Chapter 1
The ENCIC-CT Model for the Development of Critical Thinking

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1.1 Theoretical Perspectives and Approaches for the Development of Critical Thinking

This book explores critical thinking (hereinafter, CT), a complex construct that is challenging to define precisely. The following sections offer insights that may help to clarify its meaning, examining how various scholars have discussed and developed this concept from philosophical foundations and cognitive psychology perspectives.

Although the formal development of the concept of CT took place in the twentieth century, it is important to recognize that similar ideas were being explored in ancient Greece, even though the term itself was not used. A significant precursor to the development of CT is found in Socrates' method. While the Greek philosopher did not use the term CT, he is credited as one of the earliest practitioners and promoters of a form of thinking we now associate with this skill. Socrates employed a technique of dialogue and questioning known as the Socratic method to foster critical reflection and analysis in his interlocutors. This method involved asking probing and persistent questions to challenge ideas, examine assumptions, and seek truth through rational discussion (Farnsworth, 2021).

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A. J. Franco-Mariscal (ed.), *Critical Thinking in Science Education and Teacher Training*, Contemporary Trends and Issues in Science Education 64,
https://doi.org/10.1007/978-3-031-78578-8_1

In the seventeenth century, the philosopher and mathematician Descartes (1641) made significant contributions to CT that have profoundly impacted both philosophy and scientific methodology. Key contributions include: (a) the method of systematic doubt, which involves rigorously questioning all beliefs that are not absolutely certain, thereby highlighting the importance of self-reflection and certainty in evaluating our beliefs; (b) the Cartesian method, encompassing evidence, analysis, synthesis, and revision—essential components of CT; and (c) rationalism, which asserts that reason and logic are fundamental tools for acquiring knowledge.

Similarly, Kant's contributions to CT are crucial as they promote a rigorous and systematic examination of the foundations and limits of knowledge, morality, and reason, offering tools for a more profound and reflective analysis of our beliefs and practices. His key contributions include: (a) *The Critique of Pure Reason*, where Kant (1781) investigated the boundaries and capacities of human reason, introducing the idea that reason has inherent limits on what it can know; (b) transcendental epistemology, which explores how cognitive structures shape our understanding of the world; (c) the categorical imperative as a fundamental moral principle that guides action, providing a framework for critically and objectively assessing moral decisions; (d) individual autonomy in making rational and moral decisions independently; and (e) *The Critique of Practical Reason*, where Kant (1788) examines morality and practical reason, offering a critical perspective on how rational principles are applied to ethical behavior.

In the twentieth century, philosophers and educators like Dewey and Russell played a pivotal role in shaping the concept of CT. Dewey (1910) advocated for education as a process of reflective and CT, which involves carefully analyzing information, experiences, and ideas before drawing conclusions. This reflective thinking requires actively questioning, analyzing, and evaluating beliefs and assumptions. It is an approach that fosters CT through experimentation and the resolution of real and relevant problems. Dewey also argued that CT should be taught in schools, as education's role is to prepare individuals to actively engage in democracy and make informed decisions, which necessitates CT.

Russell's (1973) contributions to CT center around logic and argumentation, which are essential in shaping the CT construct. His contributions include: (a) the advancement of mathematical logic and reasoning, which influenced the development of formal reasoning systems and the clarification of complex arguments; (b) philosophical analysis, an approach aimed at clarifying concepts and arguments through rigorous logical and linguistic examination, essential for enhancing precision and clarity in reasoning and communication; (c) skepticism and critique of unsupported claims; (d) the defense of intellectual freedom and the right to challenge established ideas; and (e) social and political engagement on issues such as pacifism, civil rights, and education, demonstrating that CT should be applied to real-world societal issues.

Paul and Elder (2005) are considered the leading proponents of CT theory, and their contributions have influenced its understanding and teaching. Their work focuses on identifying the intellectual skills necessary for CT and the importance of explicit instruction in fostering these skills. According to their perspective, CT entails a mode of thinking where individuals enhance the quality of their cognition by engaging with the underlying structures of thought and subjecting them to rigorous intellectual standards. As a result, a critical and practiced thinker formulates problems and questions with clarity and precision; assesses and synthesizes relevant information; employs abstract ideas to interpret data effectively, and reaches conclusions and solutions based on relevant criteria. Moreover, such thinkers exhibit an open mind; recognizes and evaluates assumptions, implications, and practical consequences as needed; and communicates their insights when devising solutions to complex problems (Paul & Elder, 2005).

Another prominent author is Facione (1990), whose models and approaches have influenced the understanding and teaching of CT, emphasizing cognitive skills and dispositions or critical attitudes. This author argues that CT development is closely related to its practice, to action. According to Facione (1990), the essential cognitive skills of CT include interpretation, analysis, evaluation, inference, explanation, and self-regulation.

Interpretation consists of "comprehending and expressing the meaning or significance of a wide variety of experiences, situations, data, events, judgments, conventions, beliefs, rules, procedures, or criteria." (Facione, 1990, p. 5). It includes the subskills of categorization, decoding significance, and clarifying meaning.

Analysis is "to identify the intended and actual inferential relationships among statements, questions, concepts, descriptions, or other forms of representation intended to express belief, judgment, experiences, information, or opinions" (p. 5). This skill includes examining ideas, detecting arguments, and analyzing arguments.

Evaluation is "to assess the credibility of statements or other representations which are accounts or descriptions of a person's perception, experience, situation, judgment, belief, or opinion; and to assess the logical strength of the actual or intended inferential relationships among statements, descriptions, questions or other forms of representation" (p. 6).

Inference means "to identify and secure elements needed to draw reasonable conclusions; to form conjectures and hypotheses; to consider relevant information and to reduce the consequences flowing from data, statements, principles, evidence, judgments, beliefs, opinions, concepts, descriptions, questions, or other forms of representation" (p. 6). As sub-skills, it includes querying evidence, conjecturing alternatives, and drawing conclusions.

Explanation is understood as the ability to present the results of one's own reasoning reflectively and coherently. This involves being able to provide someone with a comprehensive view of the entire landscape, both "to state and to justify that reasoning in terms of the evidential, conceptual, methodological, criteriological, and contextual considerations upon which one's results were based; and to present one's reasoning in the form of cogent arguments" (p. 6). The sub-skills of explanation include describing methods and results, justifying procedures, proposing and defending with good reasons one's causal and conceptual explanations of events or viewpoints, and presenting complete and well-reasoned arguments in the context of seeking the greatest possible understanding.

Self-regulation means “self-consciously to monitor one’s cognitive activities, the elements used in those activities, and the results educed, particularly by applying skills in analysis, and evaluation to one’s own inferential judgments with a view toward questioning, confirming, validating, or correcting either one’s reasoning or one’s results” (p. 7). Self-examination and self-correction are its sub-skills. Some authors refer to this skill as metacognition.

Facione (1990) asserts that critical thinkers can be characterized not only by their cognitive abilities but also by their approach to and way of living life. These dispositions or critical attitudes encompass: curiosity about a broad range of issues, a commitment to staying well-informed; alertness for opportunities to apply CT; confidence in reasoned inquiry processes; self-confidence in one’s capacity for reasoning; openness to diverse worldviews; flexibility in considering alternatives and viewpoints; empathy for others’ perspectives; impartiality in evaluating reasoning; honesty in confronting personal biases, prejudices, stereotypes, or egocentric tendencies; caution in deferring, making, or modifying judgments; and a readiness to reconsider and revise perspectives where honest reflection suggests that change is warranted.

Ennis (1987) is another pioneering author in the study of CT. His works addressed the definition and assessment of CT and have influenced the development of strategies for teaching and measuring this skill. According to Ennis (1987), “CT is a reasonable reflective thinking that is focused on deciding what to believe or do”.

Lipman (2003) advocates for an education that transcends mere knowledge transmission, instead emphasizing CT as a set of higher-order cognitive skills. This author conceives of CT as part of multidimensional thinking, alongside creative thinking and careful thinking. According to Halpern (2006), CT is central to problem-solving, inference formulation, and decision-making.

The concept of CT has extended to education in general, where it currently represents a focal point of interest by encompassing cross-cutting competencies essential for personal, social, and professional life (Vázquez & Manassero, 2020). With the exponential growth of information creation each year, CT skills are increasingly indispensable for individuals to become more adaptable, flexible, and capable of dealing with this rapidly evolving information. Drawing upon the integration of existing frameworks with recent conceptualizations of CT, Dwyer et al. (2014) propose an integrated CT framework for the twenty-first century. This framework identifies memory/knowledge and understanding as fundamental processes required for successfully applying CT (i.e., analysis, evaluation, and inference). Moreover, it also includes reflective judgment, as well as the self-regulatory functions of metacognition, which ultimately dictate how each thinking process will be carried out.

As emerges from the various perspectives provided, CT is a complex construct involving different skills and dispositions, making it difficult to find a consensus definition in the literature. Furthermore, it is essential to analyze how it is being understood within the specific context of science education.

1.2 Critical Thinking in Science Education

Currently, there is unanimous agreement regarding the importance of CT for citizens and its consideration as one of the major goals of science education (Osborne, 2014). Nowadays, science and technology play a significant role in the challenges confronting our society, many of which are interconnected with the Sustainable Development Goals (SDGs) established by the United Nations (2015) to safeguard the planet, eradicate poverty, and ensure prosperity for all individuals. Moreover, science and technology are also present in many daily life problems. It is evident that, without critical reflection on these issues, decisions in economic, social, political spheres, among others, could lead to irreparable consequences.

Therefore, it is necessary to educate CT skills in students across all disciplines and educational levels, empowering them to make decisions in society and take action (Colucci-Gray & Gray, 2022; Hodson, 2003; Simonneaux, 2014). Unfortunately, for many years, science education has overlooked the development of CT skills (Halpern & Danna, 2023), despite the current demand for science education to play an active role in addressing issues related to energy, the environment, food, or health, among others. Consequently, integrating CT into science education poses a formidable challenge (Puig & Jiménez-Aleixandre, 2022), prompting an increasing focus on this subject within the specialized literature of science education (Bailin, 2002; Jiménez-Aleixandre & Puig, 2022; Torres & Solbes, 2016).

Next, we discuss some contributions on how to understand CT and its importance in science education. Osborne (2014) suggests that criticism and questioning are essential for the practice of science, and without them, scientific knowledge could not be constructed.

Bailin (2002) suggests that many efforts to promote CT in science education have been hindered by certain misconceptions about the nature of CT, "in particular the characterization of CT in terms of processes or skills and the separation of CT and knowledge" (p. 361). This author argues that CT always emerges in response to a task, question, problematic situation, or challenge. This encompasses activities such as problem-solving, theorizing, evaluating theories, conducting research, and engaging in creative tasks, all of which are inherently context-specific. Addressing these challenges critically involves drawing upon a complex range of knowledge that is context-dependent. Given the contextual nature of CT, its application in science education necessitates a focus on tasks, problems, and issues within the scientific curriculum that call for, or stimulate, CT.

Solbes and Torres (2012) define CT as a necessity for individuals to develop their own way of thinking, enabling them to engage with social situations and play an active role in scientific and cultural decisions. For these authors, CT development requires individuals acquiring a set of skills to address and discuss socio-scientific issues, alongside understanding science as a human activity that is related to technology, environment, and society. Among the skills highlighted by Solbes and Torres (2012) are questioning argument validity, transcending dominant discourses, identifying argumentative fallacies, comprehensively analyzing socio-scientific issues, making informed decisions, among others.

Blanco-López et al. (2015) in a study on the key aspects of scientific competence for citizenship, found that critical attitude/thinking was the aspect with the highest level of agreement and consensus among a group of Spanish experts in science from different spheres and fields: scholar-scientists and engineers, researchers and private sector scientists, philosophers of science, science educators, and science communicators. In addition to CT, four other aspects were emphasized: individual responsibility; ability to reason, analyze, interpret, and construct an argument in relation to scientific phenomena and knowledge; ability to search for, analyze, synthesize, and communicate information and; ability to work as part of a team. These authors conclude that:

> the five key aspects identified in this study should be considered jointly in the context of school science education, since they are interrelated skills that citizens will require when tackling important issues and making decisions in various spheres of their life (personal, social, professional, etc.) (p. 164).

According to Vieira and Tenreiro (2016), CT shares common attributes with scientific literacy. Its core components encompass knowledge (including great ideas and scientific explanations, history of science, Nature Of Science, STS relations), skills/processes/abilities (analyse and assess information, evidence and arguments; formulate and test hypotheses, conjectures; draw and assess conclusions; make and assess generalisations; make and assess judgements; argue; communicate; assess courses of action), dispositions/attitudes (open-mindedness; impartialness; intellectual integrity; perseverance; respect for evidence; appreciation and enthusiasm for science) and standards/criteria (rigour, accuracy, clarity, consistency, validity, control of variables).

Vázquez and Manassero (2018) synthesize CT into four dimensions: creativity, reasoning and argumentation, complex processes (problem-solving and decision-making), and evaluation and judgment. Each dimension encompasses various skills that extend beyond mere cognitive abilities. Moreover, contexts, attitudes, values, and emotions are acknowledged to play crucial roles in CT. In this regard, it is important to highlight that research has shown that science education is influenced by feelings, values, and ideals, which can act as facilitators or obstacles to learning (Membiela et al., 2022).

Jiménez-Aleixandre and Puig (2022) indicate that CT comprises a series of components related to deliberate judgment (argumentation), and other components linked to citizenship education. This latter aspect involves the ability to develop an independent opinion, challenge socially and culturally established ideas, and analyze and critique discourses that justify social inequalities (Fairclough, 1995). According to these authors, CT implies not only thinking reasonably but also "independently." In essence, it involves developing an informed opinion that integrates scientific reasoning and values, as well as independent CT for social action.

García-Carmona (2023) examines the differences and relationships between CT and scientific thinking, two key intellectual processes essential for the comprehensive scientific education of citizens, which are sometimes ambiguously employed in specific literature on science education. As a result, some studies interchangeably refer to either type of thinking to represent the same cognitive and metacognitive abilities, frequently leaving their differences and similarities unclear. This study concludes that while they differ in terms of the purposes of their application and some skills or processes, they also share common elements. Moreover, they form a symbiotic relationship metaphorically, meaning each gains coherence or develops optimally when nourished or enriched by the other.

Furthermore, the difficulty associated with the CT construct extends beyond its definition or the skills it encompasses. Educators also encounter obstacles when attempting to bring it into the classroom, as they often lack clear examples to serve as guidance and suitable tools to evaluate the development of different skills (Hierrezuelo-Osorio et al., 2022).

In this regard, Vila et al. (2023) developed two tools, namely the Operational Map of CT (MOPC) and the Scheme for Designing CT Activities (EDAPC) respectively, to assist in designing classroom activities that enhance CT. According to the MOPC, a student must engage a set of cognitive skills while also adhering to dispositions that facilitate thoughtful action. Additionally, the student must be capable of self-regulating the emotions and values evoked by the context. These dimensions are applied to a specific context that demands the activation of relevant knowledge. Skills, dispositions, values/emotions, and knowledge enable the development of metacognitive competencies in the thinker, which are indispensable attributes for CT. The EDAPC outlines the following sequence: (1) Explicitly or implicitly define the scientific content to be addressed in alignment with the curriculum, (2) specify the CT elements (in accordance with the MOPC) to be developed, (3) select a relevant context for students that correlates with the scientific content to be explored, (4) craft the activity framework, establish scaffolding, bolster argumentation, present the activity in a multimodal format, and incorporate communicative and collaborative dimensions, and (5) integrate metacognitive questions aimed at fostering self-regulation throughout the activity.

In summary, it is essential not only to have approaches to the CT construct in science education, but also to provide examples of proposals for addressing it in the classroom at all educational levels. This book aims to fulfill precisely that objective.

1.3 The ENCIC-CT Model for the Development of Critical Thinking

Although CT can be developed through science education by addressing various types of problem (Bailin, 2002), several authors emphasize the significance of creating learning environments based on contexts where science and technology serve as driving forces of learning. These settings aim to foster not only knowledge but also skills, attitudes, and values (Chen & Xiao, 2021; Owens et al., 2021). Moreover, such learning contexts facilitate a deeper understanding of science and technology, helping students to forge connections with their everyday lives.

There is agreement on the importance of developing CT within context of daily life problems where science and technology play a significant role (Cebrián-Robles et al., 2021a; Solbes & Torres, 2012), particularly those involving controversies where citizens need to make decisions that affect them personally and socially (Evagorou et al., 2012). As a result, robust lines of research have emerged within the science education focusing on Socio-Scientific Issues (SSI) (Zeidler et al., 2019).

From this standpoint, building on Solbes and Torres's (2012) characterization of the competencies needed for fostering CT within the SSIs, Blanco-López et al. (2017) identified eight dimensions for their development in science education: vision of science, knowledge, critical analysis of information, comprehensive analysis of the problem, argumentation, personal autonomy, decision-making, and communication. Progress in CT development is closely tied to advancements in each dimension, which can be nurtured by addressing them individually, yet it's imperative to include issues where all dimensions are integrated simultaneously.

Different research conducted by members of the Science Education and Competences Research Group [ENseñanza de las CIencias y Competencias] (ENCIC) (https://www.encic.es/) support this approach to science education, which has been shown to be effective in teaching both chemistry (López-Fernández et al., 2022) and engineering (Cano-Iglesias, 2024). Recently, García-Carmona's (2023) literature review on CT considers it to be an approach that is clearly contextualized in science education.

However, in the research project from which this book originates, a thorough review of this approach has been undertaken, incorporating additional aspects not covered previously. These include dispositions towards CT, explicit references to scientific practices of argumentation, inquiry, and modeling, a restructuring of the considered dimensions into three domains (knowledge, skills, and dispositions), as well as strategies for their development.

From our perspective, considering all these aspects is essential for achieving a deeper and clearer understanding of the term CT within the context of science education. Our view of CT goes beyond isolated thinking skills, encompassing the integrated development of cognitive dimensions and dispositions, which must be systematically addressed in science education through real-world problems and SSIs. These relevant, authentic contexts enable students not only to analyze, evaluate, and synthesize information but also to apply these thought processes in making informed, well-reasoned decisions. Furthermore, to effectively promote CT in science education, it is crucial to utilize core scientific practices such as argumentation, inquiry, and modeling. These practices, combined with effective teaching strategies, provide students with opportunities to challenge assumptions, interpret data, infer, explain phenomena, make predictions, evaluate evidence, and consider multiple perspectives in problem-solving. This reflective and rigorous process helps students develop CT

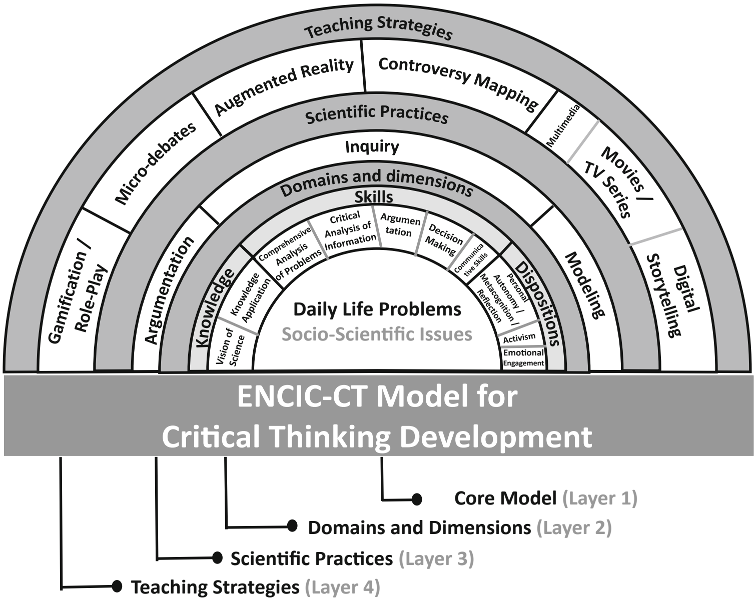

Fig. 1.1 ENCIC-CT model for the development of CT through the analysis of daily life problems

that is not only analytical but also applicable to a wide range of situations both within and beyond the scientific domain.

Figure 1.1 illustrates the ENCIC-CT model, showcasing our understanding of CT development through daily life problems in science education. Named after the research group where it originated, this model consists of four key components: daily life problems/SSIs, domains and dimensions, scientific practices, and teaching strategies. Each component is depicted as a layer, representing various levels of CT conceptualization and its practical application into science and technology education.

The first layer represents the core of the model, which involves the use of daily life problems and SSIs (Bencze et al., 2020). This serves as a strong starting point for developing CT in science education (Solbes & Torres, 2012).

The second layer displays the dimensions of CT grouped into three domains: knowledge, skills, and dispositions, as included in other CT proposals such as Vieira and Tenreiro (2016), Jiménez-Aleixandre and Puig (2022), Halpern and Danna (2023), and Vila et al. (2023). It is understood that this second layer can be applicable across any teaching area.

Now, in science education, we consider that developing these dimensions involves employing scientific practices such as argumentation (Erduran & Jiménez-Aleixandre, 2007; Kuhn, 2019), inquiry (European Commission, 2015; National Research Council, 2012), and modeling (Justi & Gilbert, 2002). These practices, which are considered major goals of science education (National Research Council, 2012), are tailored to address everyday life problems. They constitute the third layer of the model.

The fourth and final layer refers to possible strategies that can be used to develop CT in the science classroom or during teacher training. Among them, the Fig. 1.1 displays those used in the different chapters of this book: gamification/role-playing, micro-debates, augmented reality, controversy mapping, and multimedia resources such as movies/TV series or digital storytelling. However, it is important to note that these are not the sole strategies to be employed.

The use of this model for developing instructional modules or teaching–learning sequences involves making decisions at each layer, determining which specific components will be considered in the teaching design. Therefore, it is a versatile model, as the different concentric semicircles illustrating the different layers in Fig. 1.1 can be moved over one another, allowing CT to be approached from different perspectives.

The following sections provide detailed descriptions of the different layers and elements included in this model, drawing on the literature and studies conducted by the ENCIC research group.

1.4 First Layer of the ENCIC-CT Model: Daily Life Problems/Socio-Scientific Issues

In order to effectively develop citizens' CT, it is essential to approach people's everyday lives and identify socially relevant issues where they must make significant decisions before taking action. These problems should be authentic, relatable, current, open-ended, and controversial, suitable for the classroom, with information accessible to students and relevant to the content we wish to teach regarding science and technology. Furthermore, they should encompass social, ethical, economic, environmental, political aspects, etc., and enable the expression of attitudes, values, and emotions. These real-life problems constitute the central focus of the ENCIC-CT model and can affect us at three levels: as individuals (e.g., food or energy consumption), as members of a local community (e.g., water treatment or the location of a power plant), or as global citizens (e.g., global warming or biodiversity loss).

Daily life problems provide useful contexts for learning (Lupión et al., 2017) and for the development of CT, as they offer real-world scenarios that increase the likelihood of applying values and attitudes commonly used in everyday decision-making (Sadler & Zeidler, 2005). Among these problems, SSIs (Zeidler et al., 2019) are widely used approaches in science education. The SSI approach primarily focuses the scientific component while also acknowledging the social dimensions of the issues. Scientific education underscores the importance of equipping students with the ability to make informed decisions about SSIs, as their implications can significantly impact society. Hence, the importance of having scientifically and technologically literate students capable of fully exercising their rights and participating in decision-making in democratic societies. This training should empower them to adopt responsible, well-reasoned positions based on scientific and technological knowledge (Yacoubian, 2018).

1.4.1 *Socio-scientific Issues*

The SSIs refer to real, complex, and unresolved problems that are intrinsically linked to the intersection between science, technology, and society. These SSIs are controversial and can be approached from multiple perspectives (social, ethical, economic, environmental, legal, political, etc.) (Chen & Xiao, 2021; Sadler & Zeidler, 2005; Simonneaux, 2001; Zohar & Nemet, 2002). Acevedo (2006) asserts that controversies surrounding techno-scientific issues serve as clear demonstrations of the relationship between values education and science education. Consequently, SSIs require students to engage critically with science-related scenarios, enabling them to propose solutions and participate in debates on genuine problems (Jiménez-Aleixandre et al., 2000), thus fostering scientific literacy and democratic participation in society (Yacoubian & Khishfe, 2018).

Some SSIs are related to sustainable energy, food, biotechnology, etc. On the other hand, certain SDGs outlined in the Agenda 2030 (United Nations, 2015) address science and societal concerns, thus they could be considered to identify relevant problems for CT development. Health (SDG 3), energy (SDG 7), climate change (SDG 13), resources (SDG 14), etc., are some examples of these contexts focused on relevant citizenship issues. Likewise, historical episodes within the realm of science offer opportunities to explore the construction of scientific knowledge within authentic socio-cultural contexts. This allows for the explicit exploration of some features of Nature of Science (NOS) (Acevedo & García-Carmona, 2017), contributing to a holistic, functional, and realistic understanding of science (Manassero & Vázquez, 2019).

1.4.2 *Some Examples of SSIs*

In order to illustrate the potential of these issues for CT development in science education, below are a few examples.

- *Banning Single-Use Plastics*

Plastics are the most widely used material in object manufacturing, known for their durability. However, they pose an environmental problem due to their slow decomposition, persisting as waste in natural habitats, especially in oceans and seas (Elias, 2018). Additionally, their production necessitates the use of fossil fuels, exacerbating environmental concerns. Moreover, plastics and their additives are toxic to many living organisms, including humans (Eriksen & Al, 2014). In response to these issues, the United Nations set forth regulations to curb the excessive use of single-use plastics (such as cotton swabs, disposable cutlery, etc.), plastic bags, and overreliance on plastic packaging by 2022, specifying measures through a European Union directive (Koch & Barber, 2019). Addressing the environmental challenges posed by plastics demands concerted efforts across society, including education, which serves as a catalyst for instigating changes in citizens' attitudes and behaviors by fostering awareness of the far-reaching impacts of their actions on the environment (Marcén & Molina, 2006).

The problem of plastics is relevant and affects students' daily lives, as they frequently use single-use plastics. This issue offers an opportunity to explore scientific concepts such as plastic degradation, its physicochemical properties, and its environmental impact. Additionally, it allows for the examination of various dimensions of the issue, including social factors related to convenience, economic considerations, legislative aspects, and health implications. A study conducted by López-Fernández et al. (2021) with Spanish secondary students demonstrated advancements in understanding plastic chemistry and observed attitude shifts among some students regarding this issue following their participation in a role-playing game.

- *Genetically Modified Food*

Genetically modified foods are products altered using genetic engineering techniques, allowing them to acquire desirable traits in crops, such as disease resistance, tolerance to adverse conditions, or increased nutritional content (España-Ramos & Rueda, 2023). However, this practice has sparked intense debate in society due to concerns raised regarding food safety, human health, and environmental impact.

Regarding food safety, there are concerns about the potential long-term effects of consuming genetically modified foods, including the possibility of toxicity or allergies (España-Ramos, 2008). Another concern is the environmental impact of genetically modified crops. Speculation exists regarding the potential for genetically modified plants to crossbreed with wild species, potentially resulting in new herbicide-resistant species. This could complicate pest management efforts and negatively impact biodiversity. Similarly, there is apprehension regarding the potential spread of modified genes in the environment, which could have adverse effects on natural ecosystems (Wolfenbarger & Phifer, 2000). The debate continues, and it is essential to continue researching the long-term effects of genetically modified foods on both health and the environment.

- *Secure and Sustainable Energy*

The issues surrounding energy and resource usage are gaining increasing attention from the public and are part of SDG 7 (United Nations, 2015), which aims to ensure access to affordable, reliable, sustainable, and modern energy for all citizens. Recent examples of these SSIs include the adoption of sustainable energy sources as alternatives to fossil fuels, efforts to reduce energy consumption (degrowth), Europe's gas dependency following the Ukraine war, and the controversial proposal by the European Commission to classify nuclear energy as green energy (Alderman & Pronczuk, 2022), at least until 2045. This decision has sparked significant controversy as it appears to overlook the serious issue of radioactive waste generated by nuclear plants or the profound safety risks, as evidenced by various accidents in nuclear power plants or the conflict in Ukraine, with battles occurring around Zaporiyia, Europe's largest nuclear plant. The contributions that education can make to sustainability are paramount (Scalabrino et al., 2022), and as a result, there are increasingly more educational proposals addressing this issue (Cruz-Lorite et al., 2023). The energy debate is ongoing and has become a social issue that requires solutions from all sectors.

- *Sustainable Mobility*

Sustainable mobility is an issue that involves energy, environmental, health, economic, technological, and other aspects. A relevant everyday problem could be the choice of a car (Moreno-Fontiveros et al., 2022) or the purchase of a bicycle (Cano-Iglesias, 2024). These problems offer rich opportunities for argumentation and decision-making as they are influenced by various factors, with advertising playing a prominent role (Grosick et al., 2013).

The choice of a bicycle is a common situation in our daily lives, given the wide array of options available on the market, each crafted from various materials and boasting unique features. Nowadays, increasing environmental awareness (Hadjichambis et al., 2020) and the urban expansion have led many people to opt for the bicycle as an eco-friendly mode of transportation (Parkin, 2008), in addition to its use for recreational purposes. Purchasing a bicycle involves several aspects that students must consider in their decision-making process, such as selecting a model tailored to their individual interests (type, intended use), the social, environmental, and global impact of its purchase and use, or the influence of advertising messages (product, price, promotion, brand, etc.) (Blanco & Forero, 2017). This issue provides an opportunity for students to engage in discussions supported by technological and chemical evidence, delving into their understanding of metallic material properties, mechanical attributes, and associated manufacturing processes (Cano-Iglesias, 2024).

1.5 Second Layer of the ENCIC-CT Model: Domains and Dimensions of the Critical Thinking

The ENCIC-CT model groups the dimensions of CT into three domains: knowledge, skills, and dispositions. As inferred from the theoretical framework, initially CT was primarily focused on skill development (Ennis, 1987; Facione, 1990; Halpern, 2006; Paul & Elder, 2005). Other proposals highlighted the significance of knowledge (Bailin, 2002) and dispositions (Facione, 1990; Dwyer et al., 2014). However, more recent proposals (Halpern & Danna, 2023; Jiménez-Aleixandre & Puig, 2022; Vieira & Tenreiro, 2016; Vila et al., 2023) recognize the importance of integrating all three mentioned domains.

The second layer of the model involves selecting the domains and dimensions of CT to be addressed in dealing with the selected everyday life problem. It is important to note that although these dimensions are presented separately, some may possess attributes from more than one domain due to potential overlap.

1.5.1 Knowledge Domain

A consensus characteristic of CT is its requirement for specific contextual knowledge to evaluate particular knowledge or beliefs (Anderman et al., 2012). Even in environments conducive to CT development, a lack of knowledge could compromise its progress. Specifically, we consider that CT development in the context of daily life problems or SSIs requires:

- *Scientific knowledge application and knowledge about science.* Students should be able to use/apply scientific knowledge (Blanco-López et al., 2015), being well-informed about the topics addressed, not limiting themselves to dominant discourses (Solbes & Torres, 2012), and understanding alternative perspectives (Bailin, 2002).
- *Vision of science/Epistemic knowledge about science.* Understood as a human activity with multiple relationships with technology, society, and the environment. There are numerous SSI that involve situations where scientific knowledge that has not yet been consolidated is demanded. These issues, situated on the current frontier of science, serve as valuable contexts for challenging the perception of "neutrality" and "objectivity" traditionally attributed to science (Khishfe, 2014). Kolstø (2001) suggests that these issues can help promote a more complex view of science, where cases of "settled science" coexist with cases of "science in progress".

1.5.2 Skills Domain

As previously mentioned, there are various proposals of skills that underpin CT (Facione, 1990; Jiménez-Aleixandre & Puig, 2022; Vieira & Tenreiro, 2016). In the case of addressing everyday life problems, we consider that students must deploy the skills proposed by Facione (1990) across the following five dimensions:

- *Comprehensive analysis of the problem.* The problems of daily life cannot be compartmentalized like scientific disciplines; instead, they necessitate a holistic approach, considering their complexity and taking into account scientific, technical, ethical, cultural, philosophical, social, environmental, economic, and other aspects. They demand a thoughtful analysis and personal decision-making, wherein scientific knowledge, epistemological beliefs, skills, attitudes, values, disposition for action, etc., play an important role (Wu & Tsai, 2011).

- *Critical analysis of information.* Students need to be able to assess the credibility of different sources of information, considering underlying interests (Blanco-López et al., 2015). Osborne and Pimentel (2023) argue "that the current science curricula are failing to educate students to be competent outsiders to science" (p. 1). Currently, we are confronted with an excess of information (infodemic), especially on social networks. Within this flood of data, there is a significant amount of false information pretending to be scientific. Therefore, it poses a challenge to scientific literacy to prepare students to evaluate the claims on social networks.
- *Argumentation.* The development of CT requires that students be able to construct solid arguments while questioning the validity of claims, rejecting evidence-lacking conclusions, and identifying argumentative fallacies (Jiménez-Aleixandre, 2010). In the realm of science, argumentation stands as an important scientific practice (Kuhn, 2019), which is further described later on.
- *Decision-making.* Involves making rational choices and informed judgments as integral components of the arguments used to solve problems. In decision-making within SSI contexts, factors related to personal preferences, beliefs, and environmental influences come into play (Muñetón et al., 2017). This is where CT becomes relevant (analyzing, reflecting, selecting information, etc.) to ensure the most appropriate decision for the presented problem. The use of SSIs offers benefits to students such as greater mastery and retention of the subject matter, enhanced ability to articulate positions, and higher-quality decision-making (Sadler & Zeidler, 2005).
- *Communicative skills*: Being able to communicate decisions using appropriate language, according to the context and goals or intentions, constitutes an important component of CT skills, in line with the skill of explanation as described by Facione (1990).

1.5.3 Dispositions Domain

Besides skills, Facione (1990) highlighted the importance of dispositions in CT development, a component also recognized by authors such as Halpern and Danna (2023), Jiménez-Aleixandre and Puig (2022) or Vieira and Tenreiro (2016). The ENCIC-CT model includes several dispositions and critical attitudes related to:

- *Personal autonomy/Metacognition/Reflection.* Students should be able to develop an independent opinion, maintaining an open mind towards divergent world-views, flexibility in considering alternatives and opinions, impartiality in evaluating reasoning, honesty in confronting their own predispositions, prejudices, stereotypes, or egocentric tendencies, prudence in postponing, making, or altering judgments, and willingness to reconsider and revise views, whether their own or others', where honest reflection suggests that change is justified (Facione, 1990). Moreover, they must recognize their own limitations (Osborne & Pimentel, 2023). This dimension encompasses personal autonomy and facilitates decision-making

(Eggert et al., 2013). Metacognition serves as a powerful tool across various situations to enhance CT, such as in solving scientific problems or evaluating scientific evidence and detecting cognitive biases, that is, in misinterpretations of reality (Vila et al., 2023).

- *Social engagement/Activism.* It is important to recognize that CT encompasses not only reflection but also action (see examples of scientists persecuted for their contributions in the work of Solbes & Torres, 2015). As we have pointed out, the CT development involves actively engagement in its practice, as it is intrinsically action-oriented (Facione, 1990; Jiménez-Aleixandre & Puig 2022). Therefore, we advocate that addressing relevant issues should lead to responsible decision-making, leading to tangible actions that contribute to problem-solving. Hodson (2003) proposed that to effectively address current social and environmental challenges, we need a generation of critically informed individuals with scientific and political knowledge who move into action rather than simply expressing opinions and discussing these issues. From this standpoint, the approach of socio-political activism is closely linked to CT, within the framework of a critical scientific literacy that becomes a driving force for socio-political action.
- *Emotional engagement.* CT can be driven or inhibited by emotions, as they influence how individuals approach decision-making and problem-solving. They provide a subjective perspective that complements rational analysis, thus they can either promote or hinder reflection, analysis, and decision-making (Elster, 1994; Kang & Keinonen, 2018). Furthermore, emotions can help establish an emotional connection with the problem, which may increase empathy and understanding across different perspectives. They can stimulate creativity and new ideas (Abdullah et al., 2022). Different researches suggest that positive emotions among learners are associated with engagement in challenging projects and creative problem solving, while negative emotions have been linked to poor academic performance and school attrition (Bellocchi, 2015; Pekrun & Linnenbrink-García, 2014).

The dimensions of CT presented are closely interconnected with each other, with all of them being equally important. Additionally, the order in which they appear in Fig. 1.1 does not imply a sequence in which they must be developed, nor does it imply addressing all dimensions simultaneously in every activity. For instance, we can utilize knowledge followed by critical analysis of information to argue about science or technology, leading to decision-making and ultimately communication. It is essential to emphasize that fostering CT in students is associated with progress across all dimensions and, most importantly, with their integration.

1.6 Third Layer of the ENCIC-CT Model: Scientific Practices

Science education has long benefited from robust research areas focusing on what are known as scientific practices (Next Generation Science Standards, 2013; National Research Council, 2012), which prominently include argumentation, inquiry, and modeling. These practices, in the context of everyday life problems, are suitable for promoting the development of CT as they involve acquiring and applying knowledge, utilizing skills related to analysis, explanation, inference, decision-making, etc., and in their development, important dispositions such as personal autonomy, emotional engagement, or activism are crucial. The development of scientific practices in science education is framed within an approach that views learning as a process of socialization within scientific culture (Driver et al., 2000), involving students' participation in the characteristic practices of the scientific community. This entails constructing scientific knowledge and understanding why it is constructed, examined, and evaluated in a particular way (Reiser et al., 2012).

1.6.1 Argumentation Scientific Practice

At this point, it is important to distinguish between the argumentation skill, integrated as a dimension of CT within the skill domain of the ENCIC-CT model, and the argumentation as scientific practice outlined in the third layer. The argumentation skill refers to students' general ability to construct effective arguments, while the scientific practice focuses on how this skill is applied in the context of scientific research.

Argumentation is indispensable in the construction of scientific knowledge, as it facilitates the exchange and examination of ideas and concerns. Through this process, more significant and comprehensible conclusions about phenomena are crafted. Argumentation is the expression of rational judgment in which the verbal articulation, in social contexts, reveals the reasons for accepting or refuting a viewpoint or set of ideas (Hahn & Oaksford, 2012). This skill enables individuals to move beyond their intuition to justify their ideas and conclusions to themselves and others (Mercier & Sperber, 2011).

Arguing about daily life problems involves informal reasoning processes. This type of reasoning is applied outside formal contexts, where problems may not be well-defined, premises may not be explicitly stated, and conclusions may not be delimited (Cruz-Lorite et al., 2023; Wu, 2013). Various authors indicate different types of informal reasoning according to the domains to which arguments are oriented (e.g., scientific-technological, economic, social, etc.) (Cano-Iglesias, 2024; Christenson et al., 2012; Ozturk & Yilmaz-Tuzun, 2017) or based on the considerations they rely on (rationalistic, emotional, or intuitive) (Sadler & Zeidler, 2005). The use and prevalence of these types of reasoning can be influenced by the problem being addressed or prior knowledge. For instance, Christenson et al. (2012) found that in SSIs related to global warming or nuclear energy, students used reasoning primarily based on attitudinal, affective, or value-based evidence.

On the other hand, different studies reveal that the main challenges students encounter in making reasoned decisions about daily life problems are associated with a lack of scientific knowledge to argue effectively (Cebrián-Robles et al., 2021b; Henderson et al., 2018; Rodríguez-Mora et al., 2022), or with the frequent use of beliefs or values in decision-making (von Winterfeldt, 2013). This fact is concerning in science education, which aims to teach making reasoned decisions based on scientific evidence (Bravo & Jiménez-Aleixandre, 2018), on social attitudes and values (Siribunnam et al., 2014), and on the use of justifications grounded in scientific knowledge.

Therefore, argumentation constitutes an important aspect for decision-making (Bravo & Jiménez-Aleixandre, 2018) because science education involves both learning science, which concerns epistemological content, and learning to do science, which considers it necessary to develop the inquiry skills inherent to science, including the development and evaluation of arguments (Duschl & Osborne, 2002). Doing science entails proposing and discussing ideas, evaluating alternatives, and choosing among different explanations (Jiménez-Aleixandre, 2010). Moreover, it requires the construction and critique of arguments (Osborne et al., 2016).

1.6.2 Inquiry Scientific Practice

Another important scientific practice is inquiry, also known in science education as Inquiry-Based Learning (IBL) or Inquiry-Based Science Education (IBSE). The term inquiry has various meanings in the educational context (Barrow, 2006). Sometimes, it is understood as a cognitive skill –the ability to inquire and investigate scientifically- that students need to develop. In other cases, it refers to the understanding of the methods used by scientists, that is, the nature of scientific inquiry. A third interpretation refers to various teaching strategies aimed at fostering students' inquiry skills, facilitating their understanding of scientific inquiry, and mastering scientific concepts.

A widely accepted definition is proposed by the National Research Council (2000), which describes inquiry as a multifaceted activity involving observation, question formulation, information gathering from various sources, as well as planning and designing investigations. Moreover, it entails reviewing ideas based on available experimental evidence, using tools to acquire, analyze, and interpret data, formulating responses, explanations, and predictions, and ultimately, communicating findings. The report "Science Education for Responsible Citizenship" (European Commission, 2015) defines it as:

> […] *A complex process of sense-making and constructing coherent conceptual models where students formulate questions, investigate to find answers, build new understandings,*

meanings and knowledge, communicate their learning to others and apply their learning productively in unfamiliar situations. (European Commission, 2015, p. 68).

There is a wide variety of methodological approaches to inquiry in the classroom (Rönnebeck et al., 2016). The 5E learning cycle approach by Bybee et al. (2006) is one of the most commonly used, organizing teaching into five stages: Engage, Explore, Explain, Elaborate, and Evaluate. In the National Research Council proposal (1996), these stages, understood as characteristics of inquiry-based teaching, are formulated as: (1) Raising science-oriented questions that allow active student participation, (2) gathering evidence by students to develop and evaluate their own explanations for the questions posed, (3) developing explanations to address the questions based on the evidence gathered, (4) evaluating the explanations, which may incorporate alternative explanations reflecting scientific understanding, and (5) communicating and justifying the proposed explanations.

Various authors modify these proposals in different ways.

Pedaste et al. (2015) propose a nonlinear model comprising five phases and nine interrelated sub-phases, connected through multiple pathways. This configuration represents the diversity of possible implementations in the classroom. Discussion, communication, and reflection are proposed as overarching elements of the model, largely determining the quality of the inquiry carried out by students. Bevins and Price's (2016) inquiry approach includes conceptual, procedural, epistemic, and personal aspects related to affective and motivational factors.

Drawing on an analysis of various inquiry proposals, Franco-Mariscal (2015a) developed an approach that identifies the inherent dimensions of this practice, aimed at fostering the development of scientific competencies through contextualized situations. According to this approach, scientific competency includes seven dimensions: research formulation, information management, research planning and design, data collection and processing, data analysis and concluding, results communication, and attitude or critical reflection and teamwork. This approach highlights some aspects that are often not sufficiently considered in science education, such as information management, results communication, critical reflection, and teamwork. These dimensions, in turn, would be linked to CT.

It is necessary to consider the role that inquiry can play in addressing everyday life problems. In broad terms, students as citizens interact with science based on information from the media, and increasingly, from social networks, regarding research, scientific advancements, or SSIs (Kolstø, 2001). Therefore, individuals are not required to gather data in the manner of scientists. Instead, to comprehend and engage with problems effectively, they must analyze the data presented to them within news and information sources. They need to consider the potential biases and limitations inherent in such sources, and based on this assessment, evaluate their credibility and make informed decisions. Nevertheless, in the context of daily life problems, it is possible to involve students in citizen inquiries (Moraga-Toledo et al., 2024). In these inquiries, students can assume the roles of concerned and critical citizens, collectively addressing SSIs that directly impact them (e.g. the nutritional habits of peers or families, research on recreational possibilities for children in the community, identification of sources of pollution near the school, etc.). They gather information, collect data from reality, propose solutions, and, if possible, implement or at least disseminate them, even on a small scale. For more complex issues, a comprehensive inquiry cycle could be undertaken, but without gathering data from reality, which would be replaced by data provided by scientists.

1.6.3 Modeling Scientific Practice

Modeling is considered an essential component of scientific activity (Justi & Gilbert, 2002), and teaching through models is a key area of research in both science education and CT (Clement & Rea-Ramírez, 2008; Gilbert & Justi, 2016). The development and use of models are considered significant scientific practices (National Research Council, 2012), and it is recognized that they should be part of students' foundation in basic science education (Oliva et al., 2015).

Modeling is understood by some authors as a necessary competence to construct and enhance models of physical objects, processes, or phenomena. However, providing a precise definition is challenging due to the fragmented nature of the theoretical frameworks that address it (Nicolaou & Constantinou, 2014). Nevertheless, it is possible to establish common characteristics (Justi & Gilbert, 2002). Modeling could be understood as an integrated set of knowledge, metaknowledge, skills, and epistemic values necessary for carrying out the task of modeling comprehensively. This encompasses not only learning the models of school science but also working with them, elaborating on them, revising them, as well as discussing and opining about them, understanding their value, usefulness, approximate and evolving nature, and their limitations (Oliva et al., 2015). Consequently, modeling represents a complex task that demands a wide range of skills. In addition to knowledge of the specific domain, it involves numerous strategies, skills, and certain epistemological commitments (Halloun, 2007; Harrison & Treagust, 2000; Justi & Gilbert, 2002; Prins et al., 2009), as well as attitudinal aspects such as the willingness to model (Ammoneit et al., 2024).

Modeling involves processes closely related to the components of the scientific research cycle: posing problems, formulating hypotheses, seeking information, developing new ideas and explanations, etc. This would also require tasks such as interpreting, manipulating, and expressing phenomena through a variety of signs, whether propositional or iconic (Perales, 2006). Furthermore, models are laden with values that define and justify the "rules of the game" of a scientific discipline. These values pertain to perceiving the rationality of models, recognizing their role in the development of hypotheses, explanations, and scientific arguments, as well as appreciating their utility and their approximate, limited, and evolving nature.

Modeling has been commonly used in science education within the context of scientific problems, and there has even been questioning about whether it is possible to integrate approaches from everyday life contexts with modeling in educational practice. This involves considering if the situations that enable modeling are the same as those that facilitate the application of knowledge in everyday contexts (Izquierdo, 2013). However, according to Ke et al. (2021), modeling serves as a valuable tool for analyzing SSIs, as it enables the display of relevant aspects of these matters through multiple models, aiding in understanding their complexity, exploring their causes and effects, and facilitating the proposal of potential solutions. According to these authors, multiple models contribute to improving the understanding of the phenomena of interest and can be mechanistic, systemic, mathematical, or socio-scientific models. Mechanistic models explain phenomena, allowing students to adjust their perception of reality. Systemic models describe variables and interactions to predict behaviors and properties. Mathematical models utilize empirical data to reach quantitative conclusions about causal relationships. Socio-scientific models consider social contexts to explain and predict outcomes, distinguishing themselves from purely scientific models.

In summary, the use of models and modeling helps students enhance their reasoning skills and epistemological beliefs about the nature and purpose of scientific models (Soulios & Psillos, 2016), and thus, CT.

1.7 Fourth Layer of the ENCIC-CT Model: Strategies for Developing Critical Thinking

Different research conducted by the ENCIC research group has highlighted some strategies with the potential to develop CT in students at various educational levels. Among them, gamification and role-playing, micro-debates, controversy mapping, and various technologies like augmented reality, as well as multimedia resources such as movies, TV series, and digital storytelling, stand out.

In initial teacher training, in addition to using these strategies by putting students in the role of science learners, the analysis or design of educational proposals is also employed, in which they adopt the role of teaching learners. This section describes these strategies.

1.7.1 Gamification and Role-Playing

Gamification entails applying game strategies and mechanics in non-gaming contexts, such as education, to enhance learning outcomes (Deterding et al., 2011). Among its advantages, it stands out for fostering motivation by presenting scientific knowledge in a "wrapper" (the game) that captures students' attention and encourages them to dedicate time to the proposed activities. The use of games promotes active, cooperative, and competitive learning, creativity, and imagination (Kapp, 2012). Additionally, they help students relate to their peers, thus working on dispositions such as emotions, self-control, or concentration on the task, aspects that enhance the classroom climate.

The use of educational games can contribute to developing skills and positive perceptions towards science, which will impact improving motivation regarding the learning of scientific content (Franco-Mariscal et al., 2016). The literature includes a wide variety of games: puzzles (Granath & Russell, 1999), cards (Martí & Rubio, 2014), word formation (Helser, 2003), board games (Girón & Franco-Mariscal, 2023), daily life contexts such as a house (Franco-Mariscal et al., 2018), a car (Franco-Mariscal, 2015b), or food (Franco-Mariscal, 2018), football competitions (Franco-Mariscal, 2014), role-playing (Franco-Mariscal et al., 2023), etc.

This book will focus on role-playing, a simulation game where each participant assumes a specific role in the context of a simulated issue (Cruz-Lorite et al., 2023), following certain rules and interacting with other participants. This strategy not only promotes students' CT but also allows teachers to design and implement a range of tasks to encourage its development. Additionally, these games offer an alternative approach with the potential to boost motivation and provide meaningful learning experiences (Franco-Mariscal et al., 2023). Therefore, an educational component is added to the gaming aspect.

The main feature of role-playing is their simulation of specific situations through gameplay and various characters, which stem from a real-life problem (although it may be more or less fictionalized). Thus, they incorporate a theatrical element that allows participants to draw on science and technology to develop their roles.

Role-playing games are highly suitable for addressing SSIs in the classroom (Simonneaux, 2001), as they start from an issue and a scenario involving various roles representing different perspectives. Their development requires establishing instructions and game rules both for the staging and for the subsequent synthesis and conclusions phase. In their design, it is also necessary to create a dossier with news and other documents related to the issue to assist students in preparing for the different roles.

This activity prioritizes the process over the content, with the active involvement and participation of students for its successful execution (Rashid & Qaisar, 2017). Despite the educational benefits offered by role-playing, their use in science classrooms remains limited (McSharry & Jones, 2000) due to their complexity, requiring substantial preparatory work by teachers and a strong focus on student engagement.

According to España-Ramos (2023), role-playing enable the achievement of these objectives:

- Identifying problems, searching and selecting information, and proposing solutions and actions.
- Bringing orality into the classroom (Simonneaux, 2001), as it requires dialogue among participants, both during the preparation of the game and in its staging.
- Enhancing the capacity to argue by connecting explanations with evidence. Engaging with different arguments can aid in clarifying one's own ideas.
- Facilitating the expression of different perspectives on an issue and the criteria on which they are based, as well as the possibility of experiencing changes in

opinion. This helps identify the criteria supporting one's own position and those of other positions (Simonneaux, 2008).

- Making decisions responsibly and based on a solid foundation (López-Fernández et al., 2021).
- Highlighting attitudes, values, and emotions regarding the problem presented (España-Ramos, 2008).
- Facilitating the comprehension of scientific and technical content pertinent to the issue, infusing this knowledge with significance by demonstrating its practical relevance in addressing real-life challenges, and engaging students in situations where they must persuade others with differing viewpoints using reasoned arguments.
- Developing collaborative work. Role-playing is a collective activity that demands interaction and collaboration, both in the preparation phase and during enactment. Therefore, it is important for roles to be prepared by teams of several students.

As evident, these objectives are closely intertwined with the dimensions of CT in the ENCIC-CT model, which are also associated with creative thinking and careful thinking (Lipman, 2003), as well as a range of key competences, particularly scientific competence (Blanco-López et al., 2015).

1.7.2 Micro-debates

Debate is considered a suitable activity for developing CT from everyday life problems, as it is based on reasoning, argumentation, decision-making, and communication (Fang et al., 2019; Simonneaux, 2001). The debate involves students evaluating and identifying data and information, reflecting on various opinions, defending their position in a reasoned manner, and making decisions based on quality evidence (Wang et al., 2017). All of this facilitates the presentation of different perspectives. Thus, debate becomes an effective strategy for promoting CT as its dimensions are involved in a large number of tasks. Additionally, debate enhances the acquisition of competences and knowledge, while fostering autonomy and participation, thereby contributing to comprehensive student education by developing knowledge and attitudes in a cross-cutting and interdisciplinary manner (Erduran & Jiménez-Aleixandre, 2007). Studies such as Simonneaux (2001) indicate that debates and role-playing promote changes in students' opinions, whereas these changes do not occur in other activities such as visits to exhibitions. Martini et al.'s study (2021) reported that approximately 50% of students changed their opinions after a class debate on nuclear energy.

Next, the Micro-debate strategy is described, a short-duration debate specifically designed to develop CT (Cano-Iglesias, 2024). This activity aims to instruct and enhance students in argumentation skills, critical analysis of information, and decision-making, either through active participation in a debate on an SSI or as an audience member. The participants in this activity are three students (presenter and

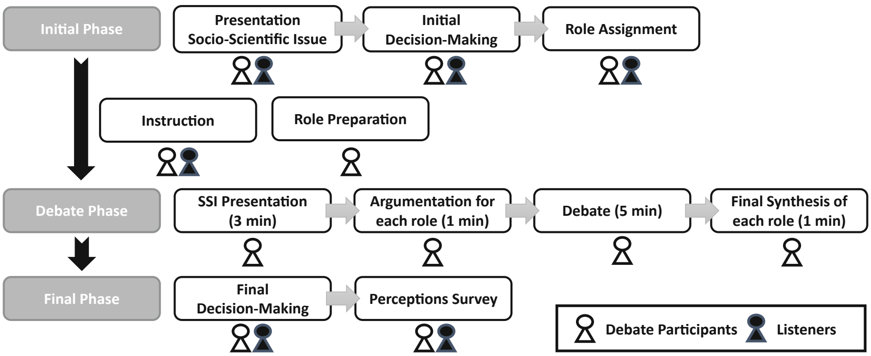

Fig. 1.2 Structure of the micro-debate activity

two debaters, one in favor and one against the issue) and the rest of the students who act as listeners. The Micro-debate activity is structured into three phases (Fig. 1.2).

- *Initial phase*: The SSI is presented through a question, and students are asked to make an initial reasoned decision without accessing information. In this phase, the presenter and debaters for and against the issue are assigned, with one week given for information gathering. All three roles must complete a form with at least five arguments to be used in the debate. In addition, debaters must include counterarguments for refutation, and the presenter must include a fake news item. Information can be sourced from any written or audiovisual medium with scientific rigor, and sources must be cited.

Between the initial phase and the debate phase, students receive a three-hour instruction in which different authors' understandings of CT and argumentation, critical analysis of information, and decision-making are presented. This training includes the ENCIC-CT model and the argumentation models of Toulmin (2003), Jiménez-Aleixandre's adaptation (2010), and Osborne et al.'s (2016) learning progression. Additionally, students engage in some straightforward tasks involving critical analysis of information and argumentation.

- *Debate phase*: Involves a three-minute presentation of the SSI by the presenter, supported by a digital slideshow. Following this, each debater is given an initial minute to present their arguments. Subsequently, there is a five-minute debate period, and finally, each debater has one minute for a concluding statement to persuade the audience of their position.
- *Final phase*: After the debate, all students, including the listeners, complete a questionnaire that includes a final decision-making aimed at assessing potential changes in stance resulting from the influence of the arguments presented during the debate. The questionnaire also investigates their perceptions of the activity's development.

Sufficient time should be allocated for this activity to ensure that all students have the opportunity to participate as debaters. Additionally, the teacher should assign each group of students a specific day for the activity and inform them of the assigned issue at least one week in advance.

1.7.3 Controversy Mapping

The Cartography of Controversy is a didactic methodology derived from Actor-Network Theory (Latour, 2007; Simonneaux, 2020; Venturini, 2010), providing to be an effective pedagogical approach for exploring and visualizing SSIs. Its capacity to unravel complex scenarios, such as the current model of meat production and consumption, addressing COVID-19, urban care, and controversies related to water use (España-Naveira et al., 2023), among others, makes it particularly valuable.

This methodology posits that understanding the formation of social phenomena requires more than examining individual actors; it is crucial to analyze the networks of actors that emerge in their various interactions (Venturini & Latour, 2009). In this context, participants in the controversy are termed actants, defined as any entity, whether human or not (including people, ideas, animals, objects, etc.), capable of influencing the controversy (Latour, 1996). Among the tools within the Cartography of Controversy, controversy mapping stands out as the most popular, capable of analyzing the complexity of SSIs (Christodoulou et al., 2021). These maps offer a visualization of controversy complexity by depicting actants (grouped according to their affinity into zones known as poles) and the favorable or unfavorable relationships established among them.

Cabello-Garrido et al. (2023) employed controversy mapping to explore and visualize the viewpoints and ideas of preservice science teachers regarding controversies associated with the meat production and consumption model. They then compared these initial controversy maps with those crafted by the research team, which were informed by a more detailed socio-epistemological analysis. The findings suggest that this approach is a useful way to engage students in addressing common questions, providing a framework for expanding their inquiry and understanding. It offers a platform from which they can develop their CT skills to take action for change.

Actants involved in an SSI can be introduced into the classroom through strategies that facilitate the simulation of arguments and counterarguments, such as role-play (España-Ramos, 2023). In these games, debate assumes a central position (Colucci-Gray & Gray, 2022), fostering the exploration of academic content by incorporating multiple viewpoints and argumentative perspectives (Simonneaux, 2008).

1.7.4 Augmented Reality

Different reports predict an increase in the use and integration of devices and applications in education as innovative quality factors. The Horizon Report (2021), compiled by experts globally to identify and describe emerging and disruptive technologies that could impact teaching, learning, and research, already highlighted in its ninth edition Mobile Learning, game-based learning, and augmented reality (AR) and virtual reality (Michael & Chen, 2006). In the educational settings, the use of digital technologies represents an innovation for both teachers and learners, enhancing educational standards. This transformation endeavors to reshape the curriculum, methodologies, and modes of knowledge dissemination, thereby offering new alternatives for teaching and learning.

This book focuses on the potential of AR, which is receiving considerable attention in education (Cortés et al., 2021; Geroimenko, 2020). AR enables the creation of mixed reality teaching and learning environments where real and virtual elements are combined within an interactive real-time setting (Moreno-Martínez & Franco-Mariscal, 2020).

AR in education involves integrating three-dimensional virtual elements or objects, generated by computers or additional digital information, into the learning context in the classroom, using devices such as mobile phones, tablets or AR glasses. Its objective is to complement, reinforce, enhance, amplify, and enrich learning experiences. By providing students with more stimuli, AR not only facilitates content learning but also cultivates students' creativity and sparks their curiosity to investigate and explore, thus empowering them to construct knowledge. This tool is highly motivating and holds immense potential for transforming learning (Abdullah et al., 2022).

AR applied to science education becomes an innovative, inclusive, formative, versatile, open, interactive, and dynamic methodology that enhances teaching and learning processes. Within this context, there is a wide range of AR tools available to create useful scenarios for teaching physics, chemistry, biology, and geology. By adding 3D objects and layers of virtual information, these tools enrich the information and stimuli provided by the surrounding physical environment. Moreover, these tools are not exclusive to the scientific field and allow for the creation of scenarios in other educational areas.

Some applications, such as AR Viewer or Sketchfab, enable the projection and integration of any three-dimensional model downloaded from 3D object galleries like 3D Warehouse or Archive 3D in various formats. Additionally, they support the inclusion of 3D objects previously crafted using graphic design and 3D modeling software such as 3DC or Tinkercad into real-world settings. Moreover, tools like Object Viewer Merge, Merge Things, Explorer Merge, or Mr. Body necessitate the printing and assembly of the Merge cube for visualizing AR scenarios. Noteworthy tools for science education encompass Unite AR, Hope, Augmented Class!, Zapworks, ARLOOPA, and Jigspace (Moreno-Martínez & Franco-Mariscal, 2023).

AR can promote the development of CT by providing practical experiences that encourage problem-solving, facilitate exploration and discovery, promote collaboration and communication, and teach users to critically evaluate information.

In relation to problem-solving, AR allows students to confront challenges within these environments to evaluate possible solutions and make decisions regarding complex issues. Similarly, AR offers opportunities for exploration and discovery in both virtual and real-world settings. Students can investigate and discover new concepts, relationships, and phenomena, which promotes CT by questioning, analyzing, and synthesizing information. Hence, AR, in addition to incorporating gamification-based learning, promotes discovery-based learning.

AR also facilitates collaboration among students by enabling interaction and cooperative work in shared virtual environments. This fosters CT by involving them in collaborative discussions, debates, and analysis to reach shared solutions and conclusions. Furthermore, AR environments empower students to interact with and access information within these scenarios, which they must analyze and evaluate for its quality and reliability. This promotes CT by teaching users to question and analyze information before accepting it as valid.

In summary, AR opens up new perspectives for fostering CT within science education, leveraging the broad opportunities afforded by the design and implementation of associated technologies. These technologies introduce novel methods of accessing and processing information. Likewise, AR proves highly advantageous for educators, facilitating content creation through a collaborative approach based on the principles of the makerspace philosophy (Vuorikari et al., 2019).

1.7.5 Multimedia Resources

Multimedia integrates various forms of media, including text, video, audio, graphics, and animation, into the learning environment, offering a potent new educational tool (Asthana, 2008). The utilization of multimedia resources with daily life problems could aid students in developing several thinking skills. Problem-based learning fosters CT and problem-solving abilities, empowering students to construct their knowledge actively (Hoffmann & Ritchie, 1997; Neo & Neo, 2001).

This book explores the potential of movies and television through excerpts from movies or series, which allow for the illustration of knowledge, stimulate debate, contextualize information, and offer insights into the scientific approach to various issues. Additionally, the exploration of digital storytelling is emphasized. Through students' creation and recording, contextualized within the resolution of scientific problems and complemented by music and sound effects, digital storytelling can effectively enhance CT. Moreover, it serves as a catalyst for promoting digital competence and nurturing creativity (Zagalaz, 2021).

1.7.5.1 Movies and Television Series

Science and technology permeate various modes of communication, including radio, television, news, magazines, music, and cinema (Gough, 1993). Particularly, cinema, television, and the internet are extensively utilized by the general population, owing to their broad accessibility, consumption, and influential capabilities (Government of Spain, 2021).

In general, science fiction movies depict issues related to science and technology that prompt viewers to question their feasibility in real life (Rose, 2003). Consequently, they represent promising strategies for facilitating the learning of scientific content portrayed in their scenes (Petit et al., 2021) and for fostering problem-solving challenges, thereby promoting CT. Furthermore, they offer a perspective on science that may diverge from reality (Dudo et al., 2011), which can contribute to its enhancement.

Several authors have explored the advantages of incorporating fictional resources such as films, TV programs, series, stories, or novels into science education (Fraknoi, 2002; Franco-Mariscal, 2021; Hamalosmanoglu et al., 2020; Koutnikova, 2017). These resources can facilitate the creation of mental images that correlate with underlying scientific theories, aid in comprehending abstract concepts, offer visual engagement, foster enjoyment, enhance the practical application of learned content, and stimulate interest in science, among other benefits (Allday, 2003; Barnett & Kafka, 2007).

The literature provides examples of how physics can be taught by presenting challenging situations of interest using sequences from TV series or movies. For instance, concepts of kinematics can be illustrated using scenes from Game of Thrones (Franco-Mariscal, 2021), principles of dynamics can be demonstrated through Prison Break (Franco-Mariscal, 2009), and optics can be explored using Peppa Pig (Franco-Mariscal, 2016). In the field of chemistry, Mojica (2019) demonstrated the use of a diverse range of video clips from movies, TV series, and YouTube to enhance the teaching and learning of this subject. Likewise, various biology-related topics are explored in films such as Jurassic Park, The Martian, GATTACA, Twenty Thousand Leagues Under the Seas, Planet of the Apes, Frankenstein, and The Walking Dead, all of which feature plots with biological origin (Barnett & Kafka, 2007). The work of Lawrence and Malinconico (2008) demonstrates how to teach geology using films such as Dante's Peak, Deep Impact, or The Day After Tomorrow. Ultimately, fiction often presents concepts, situations, or ideas related to real science that prompt viewers to contemplate and question whether these scenarios could occur in real life (Rose, 2003), thus helping to enhance CT.

1.7.5.2 Digital Storytelling

Digital storytelling is an effective strategy for developing CT, as it involves narrating a story in audio format to facilitate learning and instruction (Lambert, 2009; Xu et al., 2011). Instead of reading, listeners experience the narrative through audio playback devices. Digital storytelling often incorporates sound effects and music to enrich the listening experience and captivate the audience. Stories can be delivered by a single narrator or a collaborative team. This strategy enjoys popularity across various entertainment platforms, including radio programs, podcasts, mobile applications, and audio streaming services.

Narrative is a key feature of this multimedia resource (Negrete, 2003; Solomon, 2006) as it not only sparks students' interest in science by connecting it to everyday life problems (Franco-Mariscal, 2007), but also enhances scientific communication by conveying information in a precise, engaging, and imaginative manner. Additionally, it opens up opportunities for dramatization.

Digital storytelling can significantly enhance CT when students are actively involved in both designing and recording the story. By participating in the creation of digital stories, students are required to analyze, evaluate, and synthesize the scientific information they wish to convey, which fosters a deeper understanding of the science. To facilitate the design process, it is useful to highlight that scientific explanations can be structured similarly to traditional narratives. This means that the scientific content should feature protagonists (such as electrons or genes) who go through a sequence of events leading to an outcome (the phenomenon being studied) (Ogborn et al., 1996). This structural similarity not only aids in organizing the scientific information but also makes the learning experience more engaging and accessible for students.

Knowledge is present in students' understanding and application of scientific and technological concepts to develop the storyline of digital storytelling. Their vision of science is also reflected within this domain (Hadzigeorgiou, 2017).

Critical analysis of information stands out as a key skill, as students must analyze elements related to the plot, character development, conflicts, and scientific knowledge associated with the narrative to create a coherent and compelling scientific storyline. Additionally, during the process of searching for information for the story, students must assess the quality and reliability of their information sources.

The dispositions are also highly present in the creation and recording of digital storytelling, particularly science communication and emotional engagement. When crafting a digital storytelling piece about a scientific topic, students must effectively communicate their ideas through narration and audio production. This entails carefully selecting appropriate scientific terminology and considering the target audience. Creativity plays a vital role at this stage, allowing students to infuse their narratives with imaginative elements.

Emotions are expressed in various forms throughout the process. During recording, students may experience a range of feelings, including excitement, nervousness, satisfaction, frustration, or joy, driven by the creative challenges and character interpretations involved. Additionally, digital storytelling aims to evoke emotions in listeners, prompting students to skillfully convey these emotions through their narration, intonation, and vocal expression to elicit a heartfelt response from the audience. Moreover, personal autonomy/metacognition/reflection are essential aspects because, after completing the digital storytelling, students can reflect on their creation process, identify areas for improvement, and assess the effectiveness of their work in terms of how they communicate science and how it has impacted their peers.

Finally, digital storytelling is beneficial for developing CT in science education as it enables students to select, analyze, evaluate, synthesize, and communicate scientific information in a creative and meaningful way. Additionally, it requires students to establish connections between science and everyday life, and to reflect on the implications and applications of the knowledge gained.

Acknowledgements This work is part of the Spanish National Plan R+D+i Project entitled "Citizens with critical thinking: A challenge for teachers in science education", reference PID2019-105765GA-I00, funded by MCIN/AEI/10.13039/501100011033.

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