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Critical thinking: Conceptual clarification and its importance in science education

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Abstract
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. However, this objective has not been appropriately implemented in classrooms. One of the obstacles is the fact that teachers do not have a clear idea about critical thinking because the meaning ascribed to critical thinking in different contexts is rarely explicit. This paper attempts to clarify this concept, evincing its relationship with other concepts such as scientific literacy and to present and discuss a framework for promoting students' critical thinking in science classrooms.

Key words: *Critical thinking, Science Education*

Introduction
Interest in critical thinking [CT] goes back to the primordial days of education. Authors such as Sternberg (1986) point to Plato and Aristotle as founders of the "critical thinking movement". According to Baron (1994), the idea that education has the obligation of teaching people to think dates back to Socrates, and the understanding of how to do so has been intensified throughout time.

However, since the 80s, there has been a growing interest and a renewed concern for the promotion of CT. Boisvert (1999) considers this decade to be a milestone for three phases that represent the evolution of CT in education. During the first phase, before the 80s, education focused on CT abilities which could be chosen as objectives and seen as an end in itself. In the second phase, during the 80s, the focus was on processes of critical and creative thinking required for problem-solving, decision-making and research, considering that cooperative learning and graphical organizers were two pedagogical innovations which further characterized this period. The third phase, which started in the 90s, is characterized by the attention and importance ascribed to the use of CT processes and abilities in diverse situations within the school and students' personal lives. During this latter period, there is a certain insistence on the creative use and transfer of these thinking abilities as a means for meta-cognitive reflection, in which students are expected to become more aware of their own thinking processes and better informed about thinking strategies of others.

Within this framework, critical thinking gained in impetus to the point of allowing one to state the existence, over the last 25 years, of a true movement of critical thinking (Brown, 1998; Vieira, 2003). Evidence of this is the fact that:

• several education systems include the development of CT as an objective to be achieved within the context of several subjects at different school levels (Vieira & Tenreiro-Vieira, 2005);
• more articles and books are being written on the subject of CT, many of which relate to the integration of CT in specific curricula areas (Paul, 1993); and
• the number of conferences, such as the "Annual International Conference on Critical Thinking at Sonoma State University" and of workshops, have increased throughout the last decades, some of which have focused on facilitating CT. Simultaneously, editors, aware of this movement, have started to develop attempts to incorporate facilitating situations for the use of CT abilities in curricula materials, although school books, which explicitly focus on CT, are still scarce in several countries, such as Portugal.

Educational literature on CT argues that:
• it is a basic ability and an imperative of modern life which should focus on ascribing meaning to the world, examining thought in detail and requiring an active mental effort with a purpose on behalf of the student (Barak, Ben-Chaim and Zoller, 2007; Dam and Volman, 2004; Gunn, Grigg and Pomahac, 2007);
• it should be explicit, systematic and promoted within the context of different subjects at all levels of education (Abrami, Bernard, Borokhovski, Wade, Surkes, Tamim and Zhang, 2008; Pithers and Soden, 2000);
• it should not be reduced to the application of a set of prescribed recipes, just as there is no unique and infallible method to do so (Boisvert, 1999). CT requires, as further stated by this researcher, reflective work and a significant amount of courage to take on the risks inherent to the choice of this objective; and
• "Thinking is clearly and undoubtedly a difficult task, particularly when one is learning how it is done" (Chaffee, 1998, p. 17), given that it is practically consensual that the student should be an active element in the improvement of their CT.

Authors like Davson-Galle (2004) and Marples (1999), write that for many years, the objectives in education were supported by liberalism and centered on autonomy. Currently, according to the last author, these objectives have expanded and include: social justice, national identity, the curriculum, social practices and critical thinking. From this perspective, CT is the central idea in education and the social basis for the acquisition of equal rights and citizen freedom, within democratic countries (Hare, 1999).

To sustain this point, arguments concerning the interest in CT as an objective for education shall now be presented. Given the existence of conceptual diversity, the purpose of the following arguments is to present a clarifying and guiding reference for CT as an objective for education in general and of science education in particular, evincing its relationship with other concepts, such as scientific literacy. Then, recognizing the relevance of promoting students' critical thinking in science classrooms, we present and discuss a way of how it can be done.

Reasons for the Educational Interest in Critical Thinking
Several reasons justify the interest which has started to emerge among researchers and educators concerning CT. The reasons we present, for education in general and specifically for science education, are a summary of those presented by Vieira (2003).

The first is the meaning of CT in itself. As stated by Wright (1992), "[…] education in itself requires, per its definition, critical thinking" (p.37). This implies that each individual be able to think critically about their beliefs, providing rational reasons which sustain and justify them. Additionally, they should be able to protect themselves from manipulations, safeguarding themselves from deceivers and exploiters (Boisvert, 1999).

A second reason, according to Wright (1992), results from the assumption that the promotion of CT helps people to break away from egocentric attitudes. Another reason is related to the idea that CT is necessary to be able to live in a plural society with citizenship competence, for example, which contributes towards a conscientious participation in democratic institutions, where citizens are confronted with the need to make rational decisions. It is actually stated that in order for democracy to exist and work, citizens are required to think critically, i.e., to have the ability to make judgments of value and interact with others. These, as well as other abilities are indispensable, especially within a scientific-technological society, in which workers are also expected to identify and solve problems and work collaboratively with co-workers to find adequate solutions (Gunn, Grigg & Pomahac, 2007).

The complexity and growing interdependence of modern life places a significant emphasis on human rationality and critical thinking, namely with regard to issues which generate disagreements (Barak, Ben-Chaim & Zoller, 2007; Kurfiss, 1988). According to authors, such as Ennis (1996) and Paul (1993), for the citizens to live, work and function efficiently they need to use CT abilities to assess, make decisions and judgments with regard to the information citizens need to obtain, in which they are required to believe and use. Citizens also need to use such abilities to guarantee global socio-economic development, taking into account human wants and the need to protect the environment, guaranteeing the integrity of ecological environments which human beings are dependent on for their survival (Boisvert, 1999). These abilities can help people to ascribe meaning to life itself and assist them in overcoming the "existential vacuum" in which they live (Chaffee, 1998).

On the other hand, for citizens to have rewarding personal lives, which include managing private tasks, continuing to learn and benefitting from culture, CT abilities need to be used (Dam and Volman, 2004; Newman, 1990). Encouraging CT in students allows them to become lifelong, independent learners – one of the long-term goals of education (Tsui, 1999). Authors, such as Abrami et al. (2008), Genç (2008) and Browne and Keeley (2000), even defend the view that CT abilities are useful for people throughout their school experience and as citizens. As students, these abilities can be useful when students are requested to:

- react critically to an essay or evidence presented in a text,
- assess the quality of reading or of discourse,
- build an argument,
- write an essay based on previous reading or,
- participate in class.

CT is important for the students' future, given that it prepares students to deal with a multitude of challenges which will appear in their lives, careers and at the level of their personal obligations and responsibilities (Tsui, 1999).

> *"As a citizen, you should find them especially helpful in shaping your voting behavior and your purchasing decisions, as well as improving your self-confidence by increasing your sense of intellectual independence" (Browne & Keeley, 2000, p. 2).*

These reasons, which justify the interest and importance of CT, are included as pragmatic and intellectual justifications, according to Hare (1999). However, in this philosopher's opinion, there is a third line of justification – ethics, according to which the human being has potentials that no other animal possesses. This is the reason why the child, like the adult, should be treated with the respect shown for someone who is able to grow in an autonomous manner. In this sense, "[...] good teaching requires that our educational aims include the development of critical thinking" (p. 95).

Critical Thinking and Science Education

Besides the reasons previously presented for the interest in CT, specifically in Science Education, science education can and should be a central component in education, dedicated to the promotion of rationality and CT (Siegel, 1989). This author stresses that the power of nations is now not essentially economic, but increasingly related to CT abilities.

On this issue, Tenreiro-Vieira (2000) draws attention to the following: "In carrying out scientific activity, which requires the analysis of procedures and scientific results, the application and integration of information, both knowledge and critical thinking abilities, are necessary" (p. 1). These also allow each citizen to understand the work and action of those who have a scientific and/or technical occupation (Vieira and Tenreiro-Vieira, 2005) and, simultaneously, to understand new discoveries which constantly allow Scientific and Technological knowledge to evolve (Gunn, Grigg and Pomahac, 2007).

We live in a world where Science has become an intrinsic part of everyone's life, in which we witness an explosion of scientific information which 'bombs' the world with new discoveries every day. In truth, according to Tenreiro-Vieira (2000), never before has there been as great a need to prepare students to face the dynamic and unpredictable flux of outdated scientific and technological knowledge. This author adds that the use of CT abilities also allows individuals to take a stand on scientific issues, logically rationalizing the issue under discussion, in order to detect fallacies in arguments, or to suspend the taking of a decision when should there be insufficient evidence to trace and sustain a conclusion.

Hence, students should learn the Sciences to understand, assess and use scientific knowledge. In this context, CT abilities are the key to successful learning (Barak, Ben-Chaim & Zoller, 2007). Additionally, they are necessary for all those who intend to follow careers related to Science. From this perspective, CT may contribute towards a better understanding of Science, to be prepared to act in the context of problem solving and decision making with regard to the way Science and Technology are used to change society and vice-versa. In fact, finding appropriate solutions for problems, both within the areas of Biology, of Medicine, or of any other scientific/technological area, requires the use of CT abilities for individuals to make decisions, based on the relevance of the reasons found, rejecting partiality and arbitrariness in the assessment of arguments. This is one of the ways of constructing a more realistic image of Science.

Critical Thinking, scientific literacy and competences

Critical thinking has been presented as being a multifaceted concept. For example, several researchers, who share the philosophical tradition, focus on CT and the logical aspects of thinking. Others adopt the tradition of cognitive philosophy, focusing on the identification of thinking abilities. This why, according to authors like Dam and Volman (2004), Genç (2008), Kurfiss (1988) and Piette (1996), CT is contextualized by two main theoretical perspectives:

the philosophical and that of cognitive psychology.

The philosophical perspective has been particularly concerned with teaching, especially in courses of logic, principles of rhetoric and argumentation. The main objective of these courses has been to favor the promotion of students' CT, encouraging them to learn to refine and discipline their thought. In that sense, the subject is encouraged, among other activities, to:

- question the validity of arguments;
- reject conclusions which are not supported by valid reasons;
- detect tendencies, thinking and logic errors;
- assess the credibility of sources of information;
- identify the explicit and/or implicit assumptions in a statement or argument (Piette, 1996).

The terms more frequently used by the authors who defend this perspective are those of CT and teaching of critical thinking.

On the other hand, the authors affiliated to the cognitive psychology perspective frequently prefer the broader, more general expression of teaching of thinking, or the teaching of thinking skills, which is more specific than the teaching of CT. For these, 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).

According to this last author, these two theoretical perspectives, despite cohabitating, have led to the prevalence of a certain ambiguity around the meaning of the term CT. However, it is stressed that these two perspectives are mutually reinforced with developments from each area and that, frequently, in educational terms, complement each other. In fact, the majority of authors consider the two perspectives to be complementary (Piette, 1996).

Nevertheless, by considering the nature of thought, various designations, with overlapping meanings, have been used, such as the following: "critical", "creative", and "of high order." Pithers and Soden (2000) write that "good thinking" and "thinking well" are terms used under the umbrella term "critical thinking." In this sense, the latter can distinguish itself from thinking which is reproductive and repetitive (low order).

Several definitions for CT have been proposed. Ennis (1985) 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 in the following operational definition:

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

In Ennis's conceptualization, the term "focused" evokes the idea of a conscientious activity, directed towards a goal, which did not arise by chance or without a reason (Boisvert, 1999). This adopted definition also draws attention to the extensive role CT plays in everyday life, as all behavior depends on what one believes and all human action depends, in some way, on what one decides to do.

It is worth noting that CT involves as many abilities as dispositions. Abilities refer to the more cognitive aspects and dispositions to the more affective. Several efforts have been made in order to identify and list these dispositions and with this purpose, several tables and/or

taxonomies have been proposed. In the first part of the taxonomy by Ennis (1985) (the most updated version in Portuguese can be found in Vieira & Tenreiro-Vieira, 2005), 14 dispositions of CT can be found. The first seven are highlighted below:

1. Look for a clear proposition of the topic or thesis
2. Look for reasons
3. Try to be well informed
4. Use and mention credible sources
5. Take into account the situation from a global perspective
6. Try not to deviate from the core of the issue
7. Bear in mind the original and/or basic concern

In the second part of the Ennis taxonomy, the abilities are organized into five areas: elementary clarification, basic support, inference, elaborated clarification, and strategies and tactics. In each of these, one or more groups of abilities can be found. For example, in the area of elementary clarification, there are three groups: focusing on an issue, analyzing the arguments and asking and answering clarification and challenging questions. When analyzing arguments, the abilities called upon are:

a) Identify conclusions
b) Identify the reasons presented
c) Identify the reasons not presented
d) Look for similarities and differences
e) Identify and deal with irrelevancies
f) Look for the structure of an argument
g) Able to summarize

CT is, however, centrally a normative concept, given that it is good thinking (Bailin, 2002). It is the quality of thinking, this researcher maintains like others who share this view, namely Angeli and Valanides (2005), which distinguishes CT from non-critical thinking; bearing in mind that the latter is determined by relevant criteria/norms. It is, therefore, the approval of a criterion, which governs the quality of thinking and judgment of values in a certain area, which constitutes the defining characteristic of CT. Some of these criteria, which are also applicable to science, are:

- accuracy of the data,
- control of variables,
- credibility of the sources, and
- validity of inferences.

These definitions of CT illustrate the diversity which can be found in the literature on the issue. But there are points of congruence: all the definitions perceive CT 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 (Piette, 1996).

Based on the definition by Ennis, we argue 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 (that which motivates critical thinkers to use critical thinking abilities in their own thinking and in that of others). Furthermore, when thinking critically a person consciously and deliberately must seek and use knowledge and criteria relating to the issue or question under consideration. As Ennis (1985) states, we cannot expect a person who is ignorant relating to the questions under discussion will be good at making value judgments and explanatory inferences.

The context in which critical thinking occurs plays an important role in what counts as reasonable application of criteria to think critically. So, to think critically about scientific issues implies to know and to act in accordance with scientific criteria such as accuracy, control of variables, reliability of sources and validity of inferences. It also implies to deal with basic concepts in the area like necessary and sufficient conditions, correlation and cause and hypothesis testing.

Critical Thinking and Scientific Literacy

Critical thinking and the concept of scientific literacy, as defined by NRC (1996), overlap:

> Scientific Literacy is the knowledge and understanding of scientific concepts and process required for personal decision making, participation in civic and cultural affairs, and economic productivity. [...] It means to be able to read with understanding articles about Science in the popular press and to engage in social conversation about validity of the conclusions. […] implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it. Scientific literacy also implies the capacity to pose and evaluate arguments based on the evidence and to apply conclusions from such arguments appropriately. (p. 22)

The purpose of critical thinking abilities emerges from this definition. To be scientifically literate implies not only the use of scientific knowledge, but also of thinking abilities, namely of CT (Gunn, Grigg and Pomahac, 2007; Tenreiro-Vieira and Vieira, 2001). In fact, in this definition of scientific literacy, explicit reference is made both to the dispositions of CT (for instance, to seek to be well informed), as well as to CT abilities (for example, assess the credibility of sources and formulate conclusions) (Brewer, 2008; Gunn, Grigg and Pomahac, 2007).

The concept of scientific literacy has varied from straight confinements to more general competences. Maybe because of this and according to Norris and Phillips (2002), the word literacy is associated with the concept of competence. "Concrete or abstract, common or specialized, of easy or difficult access, a competence allows a set of tasks and situations to be faced regularly and adequately, calling upon notions, knowledge, information, procedures, methods, techniques, as well as more specific competences" (Perrenoud, 2008, p. 31). This author specifies that possessing knowledge or abilities does not mean being competent, given that it is necessary to know how to mobilize them pertinently, and at the right moment, namely in a working situation. Hence, competence is realized through action.

As noted by OECD (2005), the use of the term competence reinforces the idea of knowing in use/action, since the notion of competence refers to something more than the memorization of knowledge. It involving knowing and being able to handle complex situations mobilizing intellectual resources (including critical thinking abilities, attitudes and the construction of useful knowledge to be usable in everyday life), in particular contexts.

The following figure shows a conceptual map, starting from the key concept of "literacy for all". It represents a framework to guide teacher's actions to promote student´s critical thinking in order to achieve better levels of scientific literacy.

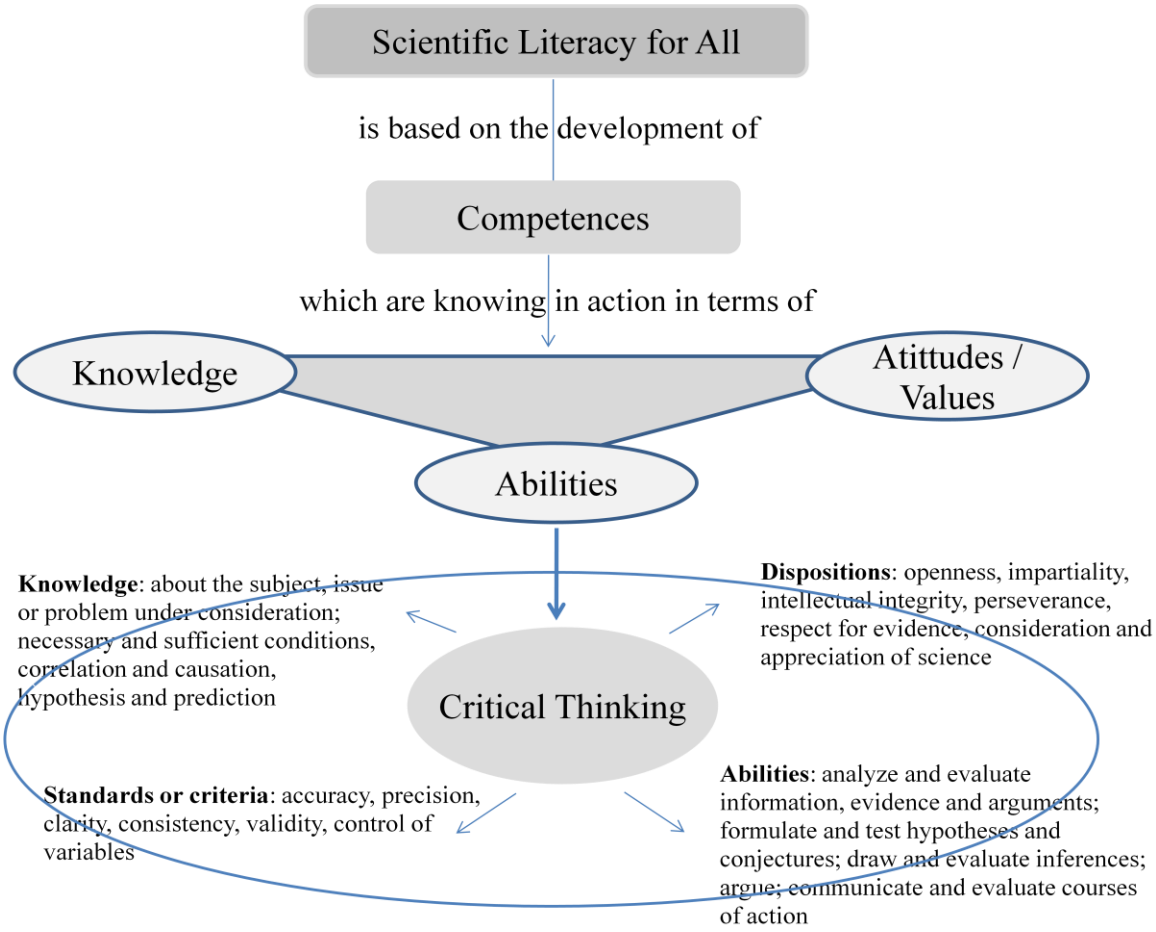

Figure 1: Framework for promoting student´s critical thinking in science classrooms

The figure highlights the overlap between scientific literacy, competences and critical thinking. Scientific literacy implies the development of competences that is the integrated use of intellectual tools, namely knowledge, attitude / values and thinking abilities, such as critical thinking. It suggests that critical thinking is fundamental to scientific literacy; critical thinking involves abilities, dispositions / attitudes, knowledge in terms of overarching ideas and standards or criteria that are essentials to scientific literacy.

Promoting Critical Thinking in Science Education Classrooms

Recognizing the importance of the attainment of critical thinking as an educational objective and that Science Education needs to contribute towards its development (Popper, 1970, quoted by Siegel, 1989), many school curricula, in different countries, have introduced this objective. For example, in the USA, the "National Science Education Standards" (National Research Council [NRC], 1996), emphasizes CT, i.e., the importance of developing this ability in students is made explicit. In Europe, is the same; for instance, for Malamitsa, Kokkotas and Kasoutas (2008) the new Curricula for elementary and secondary education in Greece clearly state that critical thinking is an important educational aim.

Focusing on the Science Programs of Basic Education in Portugal, the inclusion of developing CT abilities can be identified in activities such as organizing research, observing, formulating questions and problem solving. Similarly, the proposition of methodological suggestions, such as asking and answering questions, creating observation registers and inferring conclusions, calls on CT. Likewise, curricula objectives which address students' scientific literacy are, even more explicitly, focused on the development of reasoning/thinking i.e. CT. For example, in the National Basic Education Curricula, (ME-DEB, 2001), references to CT can be found in specific competences in two domains: reasoning and communication. In the first, reference is made to CT abilities such as "[…] evidence and explanations, confronting different perspectives of scientific interpretation, constructing and /or analyzing alternative situations which require the proposal and the use of diversified cognitive strategies" (p. 133). In the second case, CT abilities related with argumentation and inference are pointed out, which should allow students to evidence "[…] the logical structure of the text according to the approach to the subject" (p.133), as well as the use of scientific language and information and communication technology.

Teaching Strategies for Critical Thinking

In order to promote student's critical thinking in science classrooms, teachers must use teaching strategies, as well as learning activities, which focus on the involvement of critical thinking. To do so, the framework presented in figure 1 can be used to plan questioning strategies and learning activities, such as:

- participate in discussions,
- writing positional articles, and
- analyze journal papers about controversial socio-scientific issues.

In this context, students should be asked to:

- generate relevant knowledge, using credible sources,
- state an informed position;
- construct valid arguments and contra-arguments based on accurate evidence;
- analyze arguments and contra-arguments; and
- ask and answer questions that clarify or challenge.

During the discussions or the presentation of positional articles, students must be encourage to seek precision and reasonable reasons, to be open-minded, to keep in mind the situation as a whole and to focus on the issue under consideration.

In focusing attention on teachers' questioning, particular questions arise which can be a useful help to promote students' critical thinking (Vieira and Tenreiro-Vieira, 2003).

1) Questions focused on the identification and clarification of the main question – examples:
    - On what is this?
    - What is the main issue?
    - What is the purpose or primary objective?
    - What is the thesis that [the author] is trying to prove?
    - What are the conclusions?
2) Questions focused on seeking reasons – examples:

- What are the reasons that [the author] points in support of the findings?

3) Questions focused on the inference process
    - Are there plausible alternatives to the conclusions drawn?
    - What are the assumptions the author is making?
    - What are the implications of that asserted by [the author]?
    - Can anyone disagree with the conclusions drawn by [the author]? Why?

It is worth noting that 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.

Final Considerations and Implications

Critical thinking has been an educational ideal for a long time. But since the 1980s it has been, more and more explicitly, included in educational curricula in various countries.

Unfortunately, research which has been carried out shows that this objective has not yet been taken into account by teachers in their practices. In fact, several studies in this area, such as those carried out by Tenreiro-Vieira (2000) and Vieira (2003), provide evidence that teacher education, educational practices, school books and the majority of school materials sold and made available in Portugal do not take into account, explicitly and intentionally, the development of CT abilities. This is because, in general, repetitive strategies are developed, which are not very stimulating and emphasize the learning of isolated facts and knowledge instead of the development of critical thinking abilities.

As Pithers and Soden (2000) indicate, one way of promoting students' CT is to change the myth that current practices already take CT into account. The idea that all students develop their abilities naturally and spontaneously should no longer be accepted. While it is clear that a subject 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. Critical thinking needs to developed in students.

In order to reverse this situation it is necessary that various components of the education system be in sympathy to 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 (Genç, 2008). Within this framework, it is important that those who are responsible for education policy to understand and recognize the importance of promoting CT. Otherwise, they compromise its implementation in school in general and in the classroom in particular. In order to demand effective teaching of CT, in a globally organized and systematic manner, an education policy which explicitly and intentionally contemplates CT is essential. This is already the case in several countries, like Portugal.

Moreover, those who are responsible for the education policy should recognize that teaching practices should be consistent with the philosophy and objectives established for curricula, such as science education (Tenreiro-Vieira, 2000). This entails a dynamics in teacher education focused on the teaching/learning of CT, given that the teacher is, for all intent and purposes, the central element in overcoming the discrepancies between the intentional and the

implemented curriculum. This education should create opportunities for the teachers to become familiar with and promote the objectives of education, which includes CT). CT, is a crucial dimension in promoting competences, which are, in turn, essential to achieve the objective of "enhancing Scientific Literacy for All" (see figure 1).

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