powerful process of higher-order thinking (Marrapoid, 2003). Teachers must help our students achieve their potential and engage with the learning materials in a deep and fruitful way. Achieving good thinking requires skills in both creative and critical thinking (Huitt, 1998). Creativity masters the process of making or producing, criticality a processing or judging.

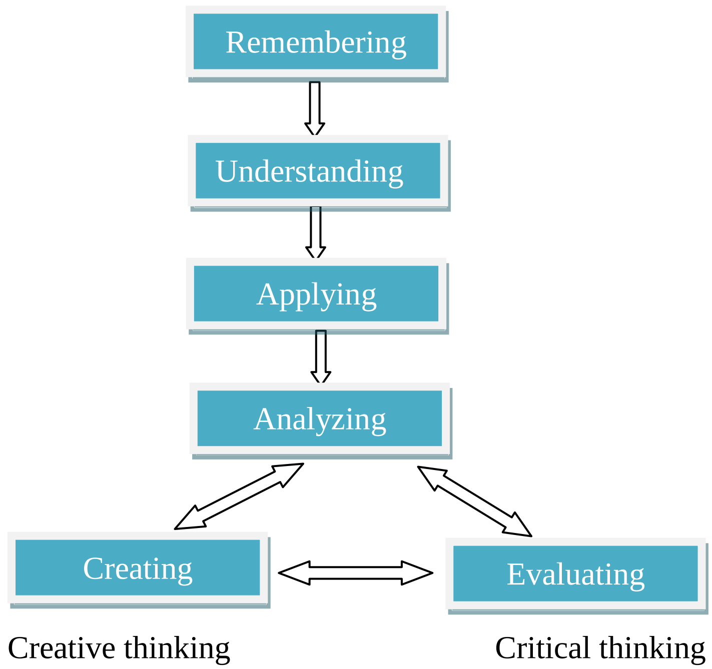

Figure 2.8 Bloom's Taxonomy of the cognitive domains

2.6 Thinking Skills

Thinking skills are at the heart of learning, it is impossible to consider learning without thinking. Researchers suggest that thinking skills are essential to effective learning and is the central goal of science education. These skills consist of knowledge, dispositions, and cognitive operations (Cotton, 1991). Knowledge is a component of metacognition that involves executive control of the declarative, procedural, and conditional information relative to a task. Whilst disposition shows the inclinations to engage in some types of behaviour and not to engage in others. Certain dispositions are associated with critical and creative thinking. Cognitive operations consist of thinking skills and thinking processes, thinking processes can be represented creative and critical thinking skills, where the objective is to solve problem and make a decision (Kizlik, 2012).

Thinking skills are developed at all key stages and centre on information-processing skills, reasoning skills, enquiry skills, creative thinking skills and evaluation skills (DfES, 2002). By using thinking skills, students can focus on learning how to learn. Piaget and Vygotsky suggested that thinking skills are developed by cognitive challenge. Teacher should use effective teaching methods in science to enhance students thinking skills (Fisher, 2006b).

In conclusion, thinking skills are mental processes used in cognitive functions which enable students to create, compare, solve problems, make decisions, plan and organise, categorise, synthesise and analyse information, communicate, and apply.

It seems that some of the above skills are creative, while others are critical. Still others involve both creative and critical aspects of scientific thinking (Lawson, 1989). The next section discusses in detail how these thinking skills relate and intersect with learning context and knowledge to solve problems.

2.7 The Learning Process and Problem-Solving

Dewey (1933) advocates that the learning process begins when the learner is given ownership of the problem and solution process to explore, think, reflect and interact with others. This is consistent with the constructivist view of learning. A constructivist advocates a learning process, which allows a learner to experience and construct knowledge actively rather than just mechanically ingesting knowledge from the teacher or the textbook. Problem solving is a constructivist approach that promotes student involvement and active learning, which enables a learner to generate his or her own knowledge. It involves thinking that occurs internally in the cognitive structures of the learner. This thinking involves both creative and critical thinking skills, which are not only important for high-ability students but also engaging and exciting for all students.

Problem solving is central for physics learning. Physics teachers use problem solving to promote learning and thinking skills in physics (Beatty & Gerace, 2005). Therefore, problem solving requires three distinct types of mental skill, critical thinking, creative thinking and science process skills which can be effectively used by students to complete an investigation and find a solution to the problem. Science process skills and thinking skills are interrelated. The problem-solving processes provide the mechanisms for converting knowledge into behaviour as well as increased long-term memory capacity to store more information (more chunks) in LTM (Anderson, 1993).

Both the learning process and problem solving are required to use thinking processes. McClure, Sonak, and Suen, (1999) proposed that learning, whether it is discovery learning or expository learning, declarative knowledge and procedural knowledge are achieved. Gaining such declarative and procedural knowledge influences students' ability in solve the problem. The relationship between learning, knowledge acquisition and problem solving is as illustrated in Figure (2.9). Creativity and critical thinking can be seen in terms of both cognitive process and learning outcomes.

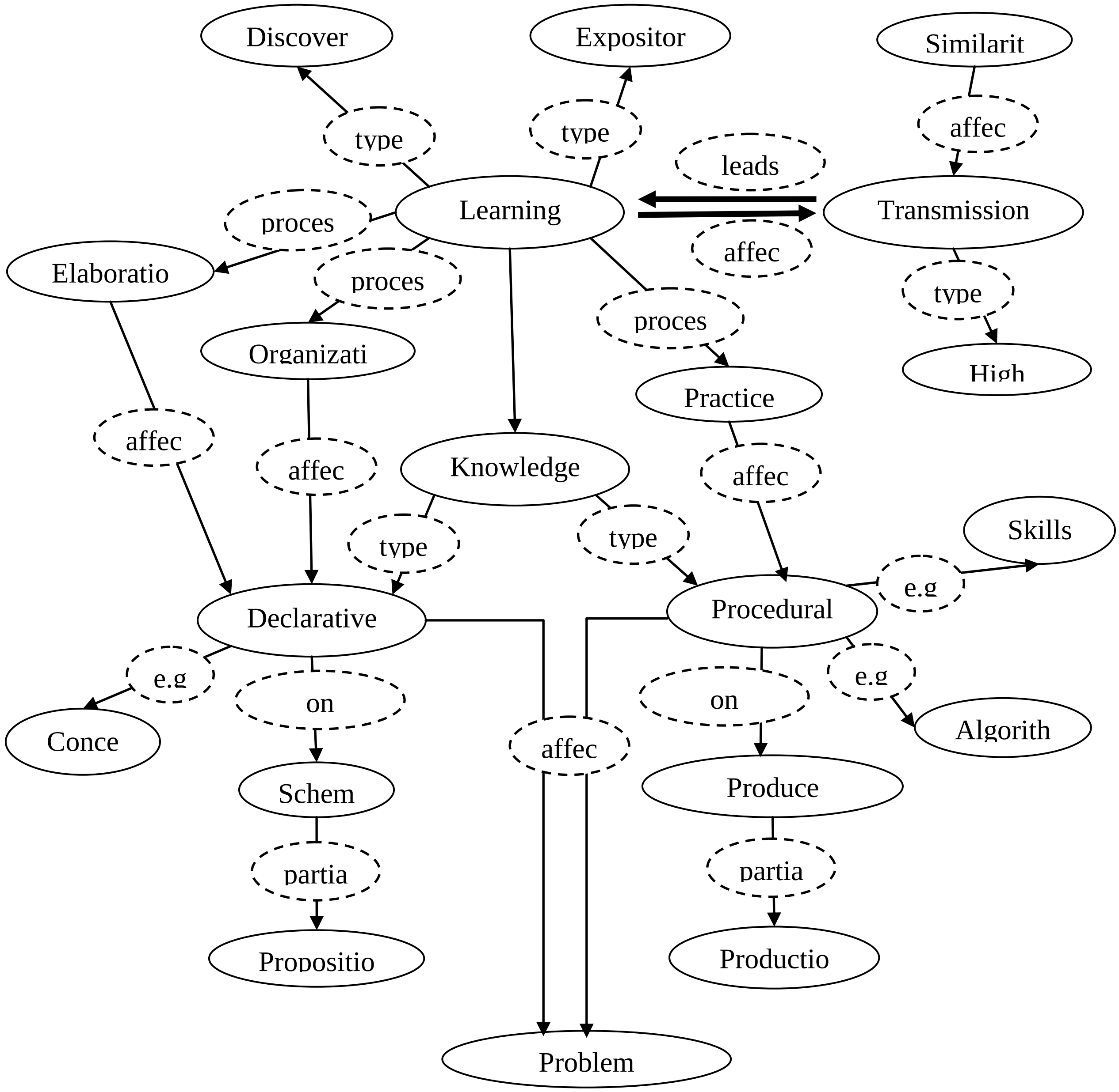

Figure 2.9 Relationship between learning, knowledge acquisition and problem solving (after (McClure, et al., 1999))

In the present study, the brainstorming technique was used in the learning of physics problem-solving. Learners used declarative and procedural knowledge and employed thinking skills such as creativity and critical thinking skills to solve the problems.

2.8 The Current Study Location among Previous Studies

The current study benefited from previous studies in several issues, including the following: how to implement the brainstorming technique in the classroom; the division of the groups in class; distribution of roles for students in the group; design activities; use of appropriate statistical methods to address the results; viewing the findings of the previous studies to compare them with the results of the current study, and in the preparation of creative and critical thinking tests.

However, the current study differs from previous studies in several issues, including the following:

i. The current study is characterized by both creative thinking and critical thinking with the brainstorming technique while previous studies had dealt with only one variable of these two variables;

ii. The current study prepared brainstorming procedures which consists of six steps (problem identification, idea generation, evaluation ideas, selection ideas, implementation, and problem solving) while previous studies have only implemented only three steps (problem identification, idea generation, and evaluation ideas);

iii. The current study focused on the preparation of two tests to measure creative thinking skills (fluency, flexibility and originality) and critical thinking skills (inference, recognizing assumptions, deduction, interpretation, evaluating arguments) in physics while previous studies used ready and general tests not specific for physics; and

iv. Previous studies had used samples at various stages; the researcher did not find any study which had applied the brainstorming technique for Secondary Iraqi second grade intermediate students.

2.9 Chapter Summary

In conclusion, the literature review points that the brainstorming technique has been used in science education in general, and in teaching of physics in particular. Nevertheless, most of the previous studies have focused on measuring the productive aspect of brainstorming and comparing individual and group brainstorming.

There are no previous studies which have employed brainstorming to examine both types of thinking, creative and critical thinking in science education. Although, brainstorming is a technique for enhancing thinking skills among learners, the researcher found that only limited previous studies have utilized brainstorming technique in physics education. This could be because there are misconceptions about the brainstorming technique, creativity and critical thinking among researchers and teachers. Previous studies have shown that there are difficulties and challenges for developing creative and critical thinking in science education. Therefore, in the context of this study, the researcher has focused on both types of thinking, rather than just one.

The next chapter will focus on the theoretical framework underpinning of this study.