Journal of Education and Practice
ISSN 2222-1735 (Paper) ISSN 2222-288X (Online)
Vol.8, No.20, 2017

The Role of Critical Thinking in Science Education

Luis Fernando Santos
Institute of Curriculum and Instruction, Nanjing Normal University, 122 Ninghai Road, Nanjing 210000, China

Abstract
This review aims to respond various questions regarding the role of Critical Thinking in Science Education from aspects concerning the importance or relevance of critical thinking in science education, the situation in the classroom and curriculum, and the conception of critical thinking and fostering in science education. This review is specially addressed to educational contexts (teachers) where Critical thinking has had a very few presence in Science Education, particularly in the classroom. The findings and discussion of this review explain the relevance and strong relationship between Critical thinking and science education. Nevertheless, problems were found when implementing critical thinking in the science classroom. One of these problems related to the lack of clarity for applying Critical thinking classroom techniques in science subjects. Though, its nominal (not practical) presence and recognition in science curricula, as well as in curricula in general, is not a problem. There are practical Critical thinking-related strategies that can be applied in science classrooms to improve science education results and critical thinking dispositions on students, one of these is 'questioning', regarded among the most powerful tools.
Keywords: Critical Thinking, Questioning, Critical questioning, Science, Science Education.
摘要
本评论的目的是基于批判性思维在科学教育所扮演的角色回答一些回答，主要从以下几个方面着手：批判性思维在科学教育中的重要性或相关性，课堂教学和课程实施的现状，批判性思维的概念以及如何在科学教育中形成。除此之外，本文强调了在现实教育情境中批判性思维在科学教育中的缺失。文章的结果和讨论部分分析了批判性思维和科学教育之间的强相关性。尽管如此，在科学课堂中培养批判性思维仍然会存在问题。其中一个问题是如何在科学课上运用批判性思维不够明确和清晰，虽然批判性思维在科学课程标准的文本上是有关注的，但是在实践中如何运用批判性思维相关的策略以提高学生的科学成绩和改善学生的思维品质仍然存在问题。
Resumen
Esta revisión tiene como objetivo responder a varias preguntas sobre el papel del Pensamiento Crítico en las Ciencias Naturales desde aspectos relacionados con la importancia o relevancia del pensamiento crítico en las Ciencias Naturales, la situación en el aula de clases y el currículo, la concepción sobre pensamiento crítico y su fomento en la educación de las Ciencias Naturales. Esta revisión está especialmente dirigida a contextos educativos (profesores) donde el Pensamiento Crítico ha tenido muy poca presencia en la educación de las Ciencias Naturales, particularmente en el aula de clases. Los hallazgos en literatura y la discusión de esta revisión explican la relevancia y la estrecha relación entre el Pensamiento Crítico y las Ciencias Naturales. Sin embargo, se encontraron problemas al implementar el pensamiento crítico en el aula de clases. Uno de estos problemas se relaciona con la falta de claridad en la aplicación de técnicas de pensamiento crítico en las asignaturas de ciencias naturales. Sin embargo, su presencia y reconocimiento nominales (no prácticos) en los currículos de ciencias, así como en los planes de estudio en general, no es un problema. Existen estrategias prácticas relacionadas con el Pensamiento Crítico que pueden aplicarse en las clases de Ciencias para mejorar los resultados de la educación en Ciencias Naturales y la disposición de Pensamiento Crítico en los estudiantes, una de ellas es el "questioning", considerado entre las herramientas más poderosas.
Palabras clave: Pensamiento Crítico, Cuestionamiento Crítico, Ciencias Naturales.

1. Introduction

This review attempts to respond six questions regarding the role of Critical Thinking (CT) in Science Education. Due to the increasing importance that Critical Thinking is having in Education, and in Science Education, in particular, there are no discrepancies found about the strong relationship between Critical Thinking and Science Education, as shown in the next paragraphs. However, there is a further need to know details about the situation of Critical Thinking in Science curriculum in the last years, and how Critical thinking can be implemented into the Science curriculum. In order to provide further details about the role and situation of CT in Science curriculum, the next questions were used to guide the search process as well as the elaboration of this article:
Why is important Critical thinking in the context of Science Education and Education in General? What specific role does Critical Thinking play in Science Education? What are the concepts and conceptions of Critical thinking regarding Science Education? How to foster Critical thinking in teaching-leaning science? What is happening in the current and past practice of Science teaching-learning regarding Critical Thinking? How is presented Critical Thinking in the Curriculum of Science?

Critical thinking has been mainly thought and regarded as a study linked to theoretical philosophy, psychologic, pedagogy, and social sciences. However, Science Education has been largely disregarding Critical Thinking, in turn, attaching more emphasis to traditional teaching ways such as content-based teaching and resorting to students' memory for their learning. Nevertheless, it is quite few conceived CT as a matter attached or applicable to science or science education.

In the literature search process, the search engines or databases used were ERIC, Baidu scholar, CORE. The key words used were, Critical thinking, Science Education. The advanced search logic syntax applied was by linking these keywords with the (+) symbol. And also, full titles were entered such as, "Critical Thinking and Science", "Critical Thinking and Science Education".

The most useful search syntax entered in ERIC database ("Critical thinking")+("Science education"), by April, 2017; retrieved 175 results or records limiting the time from 2013 (last five years). Five articles were chosen belonging to periods previous to 2014, because of their relevance with to topic searched. One of these articles (the oldest one) with the title 'Critical Thinking and Science Education' by Sharon Bailin (2002). This last search procedure was carried out using the above-mentioned syntax or search logic but without limiting the time. Other syntax used to search for relevant articles were, Critical thinking+Science education (257 records by April, 2017); "Critical thinking"+"Science education", (Critical thinking)+(Science Education).

One limitation found in the search process is that some relevant, up-to-date articles were not able to download for free. It is important to note that among the articles found, there are some important primary sources and most of them published the last four years. Furthermore, some recent information was chosen from web pages and online news, which is considered useful for contrasting academic articles with mass media information, whose analysis is presented in the discussion section.

2. Findings

2.1 Why is important Critical thinking in the context of Science Education and Education in general?

The Role of Critical Thinking in the context of Science, Science Education, and Education in general, is without discrepancies deemed crucial and increasingly present throughout the last years in different education systems. This assertion is based on some authors affirmations, as it is presented below.

According to Hagop A. Yacoubian (2015), there are a number of reasons for addressing Nature of Science (NOS) in school science linked to Critical thinking. Among some of those reasons are: humanizing of the sciences and situating them in personal, ethical, cultural, and political contexts; contributing in building the ideal democratic societies, and promoting a fuller understanding of the scientific content. This author cites, many science educators have argued that having informed views of NOS would support citizens in making decisions on socioscientific issues in democratic societies (Kolstø, 2001; Zeidler, Walker, Ackett, & Simons, 2002).

Social problems linked to scientific development and globalization such as the threat of nuclear war, cybercrimes, cultural degeneration, fraud and corruption, over-individualization, irresponsibility (in the use of technology or science production), stirs up the need to solve these problems, where Educational institutions have a crucial role through moral, ethical values as well as Critical thinking promotion. (Sahin, Senar Alkin; Tunca, Nihal; Altinkurt, Yahya; Yilmaz, Kürsad; 2016)

Demir, S. (2015a) states, "the importance and effect of the ability to 'think differently' is gradually increasing in all societies. Two forms of thinking that are particularly important in this context are critical thinking and reflective thinking." In another recent article, Demi (2015b), also states, "Teachers who can think creatively and critically based on a scientific perspective, and who can see events from different angles occupy an important place in education. Training science teachers who have creative and critical thinking, as well as a scientific perspective, is particularly important for raising future generations…"; from where it is clearly manifested the importance of Critical Thinking in Science education and in education in general.

According to Osborne J. (2014), the notion of critique is deemed as a core feature of science. It is central to the Next Generation Science Standards (NGSS) that are currently being adopted by many US states. Also, the author notes that in the US National Research Council (2012a) in their report on Education for Life and Work, it is mentioned that, it is important the development of students' ability to undertake the cognitive process of complex reasoning, which includes critical thinking, non-routine problem solving, and constructing and evaluating evidence-based arguments.

Helena Pedrosa-de-Jesus, Aurora Moreira, Betina Lopes & Mike Watts (2014), assert that Critical thinking is seen as one of the very highest orders of cognitive abilities not just in Portugal, but in universities across the world. It is recognized as a key competency in higher education, particularly for science and technology.

Rui Marques, Celina Tenreiro, Isabel M. Matins (2011), affirm "In different countries efforts have been made to integrate critical thinking into science curricula, recognizing that it is necessary to live in a plural society with citizenship competence". This competence in the sense of educational competence, not commercial competence. Thus, it is recognized Critical Thinking as an important aspect for fostering Democracy.

2.2 What specific role does Critical Thinking play in Science Education?

Some authors state the role of Critical Thinking from different perspectives, above it is presented some of those views that express the link of critical thinking with science education.

Hagop A. Yacoubian (2015), regards that critical thinking is a foundational pillar for creating a pathway for Nature of Science (NOS) learning. The author cites that Developing future citizens' understandings of NOS is considered essential for fostering scientific literacy (American Association for the Advancement of Science, 1993; Bybee & DeBoer, 1994; Holman, 1997; Laugksch, 2000; Lederman, 2004; cited in Hagop, 2015); in this attempt, Critical thinking plays a crucial role.

Critical thinking has two fundamental roles in Science practice and education. One as a mean for fostering democracy, linked to the idea of fostering responsibility in the use and application of science, technology or scientific developments (Hagop A. Yacoubian, 2015; Gábor Á. Zemplén, 2007). The other is linked to the practice of science or science process, associated with the Science teaching-and-learning process, in which critical thinking principles and concepts are inherently related as explained in the next paragraphs.

It seems that Critique or Critical questioning together with the ability of question formulation is one of the most important aspects of Science linked to Critical Thinking, based on the responses of various authors reviewed that agree with this idea (Demir, S. 2015; Osborne J. 2014; Helena Pedrosa-de-Jesus, Aurora Moreira, Betina Lopes & Mike Watts, 2014; Rui Marques, Celina Tenreiro, Isabel M. Matins; 2011). Besides, an important practice that linked Critical thinking with Science is the practice of argumentation, discussion-debate and/or defending ideas (Osborne J. ,2014; Pedrosa-de-Jesus, H., Moreira, A. Lopes, B. & Watts, M., 2014; Marques, R. Tenreiro, C. Matins, I., 2011; Gábor Á. Zemplén; 2007)

Other authors agree that problem solving or finding appropriate solutions for problems is one way in which Critical thinking and Science are linked (Demir, S. 2015; Marques, R. Tenreiro, C. Matins, I., 2011; Beford, D. 2010)

One more link between Critical Thinking and Science is through evaluation, careful and rigorous testing (Osborne J., 2014), rejecting and assessment of arguments (Marques, R. Tenreiro, C. Matins, I., 2011) and/or evaluating arguments (Brow, S.; 2009)

Practices, skills or processes related to the link between Critical Thinking and Science, also are, decision making (Marques, R. Tenreiro, C. Matins, I., 2011), problem finding/identification (Demir, S., 2015a; Marques, R. Tenreiro, C. Matins, I., 2011), obtaining information and meaning clarifying (Brow, S.; 2009), Solving-clarifying discrepancies and concluding true statements (Beford, D.; 2010).

In general, Critical thinking is present in processes related to the scientific method or research, such as observation, exploration (Demir, S.; 2015), and others, as well as in the process of construction of reliable knowledge (Osborne J.; 2014). For instance, Demir, S. (2015a) notes that developing Critical and Reflective thinking skills is highly important for gaining the ability to see, think, research, question, and resolve events in a scientific way. Furthermore, Science applications, in particular, involve processes such as problem finding, problem solving, critical thinking, exploration, and investigation (Gomes, 2005; cited in Demir, 2015a). On the other hand, Gábor Á. Zemplén (2007) notes that one problem that separates science courses and Critical Thinking-focused subjects is that science is taught in a non- or pseudo-argumentative way. Nevertheless, science is an active process, and a human activity where argumentation is crucial and has a central role to play in the production of knowledge.

In sum, Critical Thinking has its role in the practice of Science in the next applications or processes:

- Research, Observation, Exploration
- Problem finding- identification and definition of a scientific problem
- Problem solving- finding appropriate solutions for problems
- Decision making
- Obtaining information
- Critique, Critical questioning, question formulation
- Construction of reliable knowledge
- Argumentation-defending ideas, discussion and debate
- Evaluation, careful and rigorous testing
- Rejecting-accepting hypothesis
- Solving, clarifying discrepancies and concluding true statements
- Clarifying meaning

Needless to say, the democratic role of Critical Thinking in Science Education is considered crucial for the responsible use and application of Science in the society.

2.3 What are the concepts and conceptions of Critical thinking regarding Science education?

There are some conceptions found in this review which have been taken from articles related to science

education titles. Above, some authors are cited regarding their conceptions of critical thinking in the context of science education.

As Bati, Kaan; Kaptan, Fitnat (2015) state by citing Obay (2009), "literature on critical thinking has not arrived at an agreed upon definition of the term yet". Though, there are some commonalities. In the next paragraphs, different conceptions about Critical thinking are presented, in which consensus and discrepancies are shown.

Duran, Meltem; Dökme, Ilbilge (2016), present a conception of Critical thinking widely shared by various authors, focus on skills such as analysis, evaluation, inference, interpretation, explanation, self-regulation as inherent to the concept of Critical thinking.

On the other hand, Özden (2011, cited in Demir, S. 2015a), conceives critical thinking in the next way, "Critical Thinking is an active and organized mental process that aims to understand the events, situations, and thoughts in our surrounding world, as well as our own person, by taking into account our own thoughts and the thoughts of the persons with whom we interact."

Nevertheless, the last two conceptions, as well as many others that use the terms, skills and process, are somehow questioned by those who disregard 'skills' and 'process' as appropriate terms or elements in the conception of Critical thinking; as it is explained in last paragraphs of this section, as well as in the discussion.

Bati, Kaan; Kaptan, Fitnat (2015), considering different views on critical thinking, affirm that it is possible to conclude that it consists of inborn (dispositional) as well as acquired traits. They cite various authors that show different point of views about CT. Above, it is cited two of them.

> Lai (2011) views critical thinking as consisted of two dimensions, namely, cognitive ability and disposition. However, she does not see disposition as an inborn quality but rather as an attitude. This view implies advantages due to the fact that, it is considered that changing or improving inborn characteristics is not an easy task Bati, Kaan; Kaptan, Fitnat (2015). Lai (2011) views disposition as "attitudes or habits of mind, include open- and fair-mindedness, inquisitiveness, flexibility, a propensity to seek reason, a desire to be well-informed, and a respect for and willingness to entertain diverse viewpoints". The 'ability' dimension of critical thinking refers to "cognitive skills of analysis, interpretation, inference, explanation, evaluation, and of monitoring and correcting one's own reasoning" (Facione, 2000. p. 2).
>
> Facione (1990) proposes that an 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.

Ennis (1996, cited in Hagop A. Yacoubian; 2015), has operationalized critical thinking into a set of concepts and has also delineated several criteria for each of those concepts. In addition to argument development and evaluation. Ennis considers the credibility of sources, to be another core concept of critical thinking.

On the other hand, Demir, S. (2015a), cites that Critical thinking is the ability to transfer knowledge learned from certain disciplines to other cognitive areas (Bronson, 2008). It involves not only the acquisition of information, but also active learning, problem-solving, decision making, and the utilization of information (Kim, 2009). Citing to Aizikovitsh-Udi and Amit (2011), Demir says that critical thinking encompasses questioning the reliability of information, and accepting, rejecting, or questioning examples and knowledge from daily life.

According to Osborne J. (2014), Critical Thinking is identified with "…higher order cognitive processes of evaluation, critique and synthesis", that should be distinguished from the "… lower order cognitive demands of recall and application." Pedrosa-de-Jesus, H., Moreira, A. Lopes, B. & Watts, M. (2014), also share this view by saying that Critical thinking is one of the very highest orders of cognitive abilities and a key competency in higher education. Moreover, Osbourne (2014), gives great importance to the ideas, critique and questioning in the practice of Critical Thinking, at the same time that disregards the focus on content knowledge.

Pedrosa-de-Jesus, H., Moreira, A. Lopes, B. & Watts, M. (2014), conceptualize critical questioning as a competency, into three domains – knowledge, skills and attitudes/dispositions. Also, the authors state three dimensions of being a 'critical questioner': context, competency, and delivery. They emphasize that context plays an important role in being a 'critical questioner'. According to these authors a taxonomic category of question-types called 'critical questions' that consists of a set of pre-elaborated questions, is not the focus of their view and deemed as inappropriate, instead, they propose Critical questioning based on knowledge and context (social settings).

On the other hand, Toman, U.; Odabaşi, S.; Cimer, A. (2014) provide a concept of Reflective thinking by citing (Wilson and Jan, 1993) stating that reflective thinking is a self-evaluation process. Which is an aspect shared with some conceptions of critical thinking.

Marques, R.; Tenreiro, C.; Matins, I. (2011), present some important concepts and reflections pointed out

below:
"Critical Thinking is a form of rational, reflective thinking, focused on deciding on what to believe or do" (Ennis, 1985, p. 46).

Ennis used the expression "critical thinking" to mean a reflective practical activity, for which the objective is a belief, or a sensible action. For him, there are five key terms – practice, reflective, sensible, belief and action – which can be combined this concept.

According to Marques, R.; Tenreiro, C.; Matins, I. (2011), there are two perspectives or philosophical traditions of CT. The philosophical perspective concerned with teaching logic (the logical aspect), principles of rhetoric and argumentation; and the cognitive psychology perspective frequently prefers the broader, more general expression of teaching of thinking, or the teaching of thinking skills, which is more specific than the teaching of CT. The above-mentioned authors cite that Critical thinking involves as many abilities as dispositions. Abilities refer to the more cognitive aspects and dispositions to the more affective. There are various descriptions, operationalization or taxonomy of both, abilities and dispositions, proposed by different authors, and those mainly differ from each other. E.g.: Ennis (1985), Angeli and Valanides (2005).

Critical Thinking is centrally a normative concept, given that it refers to good thinking (Bailin, 2002). It is the quality of thinking what matter according to this and other authors that share this view, namely Angeli and Valanides (2005).

Some concepts presented above, show certain differences. However, other concepts show points of congruence, as Piette (1996) states by saying "all the definitions perceive Critical Thinking as reflective and centered on assessment and problem-solving. It is due to this that rationality, reflection, and assessment constitute themselves as characteristics of CT".

Based on the definition by Ennis, it is argued that critical thinking involves a set of intellectual tools to be well mobilized in the context of problem-solving, decision-making and in the context of interacting with others. This set of intellectual tools includes abilities, namely, arguing and analyzing arguments, judging the credibility of a source, making inferences (reaching conclusions based on sound evidence and reasons) and deciding on action, as well as dispositions which define critical spirit.

It is important to note that the conception presented by Marques, R.; Tenreiro, C.; Matins, I. (2011) by citing the next two authors, referring that all students develop their abilities naturally and spontaneously should no longer be accepted (Pithers and Soden, 2000), while it is clear that a person thinks, or is always thinking, spontaneously (Smith, 1992), what is at stake is to think well, i.e. in an effective, conscientious and insightful manner. Therefore, according to this view, Critical thinking needs to be developed in students.

Brow, S. (2009), in his article affirms that the raw material of Critical thinking is comprehension of fundamental processes rather than knowledge of facts. Also, cites Bruner's barrier: "learning something in a generic way is like leaping over a barrier. On the other side of the barrier is thinking". This barrier is removed by making sciences relevant to everyday life, where Critical thinking is essential to accomplish this purpose.

Gábor Á. Zemplén (2007) conceives that teaching criticism is a double-edged weapon. In liberal teaching, the freedom to formed reasoned opinion is a main task of the educational system. Critical thinking and argumentation developed in Ancient Greece, was not compulsory. Critical thinking can entail the potential to question social or political status-quo. These conceptions entail the implications of Critical Thinking in fostering Democracy.

The most controversial conception of Critical Thinking found in this review was the one presented by Sharon Bailin (2002) in his article named 'Critical Thinking and Science Education'. The author affirms that there are shortcomings in almost all the conceptions of Critical thinking used everywhere, since according to him, Critical thinking is largely conceived as processes and skills and those are not identifiable and observable, neither can be standardized and used as a set or list of them applicable to every situation, which he deems as problematic. According to the author, one reason of this problem is that the conceptions of critical thinking which form its basis tend to be borrowed from the literature on cognitive development (Anderson 1980; Case 1980; Piaget & Inhelder 1958). Conversely, he states that Critical thinking entails principles, standards, especially regarding to a quality of thinking focused on a normative fashion, based on those standards, criteria and principles mainly used as means of evaluation for the quality of thinking, which the author called conceptual tools, intellectual tools, intellectual resources.

2.4 How to foster Critical thinking in teaching-leaning science?

Demir, S. (2015a) notes that, to ensure the development of critical thinking skills during formal education, it is generally recommended that different perspectives are considered and used during classes, and that these skills are practiced actively by employing suitable techniques (Bulut, Ertem, and Sevil. 2009; in Demir, 2015). Below, different practical perspectives, as well as techniques and strategies for developing Critical Thinking in the classroom are presented.

Duran, Meltem; Dökme, Ilbilge (2016), conclude that the so-called 'Inquiry-based learning' (IBL) approach

has significant positive effects on students' critical-thinking skills in science and technology courses, in the context of science technology learning, supported with the guided inquiry activities developed in line with this approach. This conclusion is based on a study carried out by the authors with students from secondary school science classes in Turkey. Meltem; Dökme, Ilbilge, 2016 cite the next authors that explain how IBL works:

> "IBL is a way of asking questions, seeking information, and finding new ideas related to an event. That is, in IBL, students learn by using cause and effect, relational and critical thinking, and combining both scientific knowledge and operations" (Parim, 2009, cited in Duran)
>
> "IBL, …is a student-centered approach focusing on the asking of questions" (Branch and Solowan, 2003)
>
> "Aiming to enhance critical thinking and problem-solving skills, the IBL approach can be implemented at different levels. These are constructed inquiry, guided inquiry, and free inquiry" (Colburn, 2000)
>
> "…guided-inquiry method, (…) the teacher provides guidance for the construction of questions, students plan their own questions and processes and they generate new concepts by creating connections between prior knowledge and new information" (Colburn, 2000).

Bati, Kaan; Kaptan, Fitnat (2015), based on their study carried out with primary school students from Turkey on the topics of 'Physical Phenomena Learning Field', and 'Electricity in Our Lives of Science' in a Technology Teaching Program, assert that the modeling based science education can influence the development of the critical thinking skills. Model-based approach or model-based inquiry are essentially processes by which scientists produce new information (Develaki, 2007). Bati, Kaan; Kaptan, Fitnat (2015), cite some authors in order to explain how this model works in the classroom, as follows.

> "…the modeling process involves steps such as: Encountering a question or problem; forming temporary models or hypotheses regarding the causal or holistic relations of phenomena, conducting systematic observations in order to test accuracy of these hypotheses; forming models based on these observations; evaluating the models in terms of their usefulness, predictive value or their capacity in explaining and revising the model and applying it to new circumstances (Windschitl, Thompson & Braaten 2007). …the modeling process refers to a process similar to that frequently used by scientists. Model-based science education has to do with teaching strategies that bring about constructing cognitive models, critiquing and changing processes (Khan, 2007). Model-based science education involves the following steps: suggesting sub-models; expressing/sharing these models with peers; planning and applying data collection in order to evaluate one's own suggestions; critiquing one's own and peers' models and changing models based on emerging evidence. (Cardoso Mendonça, Justi, 2013)."

Moreover, Bati, Kaan; Kaptan, Fitnat (2015), note that findings of two studies with different samples showed that book and newspaper reading and reviewing news on the papers significantly increased students' critical thinking skills (Kaloç, 2005; Kırıkkaya & Bozkurt, 2011).

Hagop A. Yacoubian (2015), affirms that a number of science education researchers have used argumentation as a framework through which guiding learners to develop Nature of Science (NOS) understandings and/or to engage in socioscientific decision making. He refers that engaging learners in explicit and reflective discussions on NOS are considered by some researchers as practical ideas for developing learners' NOS understanding. Khishfe's (2012, in Hagop A. Yacoubian; 2015), explains that explicit instruction of argumentation involved teaching how to formulate arguments, counterarguments, and rebuttals. It also stressed the importance of using evidence in backing up arguments. Moreover, the author states that explicit guidance in how to apply students' NOS understanding in socioscientific decision making is important to this end.

Demir, S. (2015a), regards teacher-training in Critical Thinking as an important activity for fostering and using it in Science education. He says that teachers should be trained on the implementation of Reflective thinking activities in classroom environments by receiving both pre-service and in-service trainings Tok (2008). This statement is shared by other authors (Sahin, Senar Alkin; Tunca, Nihal; Altinkurt, Yahya; Yilmaz, Kürsad; 2016)

According to Osborne J. (2014), Critical Thinking is fostered in science classrooms:

- By opportunities to engage students in critique, argumentation, and questioning. These, not only help build students' understanding of science, but also develop their ability to reason scientifically.
- By driven students to criticize or challenge knowledge already framed.
- By critically comparing the evidence with the predictions and with what we observe and by argument, by these means, science maintains its objectivity (Longino, 1990).
- By responding to students' pre- and-misconceptions referred to scientific issues

The author affirms, "Science should, therefore, naturally challenge our students' thinking by inviting critical questions" (Osborne J., 2014). Some examples are provided in his article.

Pedrosa-de-Jesus, H., Moreira, A. Lopes, B. & Watts, M. (2014), state that learning contexts designed to

elicit students' questions are necessary to foster their Critical Thinking. They also see 'questions' as central in Critical thinking development. They share that based on their experience, "different learning contexts were designed in order to elicit questioning from students, from the simple invitation for students to question during lectures to the design of problem-based episodes, case-based learning, and online discussion forums."

Furthermore, these authors assert that identifying and eliminating barriers for Critical questioning is important: context barriers, motivation, self-perceptions(awareness), familiarity with the subject matter, delivery process, as well as formative feedback, and guidelines are important elements for fostering Critical questioning.

On the other hand, Toman, U.; Odabaşi, S.; Cimer, A. (2014), in the context of their study focus upon teacher training on Reflective Thinking, found that methods which Develop Reflective Thinking in teacher training are, micro-teaching, Lesson Planning, Self-evaluation, Reflective journal. They also suggest that teachers must be given theoretical training in the courses regarding the development of teaching skills in reflective thinking, kinds of reflective thinking, and the importance of reflective thinking. By these means, make them able to effectively foster students' Critical or Reflective thinking in the classroom. Regarding activities with students, these authors affirm that reflective journals are very important to foster reflective thinking. They state:

> "Journals are the materials in which students record their own personal reactions, questions, feelings, changing ideas, thoughts, learning processes, and the knowledge related to their learning content (Unver, 2003). Students do not simply discuss their experiences during the learning process in reflective journals. These writings include the explanations, analysis, and reflections which students make about their learning" (Unver, 2003)
>
> "An important effect of reflective journals is that teachers can get feedback about the curriculum which they implement from the students' reflective writings. Therefore, teachers can design more suitable teaching and learning activities for the students."

Rui Marques, Celina Tenreiro, Isabel M. Matins (2011), by citing some authors, assert that it is possible to promote or improve students' thinking processes or abilities, by giving them programs explicitly centered on the development of these thinking abilities and dispositions (Abrami et al., 2008; Genç, 2008; Piette, 1996).

The above-mentioned authors state, to promote student's critical thinking implies the need to create and sustain a learning environment that encourages students to express their ideas, explore, take risks, to share successes and failures and questioning each other. It also requires students to be given time to think, to experiment for themselves and to be encouraged, stimulated to discuss and to reflect on action through thought-provoking questions (Rui Marques, Celina Tenreiro, Isabel M. Matins; 2011). These authors also provide in their article a detailed explanation of teaching strategies for Critical Thinking, as well as a diagram to illustrate how to foster Critical thinking linked to Scientific Literacy.

Beford, D. (2010), propose an interesting strategy for students' learning science through Critical Thinking, in topics such as global warming Evolution and others science-related topics and social-political issues, especially controversial ones. It is by the direct study or examination of misinformation of these topics presented by media; called by the author as *agnotology*. The goal of incorporating agnotology as a teaching tool in the classroom is to study how and why there is ignorance about well-established facts about science, for example, global warming. Numerous additional specific works of agnogenesis exist and could be used in the classroom, including the Hollywood film *The Day After Tomorrow*, which presented a highly misleading depiction of the possible consequences of escalating greenhouse gas concentrations. To accomplish learning outcomes in class, agnogenesis literature is scrutinized in a homework assignment, through in-class discussion, and a final exam question. Students are asked to summarize and critique several arguments and themes, both in preparation for an in-class discussion and in a written assignment. In doing so, students are required to reflect on material covered throughout the semester, strengthening their understanding of the relevant physical processes as well as practicing their critical thinking skills. When applied in this way, the agnotology approach is an active learning strategy, in which students engage with class material rather than passively absorbing it. Active learning tends to promote higher-order thinking and more effective learning (Hooey and Bailey 2005, in Beford, D.; 2010)

Brow, S. (2009), is another author that emphasizes the importance of questioning promotion in students for developing their Critical Thinking in the classroom, by questioning existent knowledge and teacher's assertions. Besides, he poses that balance between content (particular science knowledge) and critical questioning, is appropriate, as it is a context to encourage questioning. He explains that by saying, "it is necessary to expound students to a more balanced view, involving science content, science practice and the impact of science, in order to develop students' appreciation of science as a useful and useable developing body of knowledge". Brow, also mentions as important aspects for fostering Critical thinking linked to science learning, the next ideas: using students' experience or real-life cases, overcoming students' reluctance to question, using humor.

Brow, presents a model for the development of Critical Thinking (Perry's model). It is, to have the students moving from the stage of conformity or comfort-zone to a stage of reaching deeper learning and understanding of science. The author explains this dynamic as follows. It implies to have the students moving from the stage

where the preference for structured classes, a right answer to be told, and a teacher as the ultimate authority (he calls to this stage as 'dualism'), to a stage where there is preference for distinguishing between questions to which answers are known and those to which answers are yet to be obtained, which deprecate the role of the teacher (a stage called 'multiplism'). Beyond this, students gradually develop an appreciation of the importance of argument and substantiation and the need to make their own decisions. (…) transition from 'dualism' to 'multiplism' is associated with a decline in the certainty. This model involves a sequence of stages through which a student progresses by interaction with the environment. In Brow's article, a diagram is presented that well illustrate this model.

It is also said that systematic practice, guidance, and encouragement are necessary to develop critical thinking skills. Questioning attitude of students must be nurtured, 'error' should be treated as a chance to investigate and learning should be based on understanding rather than just a matter of memorization. Each teacher should model the appropriate behavior and approaches, which means that those same skills have to be even more highly developed in the teacher. (Brow, S.; 2009)

On the other hand, based on a study about a course analysis that includes Critical Thinking in Science Education in an International Baccalaureate program, Gábor Á. Zemplén (2007) notes that in order to teach certain science subject in this program, questions were the main part of its content. Especially questions such as: How to know that ´certain´ assertion is true? Or how to know that a given judgment is well grounded? These kind of questions often challenge an accepted belief, which are posed by contemporary life. Therefore, by engaging students in a critical examination of knowledge, teachers will foster an appreciation of the quest for knowledge. The author suggests that experiments can help teach science and understand science better, and that case studies can easily be incorporated into science-courses and/or Critical thinking subjects. Besides, by using a general theory of argumentation can also help both, CT and science education. By this mean, students should be encouraged both, to ask questions and to argue. Not just, asking questions. Thus, make students active participants or actors in 'science' and scientific knowledge construction/discoveries in the society.

Gábor Á. Zemplén (2007), also presents one idea to encourage students towards science. It is by presenting to them the benefits of their participation in science in economical-jobs, respect, intellectual satisfaction, and other matters. This foments appreciation for science. This idea also promotes life-long learning and responsible citizenship; that is part of what the author calls, 'politically motivated approach to self-interest and negotiation in the social realm'.

Finally, Sharon Bailin (2002) in his article named 'Critical Thinking and Science Education', states some ideas for fostering Critical thinking linked to Science teaching and learning; those ideas start from emphasizing the importance of a conceptual clarification poses by him, that disregards the focus on skills and process of Critical thinking, in turn, praise the focus on Thinking quality based on norms, criteria and standards (intellectual resources) to follow in classroom activities. He suggests, "it is through teaching the appropriate (intellectual) resources, highlighting the range of areas in which particular intellectual resources apply, and fostering the appropriate habits of mind, that we have our best chance to promote critical thinking" …" a focus not on procedures but on conceptual tools; a focus on reasoning in specific contexts. These include a focus on complex, scientifically significant problems". In his article, the author provides some explicit examples of how to apply these ideas and criteria in practical activities and exercises in the classroom related to science.

2.5 What is happening in the current and past practice of Science teaching-learning regarding Critical Thinking?

It is seen evidences of the importance of Science teachers' training and assessment about Critical thinking shown by some recent articles in this respect (e.g. Sahin, Senar Alkin; Tunca, Nihal; Altinkurt, Yahya; Yilmaz, Kürsad 2016; Demir, S. 2015; Toman, Ufuk.; Odabaşi, Sabiha.; Cimer, Atilla 2014), which also reflect the importance that some education systems from different countries attach to this matter. In the next paragraphs, it is presented some results and details that reveal the situation of in-and pre-service science teachers regarding critical thinking, as well as other problems related to the situation in the science classrooms and critical thinking implications.

Demir, S. (2015a), in an empirical experience carried out by the author related to the determination of Critical thinking and reflective thinking skills of science teacher candidates. The author concludes that science teacher candidates in this experience generally exhibited a positive stance towards their own critical and reflective thinking. However, according to the test there are certain areas that displayed inconsistencies or weakness in their thinking critically, in respect of, not supporting appropriately their views, not evaluating solutions by comparing others´ solutions, not considering alternative possible solutions, not reassessing the solution to a problem and being partial when discussing or debating some issues. In another study where science teachers from middle school were assessed, the results also showed that science teachers' level of Critical Thinking disposition is low, though their professional values' level is above average (Sahin, Senar Alkin; Tunca, Nihal; Altinkurt, Yahya; Yilmaz, Kürsad; 2016)

Toman, U.; Odabaşi, S.; Cimer, A. (2014), investigated Science and technology pre-service teachers' opinions about the methods for developing reflective thinking. This study aimed at examining the pre-service

science teachers' views regarding the methods which develop reflective thinking skills in the "Special Teaching Methods I" course. The findings were:

- Teachers stated that they did not do any practices which fostered reflective thinking before (Şahin, 2009).
- The preservice teachers who developed reflections in the technical field mostly used simple and plain expressions about microteaching implementations.
- None of the pre-service teachers had reflections regarding critical field concerning the implementations of microteaching and reflective thinking.
- It was determined that the pre-service teachers mostly (69%) had levels of reflection in the technical field.

Taggart and Wilson (2005; cited in Toman, U.; Odabaşi, S.; Cimer, A. 2014), attribute this to the fact that inexperienced (novice) pre-service teachers lacked experiences regarding the methods which foster reflective thinking. It was concluded that the pre-service teachers could not adequately reveal their skills of reflection in the technical field during the interviews. Moreover, they did not express statements regarding reflections in critical field. Furthermore, they could not use their skills of reflection in technical field.

Marques, R. Tenreiro, C. Matins, I., (2011), affirm that in the context of their study (Portugal) attempts to integrate CT into Curriculum has failed. This objective has not been appropriately implemented in classrooms. One of the obstacles is the fact that teachers do not have a clear idea of critical thinking because the meaning ascribed to critical thinking in different contexts is rarely explicit. Other recent study carried out in Turkey (Demir, Sibel; 2015b), also arrived at the conclusion that Science teachers' knowledge of critical thinking is insufficient, yet correct. Besides, they do not have in-depth understanding or interpretation of the concept of scientific creativity.

It is observed that inquiry-based teaching is not actually conducted in class to the desired extent (Capps, Crawford, & Epstein, 2010, cited in Duran, Meltem; Dökme, Ilbilge, 2016). Osborne J. (2014), notes *'the problem with school science is that it gives us answers to questions we have never asked'*. Yet opportunities for students to ask questions in science are rare (Lemke, 1990; Weiss et al., 2003). Instead, somewhat strangely, it is the teacher, who knows all the answers, who commonly asks all the questions. Osbourne wonders, "…why are student questions, argumentation and critique often absent from the science classroom?" The answer, in part, is that such competencies are not tested and they are not a feature of what we expect students to learn. Instead, focus in content is largely practiced, as Brow, S (2009) explains in the next paragraph.

Brow, S. (2009) argues that, in parallel with the rapid growth of scientific knowledge, there has been a tendency to focus on content rather than developing the skills needed to do science. In essence, what has been neglected is critical thinking. The current and common way of teaching science leaves and erroneous impression of the nature of it, mainly because the ability to question and imagine is not often cultivated in science classrooms. The focus on teaching and learning is associated with a tendency to concentrate less on thinking. This is reflected in textbooks, which often fail to encourage deep thinking (Haas, P. F. and S. M. Keeley 1998; Richardson, P. W. 2004; Rigden, J. S. 1987)

Gábor Á. Zemplén (2007), who is affiliated with a university in Budapest, in his article 'Conflicting Agenda-Critical Thinking versus Science Education in the International Baccalaureate Theory of Knowledge Course' investigates the Theory of Knowledge course of the International Baccalaureate Organization, which finding are:

- Teachers are usually trained as transmitters or diffusers of knowledge.
- In teaching any scientific subject teachers often fail to 'keep up' with the constantly and more and more rapidly changing knowledge field.

The above-mentioned author asserts that in the context of his study, problems regarding CT implementation in the curriculum of science or science teaching are due misconception of the CT concept, lack of clear guidance for including CT in the textbooks and in classroom activities, as well as lack of clarity in the objectives of the course, all of these made not to know what is expected from students regarding Critical thinking. Sharon Bailin (2002) also agreed with this affirmation about Critical thinking lack of clarity and a coherent and defensible conception.

2.6 How is presented Critical Thinking in the Curriculum of Science?

Meltem; Dökme, Ilbilge (2016), asserts 'Contemporary science reform movements emphasize the fact that inquiries in science teaching are of great importance and that science should be taught to students by means of inquiry (American Association for the Advancement of Science, 1990; National Research Council, 1996). Osborne J. (2014), also cites this instance and notes that Critical thinking is included in PISA tests in the format of the questions' test placing more emphasis on argument and critique within science. that is why there are a lot of education systems that attach great importance to Critical thinking in the Secondary Level Curriculum, as is the case of the new National Curriculum for England and Wales and in the US.

Meltem; Dökme, Ilbilge (2016), affirm that in the renovation of the Science and Technology teaching program (2005-2006) in Turkey, it was included the Inquiry-based learning (LBL) approach, as well as methods and tools in line with the student-centered approach to make students active in the learning environment. Besides, other authors affirm that, in Turkey, as in many other countries, learning objectives regarding "values" and "critical thinking" have been associated with learning areas of various courses, and made them an integrated part of the curriculum. "…teaching both of the concepts has become compulsory by various subject matter teachers rather than a coincidental approach." (Sahin, Senar Alkin; Tunca, Nihal; Altinkurt, Yahya; Yilmaz, Kürsad; 2016)

Bati, Kaan; Kaptan, Fitnat (2015), cite that The National Research Council of the United States (NRC, 2012) stated the priority of the new approach to science education disregarding scientific content and emphasizing in modeling, a critical stance and communication processes, which has to do with the model-based approach or model-base inquiry. In emphasizing the need for inclusion of critical thinking skills and disposition in teaching programs, Yıldırım (2009, in Bati, Kaan; Kaptan, Fitnat; 2015) claimed that individuals with critical thinking skills and dispositions will inevitably use them in their personal conducts.

Hagop A. Yacoubian (2015), also highlights the need for a science curriculum that engages students in developing critical understandings about Nature of Science and in making critical decisions on socioscientific issues in democratic societies with their understandings of NOS. In the context of his research in Canada, the author refers that a decision has been made about the shift of the focus of NOS on content, to the focus on the critical thinking process. The author presents a Critical thinking-Nature of Science framework, in which both aspects are interrelated in the course program through argumentation. In this, a comprehensive training in critical thinking about NOS and with NOS to students is proposed. The argumentation skills in Khishfe's (2012, in Hagop A. Yacoubian; 2015) work could be situated in a framework of critical thinking and the students could be guided to learn aspects of critical thinking that would contribute to their decision making.

Helena Pedrosa-de-Jesus, Aurora Moreira, Betina Lopes & Mike Watts (2014), share that, in the context of Portuguese higher education: Educational reforms are undergoing pedagogic and curricular reforms' (Veiga and Amaral 2009), from direct knowledge transmission to the development of knowledge generation competencies by students. In this vein, it is maintained that the ability to think critically is fundamental to the preparation for life as active citizens in a democratic society.

Marques, R. Tenreiro, C. Matins, I., (2011), regarding the implementation of Critical Thinking as a specific course in the Curriculum, refers the position of Abrami et al., (2008); Genç, (2008); Piette, 1996) who mention that it is possible to promote or improve students' thinking processes or abilities, by giving them programs explicitly centered on the development of these thinking abilities and dispositions. The authors note that since the 1980s it has been, more and more explicitly, included in educational curricula in various countries.

In different countries efforts have been made to integrate critical thinking into science curricula, recognizing that it is necessary to live in a plural society with citizenship competence. In this sense, Critical Thinking is viewed as an important aspect for fostering democracy or a Democratic view of Science. The inclusion of developing CT abilities based on the Science Programs of Basic Education in Portugal can be identified in activities such as organizing research, observing, formulating questions and problem solving, as well as in the identification and definition of the problem or question in certain scientific context. However, attempts to integrate CT into Curriculum has failed. This objective has not been appropriately implemented in classrooms. One of the obstacles is the fact that teachers do not have a clear idea of critical thinking because the meaning ascribed to critical thinking in different contexts is rarely explicit (Marques, R. Tenreiro, C. Matins, I.; 2011). Furthermore, the author cited Genç (2008), by saying that it is necessary that various components of the education system be in sympathy with the development of a harmonious, coherent and consistent approach. In this way, besides the education curriculum, teacher education and pedagogical practices need to be directed towards the development of students as critical thinkers. In other words, these all integrate knowledge in a critical and objective manner.

Brow, S. (2009) states, "Critical thinking is intrinsic to the practice of science, but, other than the 'scientific method', it is little emphasized in most classrooms. Instead, the focus is usually on content" and student's memorization and not comprehension.

Gábor Á. Zemplén (2007), expresses some problems, their causes and tentative solutions in the attempt to implement or develop Critical Thinking in the Curricula. For example, he affirms that Science curricula are not helping the accomplishment of the objectives of Education for building a Democratic Society. Present day scientific curricula are generally not suited for the task of producing knowledge that contributes to the development of responsible, independent citizenship. Science is committed to instrumental aims, providing resources for the economy. As a result, and as a matter or positive effect on this issue, more and more curricula incorporate specific subjects or allocate extra time to focus on CT topics to compensate and solve the situation.

Based on the case studied by the above-mentioned author, he identifies problems in the implementation of CT in school curricula. The problems reside on the misconception or lack of clarity of the concept of critical thinking and on the questions not clearly answered about: how much, exactly what, and when should be

incorporated CT into the curricula? He concluded that there are not explicit guidelines for showing what to expect from the students. Gábor Á. Zemplén (2007), suggests that the educational program should be clear about what values and what content is to be incorporated in the courses.

This author reveals as part of the problem that "As in most modern school systems, natural science is treated as a superior form of knowledge-production; and it is reflected in the general aims of school-education, while CT agenda is secondary, is subordinated to scientistic agendas, at the same time, science teachers show aversion of 'wasting' time on this (implementing CT in science courses). According to the author, to take CT skills and related courses seriously, separate specific subjects on this matter are created, teaching time allotted, etc.

Therefore, the problem of implementing Critical Thinking in Science Curricula is that CT seeks to question or challenge Science (scientific claims, statements) for the sake of promoting students' questioning and finding answers about those scientific facts, but there are actors not interested in this regard because of their personal agendas or interests. Thus, clear educative purpose and objectives must be set in one from these two directions or agendas, whether to seek Science education for instrumental/economic purposes in an indoctrinating way or view Science Education for a Democratic Society and students' human development through fostering their critical thinking.

Finally, Sharon Bailin (2002), notes that there is much of value in the work in science education literature devoted to the fostering of Critical Thinking in terms of useful insights, ideas, and suggestions for pedagogical practice. There are, however, problems with some of the conceptions of critical thinking and hence potential problems with some of the educational implications. Developing critical thinking is one of the goals of science education, but the field lacks a coherent and defensible conception of critical thinking. Many efforts to foster critical thinking in science rest on misconceptions about the nature of critical thinking.

In general, some of the ways in which Critical thinking is present in the Curriculum is through conceptual or theoretical expressions, guidelines, and activities in the classroom, and in objectives as well as in statements in the curricula. However, there are shortcomings or problems in the practical context due to lack of clarity of the CT concept or misconception, lack of teachers' training, and lack of clear guidelines about how to implement and develop Critical Thinking in Science Education, specifically, in the classroom.

3. Discussion

An appropriate application of Critical thinking principles and practices in Science education benefit both, students' development of their critical thinking and students' meaningful science learning. This last one, as well as other affairs, are further discussed above.

3.1 About critical thinking in the science classroom

It is seen that Critical thinking has a great potential to favor Science Education, especially through the application of classroom techniques or activities based on Critical Thinking criteria and principles. Some of those specific techniques found as commonalities between various authors are activities based on questioning, which are seen in two directions. One direction related to question formulation (Pedrosa-de-Jesus, H., Moreira, A. Lopes, B. & Watts, M. 2014), in which teachers and especially students, frame questions driving to tackle science content through CT. The other view of questioning, is in the sense of Critique, in which students are encouraged to challenge current accepted knowledge, as well as teachers' affirmations about certain scientific content (Osborne J., 2014; Brow, S. 2009; Gábor Á. Zemplén, 2007). Therefore, questioning, critique, and argumentation are deemed the most important classroom activities for fostering Critical thinking and improving Science learning-teaching.

Other important commonality is the importance highlighted by some authors about 'Context' or 'learning environment' for fostering Critical thinking in Science Education in the classroom, in particular, for stimulating students' questioning skills and attitude. It is understood that proper contexts, in which students feel free to ask questions and activities, as well as guidelines for framing good or critical questions are provided by teachers, enhance Students' Critical thinking and an effective Science education process in a symbiotic fashion between these two variables.

Based on the experiences of Demir, S. (2015a), and Toman, U.; Odabaşi, S.; Cimer, A. (2014), in-service and pre-service teachers' training is also regarded a current need in order to effectively implement Critical thinking in science education. It is understood that for developing a good process for fostering Critical thinking while teaching Science and improving the results of science education on students, teachers must first develop Critical thinking competences in conceptual and practical domains (Sahin, Senar Alkin; Tunca, Nihal; Altinkurt, Yahya; Yilmaz, Kürsad; 2016). In this sense, 'training' addressing to the implementation of Critical thinking-related activities or techniques in the Science teaching-and-learning process could be crucial.

Some of the findings of this article presented various particular activities or techniques that linked Critical thinking and Science education. For example, the use of journals by students (Toman, U.; Odabaşi, S.; Cimer, A.;

2014), in which they record their own questions and inquiries for further answering and discussion with the teacher and other students. This strategy engages students in science by the time that cultivates question-formulation. Similarly to this is the use of online discussions about science. Case studies, experiments for discussion and argumentation promotion, can also be useful and deemed as important tools. The most interesting and peculiar strategy founded in this review, for linking Critical thinking and Science Education, is one based on the examination of misinformation presented on media (agnotology) (Beford, D.; 2010). This can be a powerful strategy that has the potential to effectively engage students in Science education through Critical Thinking while developing it on them. It could be very appealing for students to use polemic and controversial topics from the news as well as funny movies and books that present distorted facts about science that can be used to 'correct' them in a critical and amusing fashion, which can result in solid and meaningful science learning.

More general strategies or suggestions for developing critical thinking and improving science education are those such as, linking science topics with real life issues, working on conceptual clarification for implementing accurately Critical thinking activities in Science education, and considering including a special course or program in the curriculum for developing Critical thinking. Though this last suggestion is still not explored about its likelihood and benefits, and some authors and practitioners can consider inappropriate, in turn, favor the idea of practicing Critical thinking criteria while tackling Science topics, which can be deemed more effective.

No matter the date of the source from where some of those techniques are picked up, these techniques and ideas still have appropriate applicability, as long as it depends on the particular abilities of the teacher and good arrangement settings to apply them in the classroom.

There are some problems regarding Critical thinking development in Science education in the classroom. Especially, because science classes are mainly carried out with the focus on content and on students' memorization, rather than on creativity, meaningful understanding and/or Critical thinking. Some good practices reported by various authors are related to the promotion of students' questioning, critique, argumentation, as mentioned before, but for doing so, it is necessary teacher-training on this regard, as explained in previous paragraphs. It is important to recognize teachers' strengths and identify their shortcomings regarding critical thinking in order to solve them through training. Problems regarding Critical Thinking misconception by teachers and education authorities can affect curriculum and course objective-setting, consequently, misguide the teaching practice in the classroom. Which can result in students' aversion toward science and/or their superficial learning.

3.2 About Critical Thinking in the Curriculum

The discussion about the implication of CT in the curriculum of Science and in general, is referred first to note that CT is widely included in the Science Curriculum of many countries, such as the ones mentioned by the authors cited in this paper. It is, in countries such as England and Wales, United States, Portugal, Netherlands, Turkey, Canada, where explicitly mentions are made by the authors. Furthermore, it seems that no disagreements have been found all over the world about the importance of Critical Thinking and its inclusion in the Science curriculum into the education systems; especially given the fact that an important international assessment program as it is PISA, embraces Critical thinking to frame its objectives, and content of this assessment (Osborne J., 2014), as well as in other official documents, such as the National Science Education Standards, and the Next Generation Science Standards (Meltem; Dökme, Ilbilge, 2016 and Osborne J., 2014) of US, in which references about Critical thinking are presented. However, there are reports of failures in the attempt of its implementation in the Curriculum. Moreover, some teachers have shown weakness about this matter and resistance towards its implementation in the classroom, mainly because their preference for traditional teaching methods based on content. Therefore, the problem in curriculum matters seems to be not regarding the inclusion or not of Critical Thinking references, its recognition or acknowledgment in official Curriculum documents or designs. One of the main problems seems to appear in the classroom; that is, in the practical implementation of CT in the educational process, as stated in previous paragraphs. It is also a matter of conceptual clarification, clear objectives, clear guidelines, and teacher training what is needed. In a more specific sense, appropriate classroom activities, techniques, and strategies are to be taken into account for an effective implementation of Critical thinking in the Science Curriculum and its further fostering in students.

Critical thinking concept clarification and objectives setting seem to be a need for further work in the level of Curriculum development, namely design or planning in some education systems.

It is also important to note that Critical thinking is recognized with great potential for contributing to Democracy education linked to science education, with the purpose of preparing citizens to use science in a responsible fashion, that is to say, for common benefits and sustainable development. In the midst of the impressive influence of technology and industrial automatization in the modern society, there are expressions of recognition of the current importance of Implementing CT-related subjects into the curriculum for preparing young people for civic and ethic life in a digital age, as stated by the Ireland's president Michael D Higgins (Blease, C.; The Guardian; January, 2017), who also notes that "redoubling investment in science, technology,

engineering and maths (Stem) subjects won´t solve the problem", when referring to the problem of the future potential mass unemployment due to outsourcing jobs by digitization. Therefore, Philosophy was introduced into Irish schools in Ireland in 2013, as a result of this claim presented by the Ireland's president.

Finally, it is interesting to reflect about the likelihood that the root of the problem about the failure of implementing CT in the science curriculum, is because education systems can be more willing to favor an instrumental view of education linked to political, industrial and commercial interests, rather than to a commitment to a real human development and a democratic society, where Critical thinking has an essential role. Some publications found on mass media and web pages of institutions linked to the economic and industrial arena, express their recent concern about the need of critical thinking as an objective in the education system for instrumental purposes, as shown by Willige, Andrea (January, 2017); Knowledge@Wharton (2016); AlphaBeta (2016). Therefore, the decision of education authorities about whether to favor this purpose or a more democratic one is crucial, and Critical thinking implementation in curricula, especially in the classroom, largely depends on it.

3.3 About Critical thinking conception

Regarding Critical thinking conceptualization and misconception, which many authors (e.g. Demir, Sibel; 2015b) deem as a problem in the implementation of CT in the science curriculum; there is a major discrepancy which presents a conception of Critical thinking in a very different fashion compared with the majority of authors who show commonalities about the CT conception, and whose conceptions associate the Critical thinking concept with terms such as, skills, abilities, process, procedures. Meanwhile, the discrepant conception associates CT with principles, criteria, standards, norms, thinking quality, thinking evaluation, namely, intellectual tools or intellectual resources. The argument that rejects the conception of thinking skills and process is that they are not observable, thus problematic (Bailin, 2002). Other conceptions complement the concept of CT by referring terms such as dispositions, competence, affective dimension, self-evaluation, belief-action (Ennis, 1985), attitude, traits and elements of thinking (Richard, Paul; 2013: xxvii). Congruence in the conceptions of Critical Thinking includes a view such as, 'reflective and centered on assessment and problem solving', in which reflective/reflection, assessment, problem-solving are keywords shared by many conceptions of CT (Marques, R.; Tenreiro, C.; Matins, I.; 2011). These authors also present two main perspectives of the Critical thinking concept. One is the logical aspect of thinking and the other is the cognitive aspect of thinking. The first is related to teaching logic, principles of rhetoric and argumentation; and the other is related to "teaching of thinking, or the teaching of thinking skills" in a broader and more general way.

What is less rejected is the affirmation that activities or processes such as questioning, problem-solving, decision making, argumentation, critique, information assessment, active learning techniques, and others alike, foster Critical thinking and improve Science education. Finally, it is important to point out the conception that asserts that students do not develop Critical Thinking naturally and spontaneously (Pithers and Soden, 2000; cited in Marques, R.; Tenreiro, C.; Matins, I.; 2011) and that Critical thinking is conceived essential for reaching objectives of freedom and a democratic society.

3.4 About Critical Thinking and Knowledge

The Critical Thinking concept deprecates every form and attempt of teaching and learning related to memorization and very often, related to content, information, and knowledge treated in a traditional way, such as mere lectures, speeches or passive readings. Nevertheless, some authors deemed important the role of knowledge in developing critical thinking and especially when tackling Science or any academic subject through Critical thinking. Suggestions of balancing knowledge, content and Critical thinking skills associated with practical application of science are presented by some authors and seen as fructiferous. Furthermore, the role of knowledge in the Critical Thinking-Science education relationship can be understood in different ways, as knowledge related to facts, content, and information associated with certain academic subject; or knowledge of principles, criteria, processes related to Critical thinking concept and development.

3.5 Recommendations and further future research

Science teacher-researchers or practitioners who want to implement Critical thinking principles and practices in Science classrooms can have a close reading of the articles cited here for more details about specific classroom techniques, strategies, and ideas that can be extremely useful for improving science education results and develop students' critical thinking.

Further research and analysis could be needed to clarify the effects of applying critical thinking classroom and teaching-and-learning activities in science learning, as well as the effects of using science topics for improving students´ critical thinking. Moreover, further research is also needed for identifying or classifying classroom activities and techniques to foster students´ critical thinking according to levels, namely, primary, secondary and tertiary education levels.

3.6 Conclusion

Critical thinking is inherently existent in Science practice, thus potentially powerful in Science education. Its importance and role in science education and education in general, is unquestionable. It has been increasingly presented from the 80's to current times in the curriculum in different ways. Nevertheless, Critical Thinking implementation in the Curricula of Science Education has frequently had problems. Those problems have been presented mainly due to the misconception of CT, as well as poor guidance for implementing CT activities in the classroom, linked to the insufficient teachers' training in topics regarding CT. However, there are reports of good experiences about successful implementations of CT in practical ways in Science curricula. Those experiences are presented in terms of activities, strategies and ideas proved by other teacher-researchers that have successfully worked in their attempts of implementing Critical Thinking in Science Education and can be emulated to improve students' science learning and Critical thinking development.

Acknowledgements

To Prof. XU Wenbin Ph.D. Research Supervisor and Professor at Nanjing Normal University, Institute of Curriculum and Instruction, for encouraging my work.

References:

Bailin, Sharon (2002). Critical Thinking and Science Education*, Science & Education*, 11: 361-375.

Bati, Kaan; Kaptan, Fitnat (2015). The Effect of Modeling Based Science Education on Critical Thinking, *Educational Policy Analysis and Strategic Research*, V.10, N.1

Bedford, Daniel (2010). Agnotology as a Teaching Tool: Learning Climate Science by Studying Misinformation', *Journal of Geography, 109: 4, 159 — 165*

Brow, Simon (2009). "On the other side of the barrier is thinking"*, Acta Dicatica Napocensia*, V.2

Demir, Sibel (2015). Evaluation of Critical Thinking and Reflective Thinking Skills among Science Teacher Candidates. *Journal of Education and Practice*, v.6, N.18

Demir, Sibel (2015). Perspectives of Science Teacher Candidates Regarding Scientific Creativity and Critical Thinking, *Journal of Education and Practice*, v.6, N.17

Duran, Meltem; Dökme, Ilbilge (2016). The effect of the inquiry-based learning approach on student's critical-thinking skills*, Eurasia Journal of Mathematics, Science & Technology Education*, 12(12), 2887-2908 doi: 10.12973/eurasia.2016.02311a

Gábor Á. Zemplén (2007). Conflicting Agendas: Critical Thinking versus Science Education in the International Baccalaureate Theory of Knowledge*..., Science & Education*, 16: 167-196.

Hagop A. Yacoubian (2015). A Framework for Guiding Future Citizens to Think Critically About Nature of Science and Socioscientific Issues, *Canadian Journal of Science*, *Mathematics and Technology Education*, 15:3, 248-260, DOI: 10.1080/14926156.2015.1051671

Helena Pedrosa-de-Jesus, Aurora Moreira, Betina Lopes & Mike Watts (2014). So much more than just a list: exploring the nature of critical questioning in undergraduate sciences, *Research in Science & Technological Education, DOI: 10.1080/02635143.2014.902811*

Osborne Jonathan. (2014). Teaching critical thinking? New directions in science education. *Perspectives on science curriculum Journal*.

Paul, Richard; Elder, Linda (2012*). Critical thinking: tools for taking charge of your learning and your life*, 3rd ed., Pearson, USA.

Rui Marques, Celina Tenreiro, Isabel M. Matins (2011). Critical thinking: Conceptual clarification and its importance in science education. *Science Education International*, V.22, 43-45.

Sahin, Senar Alkin; Tunca, Nihal; Altinkurt, Yahya; Yilmaz, Kürsad (2016). Relationship between Professional Values and Critical Thinking Disposition of Science-Technology and Mathematics Teachers, EURASIA Journal of Mathematics, *Science & Technology Education*, 12(1).

Toman, Ufuk.; Odabaşi, Sabiha.; Cimer, Atilla (2014). Analysis of pre-service science teachers' views about the methods which develop reflective thinking. *International Journal on New Trends in Education and Their Implications*, V.5.

Websites:

AlphaBeta (2016). The new basics: big data reveals the skills young people need for the New Work Order. Foundation for Young Australians, viewed 07 January 2017, <http://apo.org.au/node/63409>.

Blease, C. (January 9, 2017). Philosophy can teach children what Google can't. The Guardian. Retrieved from https://www.theguardian.com/profile/charlotte-blease

Knowledge@Wharton (2016). College vs. Business Training: What Do Employers Want? Wharton School of the University of Pennsylvania (2016). Retrieve from: http://knowledge.wharton.upenn.edu/article/college-vs-business-training-what-do-employers-want/

Knowledge@Wharton (2016). Education vs work skills: what do employers really want? World Economic Forum. Retrieved from https://www.weforum.org/agenda/2016/02/education%ADvs%ADwork%ADskills%ADwhat%ADdo%ADemployers%ADreally%ADwant?utm_content=buffer33dae&utm_medium=social&utm

Willige, Andrea (January, 2017). 8 ways to prepare our Kids for the jobs of the future. World Economic Forum. https://www.weforum.org/agenda/2017/01/waystopreparekidsforjobsoffuture?utm_content=buffer2b089&utm_medium=social&utm_source=facebook...