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Naturalizing Critical Thinking: Consequences for Education, Blueprint for Future Research in Cognitive Science

Elena Pasquinelli, Mathieu Farina, Audrey Bedel, Roberto Casati

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Naturalizing critical thinking. Naturalizing critical thinking. Consequences for education, blueprint for future research

Abstract. While very popular in public discourse about education, critical thinking education is still a work in progress. Two key conditions for successfully addressing critical thinking education are lacking: a) the availability of a clear, specific, and operational definition, and b) a deeper understanding of the natural cognitive bases of critical thinking. We therefore propose a theoretical framework for critical thinking education, grounded on a cognitive approach. Starting from a restrictive characterization of critical thinking—defined as the capacity of evaluating the epistemic quality of information, and of calibrating one’s confidence in relationship to it—we identify specific mechanisms subserving critical thinking that are present in early human development. We refer to these mechanisms as the natural building blocks of critical thinking. On this naturalistic ground, effective educational strategies can be envisaged that both harness the natural building blocks of critical thinking and help overcome its shortcomings.

Introduction

Critical thinking is the flavor of the month—invoked by teachers, parents, Ministries for Education, and international organizations alike as the necessary self-defense mechanism for fighting both misinformation and the fallacies of our own reasoning, especially in the light of recent trends in new media (Lazer et al. 2018; Pennycook, Fugelsang and Kohler 2015). Educators are called to arms to develop students' critical thinking skills. But how? Current evidence relative to critical thinking education does not provide clear indications about *what works*, or even whether existing approaches *actually work*. Psychologist Diane Halpern (2013) has summarized evidence that shows positive effects of critical thinking education with transfer to different contexts and content—especially if the intervention is specifically designed to promote such transfer (e.g. via repeated practice, use of examples of different students, and explicitation of general rules to be applied in a variety of contexts and contents). Similarly, a meta-analysis conducted by Abrami and colleagues (2015) found a global beneficial effect of educational interventions aimed at developing critical thinking, namely when these interventions include dialogue and exchange among students; concrete, situated, authentic problems to work on;

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suitable mentoring on the side of the teacher, and metacognitive interventions. This enthusiasm is nonetheless dampened by several considerations. First of all, while the development of “general capabilities” (such as “learning to learn”, socio-cognitive skills, comprehension, or critical thinking) is a largely sought-after objective in education, mastery of content knowledge remains a necessary condition for their deployment (Willingham 2007) and in fact the impact of educational interventions aimed at thinking skills is content-sensitive (according to Higgins et al. 2005 review of the literature). Secondly, caution about the efficacy of current critical thinking education strategies is motivated by the fact that what is referred to as “critical thinking education” represents in fact a vastly heterogeneous landscape (Lai 2011, Pasquinelli et al. 2020). In both the recent meta-analyses cited above, the authors report that the difficulty of their task lies in the huge differences between interventions, in terms of duration, intensity, content, targeted age, methods of measurement of their impact, and quality of the study. E.g., interventions range from imparting a few lessons aimed at equipping students with argumentative skills (Kuhn et al. 2013) to long-lasting, country-level interventions (Herrnstein et al. 1986). Long-term and distant transfer effects of critical thinking education are seldom assessed (one notable exception is represented by Fong, Kranz and Nisbett 1986). Moreover, the very objectives of critical thinking education are so diverse that they include actions aimed at reasoning skills, reading and textual interpretation, scientific skills, argumentative skills, and debiasing (Abrami et al. 2015; Higgins et al. 2005).

Why is the critical thinking education landscape so varied? A key fact here is that while definitions of critical thinking abound in the literature, they do not necessarily converge—at least not when operationalization in education is at stake (Bailin et al. 1999). Two major approaches—philosophical and psychological—dominate the scene of literature on critical thinking. Philosophical approaches focus on the goals of “good” thinking, by indicating a number of criteria and standards good thinking should be accountable to. They are thus described as “normative” (Lai 2011). Within the philosophical tradition, the concept of critical thinking is often so broadly canvassed as to encompass all the steps one can think of as necessary or at least useful for solving a problem correctly, stating an argument with clarity, and making the best choice, all things considered. Taxonomies of skills and dispositions related to critical thinking thus include tens of elements, ranging from the correct understanding of a question, to the evaluation of the contents of a piece of information, to that of clearly presenting arguments (Ennis 2011; Facione 1990). With such a broad definition it becomes difficult, if not

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impossible, to clearly indicate what critical thinking education should include—or exclude, as a matter of fact. A second difficulty with philosophical approaches is their insufficient cognitive realism: the proposed definitions are not only normative, but “ideal” in that they avoid addressing the question of the actual cognitive mechanisms that might constitute the backbone of the “ideal thinker”, at the point that “ideal” forms of thinking might not be achievable in the real world (Facione 1990).

Contrary to philosophical approaches, psychological approaches are considered to be descriptive, i.e., to identify critical thinking with a set of cognitive abilities that are functional to decision making and problem solving (Lai 2011, Halpern 2013). However, with few exceptions (such as Kuhn’s focus on metacognition and argumentation, e.g. Kuhn 1999), these cognitive abilities tend to be quite broad or unspecific—ranging from the capacity of controlling common biases, of activating algorithmic thinking (e.g. Stanovich and Stanovich 2010), to the deployment of metacognition, of dialogic abilities (e.g. Kuhn 1999), the use of strategies that allow for a better appreciation of evidence, or for a better assessment of likelihood and probability (e.g. Nisbett 2015), but also language analysis, argument analysis, more structured problem-solving, and even creative thinking (e.g. Halpern 2013)—so that it becomes difficult to tell critical thinking from thinking, reasoning, rationality—all cognitive notions that, on top of that, are themselves ill-defined. Quite like philosophers, psychologists often identify critical thinking with a form of explicit, voluntary, goal-directed cognitive activity. In so doing, they tend to pass over more basic underpinnings of critical thinking, which are interesting especially from a developmental and educational perspective.

In the light of the previous considerations, our assessment is that it is still too soon to give a definite answer to the question of the effectiveness of critical thinking education. Preliminary to any further inquiry, a specific, narrow, and operational definition of critical thinking should be provided. We are also persuaded of the importance, for critical thinking education, of identifying elementary cognitive functions that subserve the purpose of critical thinking. These functions should be as specific as possible to critical thinking (rather than, say, to the capability of drawing conclusions from premises, or of reading and interpreting texts) and it should be possible to identify them with clarity (as opposed to defining critical thinking by making reference to even more general cognitive functions, such as reasoning). We focus on the definition in the next section, and then we provide a review of candidate elementary mental processes that are necessary for critical thinking. We refer to

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these processes as to the “cognitive building blocks” of critical thinking. The operation of connecting critical thinking to its building blocks represents a form of naturalization, in that critical thinking can be at least partly explained in terms of these basic, natural mechanisms. Our primary objective is to help the conception of teaching strategies for the development of critical thinking, but we also hint at the fact that further efforts are required in terms of fundamental and translational research.

1. Defining “critical thinking”

We propose the following definition: critical thinking is *the capacity of assessing the epistemic quality of available information and—as a consequence of this assessment—of calibrating one’s confidence in order to act upon such information.*

This definition has several advantages, as compared to the existing (philosophical and psychological) approaches we have briefly reviewed above.

First, it is **specific**, in that it involves only one central concept: that of quality information. The concept of quality information is here used in an epistemological sense, meaning that we are justified to consider the information as correct—i.e., in accord with facts, consistent, or leading to successful predictions. What justifies us to judge that information is correct are a number of indicators of reliability of the content and of the source. These indicators include: i. the plausibility of the content (as judged by its coherence in respect to previous knowledge) and its relevance for the argument at stake, ii. the presence of corroborating evidence and the quality of such evidence (evidence that is gathered through rigorous methods, controlling for major biases, provides the stronger support), iii. the reliability of the source of information (e.g. the source itself has good chances of being correct, because of its privileged position in respect to the facts, or because of her expertise and knowledge), iv. the trustworthiness of the source (e.g. it can be excluded that the source has a strong motivation to manipulate or lie), and v. the convergence of multiple sources (and pieces of evidence). So, good information is information that has good chances of being correct, as far as we can judge in virtue of indicators, some of which are related to the content of the information, others to the source. There are certainly many difficulties in defining the nature of the epistemic quality of information, however this description captures some intuitions we have about good and bad quality information, and the use that should be done with it.

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The second advantage of our proposed definition is that it is **narrow**: it does not make reference to other, equally ill-defined, functions, such as reasoning or reason; it does not refer to overtly general capacities, such as the capacity of drawing inferences, and it does not include capacities that are preliminary or consequent or accessory to the evaluation itself, e.g., the capacity to read or of expressing oneself clearly.

Third, it is **operational**. Not only one immediately sees what kind of benefits the exercise of critical thinking should bring to us (i.e., making informed decisions, forming opinions that take into account the facts, and so on) but the definition has direct implications for the education and assessment of critical thinking skills. I.e., educating critical thinking is equivalent to providing knowledge and strategies for tooling the capacity of properly evaluating the (epistemic) quality of information, and for achieving better calibration of confidence; assessing this capacity and level of calibration in respect to new information represents a valid assessment of critical thinking.

Finally, our definition aspires to be sufficiently **consensual**, and we consider that it achieves this objective in that most of the current definitions of critical thinking include the idea of assessment in the light of criteria, and consider information evaluation as a defining trait of critical thinking (Lai 2011; Pasquinelli et al. 2020).

Based on the provided definition we can now ask the question: are there *elementary* cognitive mechanisms that serve the *specific* scope of *assessing* information and *calibrating* one’s confidence, so as to guide one’s decision? A review of the literature—briefly summarized below—shows that these mechanisms are in fact present since infancy and develop with age through maturation and social learning. Henceforth, we defend the view that humans are in a sense *natural-born critical thinkers* (at least in a naive manner) and that critical thinking is—in this sense—“natural”. I.e., critical thinking is not only a cultural construct (Proust and Fortier 2018) but builds on elementary cognitive precursors (building blocks). However—in order to fully benefit from the wealth of knowledge that is culturally produced and accumulated, and to deal appropriately with the transmission mechanisms through which information and knowledge circulate in contemporary contexts—critical thinkers will also need to acquire more advanced culture-specific tools, which—by nourishing and sharpening their natural core of building blocks—will make their skills more adapted to their social and cultural landscape.

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2. Natural-born critical thinkers

A vast tradition attributes to children the ability to distinguish between beliefs (representations that can be false) and reality starting from the age of 4- to 5-year-old (Wellmann, Cross and Watson 2001). Recently, this dogma has been shaken by studies showing that the sensitivity to false beliefs is present in an implicit, non-propositional way, already in 1,5- to 2-year-old children (Scott and Baillargeon 2017). One proposed solution to this apparent contradiction is to distinguish between implicit and explicit forms of attributing beliefs and other mental states to others (Apperly and Butterfill 2009). In this perspective, Mascaro and Morin (2015) studied the ability of children to deal with the notion of falsehood *before* the age of 5-year-old. Through an analysis of the literature and experiments, they have shown that the sensitivity to falsehood develops gradually and that 2-year-old children already have the capacity to consider an affirmation they hear by someone else as false. Children therefore demonstrate a form of early natural epistemology that allows them to assess the content of information as true or false. *But how is the truth-value of information evaluated?*

Sources, content and confidence assessment

An answer to the question of how children (more generally, humans) assess the quality of information is: by assessing the trustworthiness of their informants (Sperber et al. 2010; Harris and Corriveau 2011; Heyman 2008). For doing this, children (as well as adults) need to mobilize mechanisms for identifying the real intentions of their informants, and to assess the depth of their knowledge. Some of these mechanisms are known as “mind reading” or “Theory of Mind”. Mind reading capacities include the ability—cited above—of attributing false beliefs to the informer, without being limited to it: they are at stake each time one has to work out what others think, feel, want. As other capacities, mind reading seems to grow around a common, universal, inherited core, which successively matures and is shaped by cultural exposition and social learning (Heyes & Frith 2014). Other relevant mechanisms for assessing the quality of information are referred to as “epistemic vigilance” (Sperber et al. 2010) or “selective trust” (Harris and Corriveau 2011) and consist in relying on criteria and cues to assess the chances that informants might provide misleading or incorrect information (because of deception or lack of competence). E.g., 3-year-old children select their informants based on familiarity, since familiar adults are less likely to have motives to deceive them (Harris and Corriveau 2011; Koenig 2010), and preferentially

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take information from benevolent adults who have demonstrated moral behavior in the past or show respect for socio-moral norms (Vanderbilt, Liu and Heyman 2011; Doebel and Koenig 2013), while discarding informants who've been described as mean or as a liars by others (Mascaro and Sperber 2009) and are skeptical towards informants who make claims favorable to themselves (Mills and Keil 2005; Stengelin, Grueneisen and Tomasello 2018). As far as competence is concerned, children around 3-year-old preferentially follow the views of informants who demonstrate some form of general knowledge (Pasquini, Corriveau, Koenig and Harris 2007; Koenig and Harris 2005) or have direct, perceptual access to information (Nurmsoo and Robinson 2009). In word-learning tasks, the preference for learning from reliable informants can be quite precocious, with 14-month-old infants learning more new words from reliable informants than from unreliable ones (Brooker & Poulin-Dubois 2013). Children between 3- and 6-year-old also prefer informants who display signs of prestige, such as having followers or raising consensus (Corriveau, Fusaro and Harris 2009; Chen, Corriveau and Harris 2013). Experimental results indicate nonetheless that there is a developmental path in vigilance and selectiveness. First of all, selectiveness follows a period dominated by a precocious trusting bias (Jaswal, Croft, Setia and Cole 2010; Mills 2013; Vanderbilt, Liu and Heyman 2011). E.g., children younger than 2-year-old tend to choose the first informant who feeds them information, independently of her accuracy rate (Hermes, Rakoczy and Behne 2018), and this even if they are sensitive to verbal inaccuracy (Koenig and Echols 2003). Other experiments show that accuracy can overcome familiarity, but only for children older than 4-year-old (Corriveau and Harris 2009). Morality might be a more primitive or precocious value than epistemic correctness (3-month-old babies seem to possess a negativity bias towards “bad guys”: Hamlin, Wynn and Bloom 2010), but it is an open question at what point in development moral judgments are put in service of informants' selection (Mills and Keil 2005; Mascaro and Sperber 2009). Developmental trajectories are also found in relationship with the perceived reliability of self-reports (Heyman 2008). And in any event children might be more sensitive to cues that suggest deception or incompetence, that is, negative cues, than they are to positive ones (Corriveau, Meints and Harris 2008). Maturation is not the only factor involved in this development, previous experience playing its role in fostering skepticism (Heyman 2008; Stengelin, Grueneisen and Tomasello 2018). Finally, selectivity might be modulated by other cognitive functions, namely, metacognition; recent evidence suggests that children who rate low in self-confidence (as measured via implicit methods that we will illustrate below) seem to have

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more propensity to learn from unreliable sources than confident ones (thus following the “Copy when uncertain” rule) (Kuzyc, Grossman and Poulin-Dubois, 2020). More fundamental research is thus required in order to refine the milestones of this developmental path, while clarifying how different cues are played together in the choice of informants, and how different cognitive mechanisms can interact (Mills 2013).

The second answer to the question: «how do children evaluate the (potential) correctness of an assertion or opinion?», is: by referring to its content. Contents can be more or less coherent with children’s previous views, and children—as much as adults—show a preference for contents that mesh with their previous knowledge and thus sound more plausible to their ears (Sperber et al. 2010). School-aged children also demonstrate sensitivity to the quality of supporting evidence (Greene, Sandoval and Braten 2016). E.g., 6-year-old children can distinguish a test that is suitable for discriminating between competing hypotheses from a non-conclusive test (Sodian, Zaitchik and Carey 1991). However, it is still difficult even for 8- to 12-year-old children to generate by themselves discriminating, unconfounded experiments (Klahr, Fay and Dunbar, 1993; Zimmerman 2000, Morris et al. 2012) and 8- to 12-year-old children can still confound their initial beliefs with observation data when asked to justify an assertion (Schauble 1990). In fact, according to Kuhn (1989), strategies for coordinating theories and evidence do not develop *without* formal instruction.

How then can children, and adults, update their beliefs and change their mind? While it is largely documented that—when confronted with information that diverges from our opinions or with new information—we tend to prioritize our initial point of view (Mercier 2016), feeling uncertain about our knowledge makes us more prone to update previous beliefs (Mercier 2017; Morgan et al. 2015). This feeling of uncertainty is a crucial mechanism at play both in decision making and in learning, but, in order to serve us well, it must be well calibrated (Grimaldi, Lau and Basso 2015; Meyniel, Sigman and Mainen 2015). Metacognitive confidence is the aspect of metacognition that deals, implicitly and explicitly, with the evaluation of uncertainty (Grimaldi, Lau and Basso 2015) and metacognitive sensitivity is the term used to refer to the capacity of assessing correctly how uncertain (or certain) we should feel in regard to a decision, an opinion, or a representation of our own. Henceforth the empirical question: Do children spontaneously evaluate the confidence they have in their own judgments, and how accurate are their evaluations? Goupil and Kouider (2019) have recently synthesized current knowledge on

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metacognitive sensitivity (the ability to monitor the reliability of one’s own mental representations or decisions) in young children. Some experimental paradigms, e.g. including the possibility of opting out from a decision and seeking for help when uncertain, reveal that metacognitive sensitivity is present in pre-verbal children (Goupil, Romand-Monnier and Kouider 2016). Neurophysiological monitoring of brain activity provides converging evidence (Goupil & Kouider 2016). Other results show that in 5-year-old children performance and confidence correlate: children doubt themselves more when their answers are incorrect than when their answers are correct (Vo et al. 2014; this capacity was previously believed not to develop before 7-8 years old: Sodian et al. 2012). However, metacognitive sensitivity is not a matter of all or nothing. Even if metacognition can be considered as an adaptive, core human ability, aspects of its functioning are influenced by experience, culture (concepts, knowledge, practices) and personal history (Proust and Fortier 2018, Heyes et al. 2020). Metacognition evolves with age, can be influenced by other factors, such as general confidence—i.e., how confident one is in oneself (Rahnev et al. 2020)—and presents specific limits, even in adulthood (more on this below).

Intrinsic and extrinsic limits to critical thinking’s natural building blocks

Despite the optimism that sparks from the vision that critical thinking has natural foundations in our cognitive architecture, we must acknowledge that “natural critical thinking” is inherently limited, and that the building blocks that make critical thinking possible are not necessarily adapted to contemporary cultural contents nor to the informational landscape in which these contents travel. Understanding the limits of “natural critical thinking” is as important as identifying its strengths in order to devise methods of critical thinking education.

We have underlined the intrinsic limits of children’s naïve epistemology: the necessity of specific education in order to achieve a proper understanding of what counts as evidence, the existence of a developmental path (and the role of experience) for both assessing informants and for placing one’s confidence correctly and explicitly. These limits are not necessarily overcome with age and experiences in life. In complex or unusual situations—such as a broad social context, on-line communication or specialized information contents—the solutions available can miss the point, in that they are not adapted to the new information and cultural landscape (Sperber et al. 2010; Li, Van Vugt and Colarelli 2018). Several experts acknowledge that in the context of new media, the assessment of the trustworthiness of information, based on criteria such as consensus and expertise, has become

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more difficult to perform (Acerbi 2019; Tennie, Frith and Frith 2010). Another reason to worry is the presence of powerful attractors in our mind that make certain contents more salient and memorable and give them more chances of being reproduced (therefore of becoming mainstream and of circulating) in a way that can be independent from their truth (Acerbi 2019). While the search for truth is a culturally important norm, an evolutionary approach reveals a diversity of norms or objectives that are served by our evolved adaptations and each of these norms can prevail in a certain ecological context (Haselton, Nettle and Murray 2015).

In these situations, as our epistemic mechanisms are overwhelmed, we might expect our metacognitive assessment mechanisms to come to the rescue, by signaling that we are moving into an uncharted domain, and that we must remain modest. Anecdotal evidence is there to testify that our confidence can be misaligned in two ways: positive (overconfidence) and negative (underconfidence). Studies on confidence calibration confirm this observation. Examples of negative calibration are provided by implicit learning, where subjects begin to give correct answers before realizing that they have learned a new rule (Bechara et al.1997), and by the effects of stereotypes (e.g. “girls are bad at math”), where low self-confidence ratings can end up having negative impacts on performance (Shewach, Sackett and Quint 2019). Examples of excessively positive confidence estimation include optimistic biases (overconfidence towards one’s own representations and predictions or decisions), the explanatory depth illusion (overconfidence in the understanding of causal explanations: Rozenblit and Keil 2002), and the Dunning-Kruger effect (overconfidence, which shows in the case in which actual performances and knowledge are low: Ehrlinger et al. 2008). In specific circumstances, confidence calibration mechanisms can thus be overpowered or downsized. Several strands of research are currently dedicated to explore means for enhancing metacognitive skills and metacognitive sensitivity. The first via explicit instruction in cognitive and metacognitive strategies (how to plan, monitor and evaluate one’s learning: Quigley, Muijs, Stringer 2018), and the latter via computer-based training sessions during which the trainee performs perceptual tasks that imply perceptual decisions (Carpenter et al. 2019). This work is in progress and research should be pursued at fundamental and applied level.

Conclusion. The task of education

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In our analysis, critical thinking—the capacity of correctly calibrating one’s confidence in information, through a process of assessment of the epistemic quality of the same information—is built on a limited number of elementary cognitive mechanisms, with their strengths and their limits—which is why we refer to our approach as “naturalizing critical thinking”. However, culture, social learning and formal education play an essential role in the development of critical thinking skills throughout life.

In the first place, the evolution of the cultural and social context poses always new challenges to critical thinking. An exemplary case is represented by the evolution of media and communication technologies, which require specific criteria for assessing the reliability of new information sources and contents. Another example is represented by the passionate debates that—in many cultures—emerge at the crossroads between science and society, e.g. about climate change or vaccines. The growth and specialization of scientific knowledge makes it necessary to delegate one’s trust to reliable sources in order to make informed decisions, thus requiring adapted criteria for trusting rationally in this specific context. Since culture and the media information landscape evolve rather quickly, the toolbox for information assessment should do the same.

However, while individual and social learning provide opportunities for the development of critical thinking, they do not necessarily fulfill the goal of dispensing effective tools that are apt for answering contemporary needs in terms of information assessment. Formal education should thus endorse the objective of overcoming the limits of natural critical thinking and filling the gaps of informal learning by providing learners with the necessary set of tools: a. sophisticated criteria for identifying reliable sources in the information landscape; b. methodological criteria that are necessary for assessing the quality of evidence in favor or against assertions and opinions; c. content knowledge, against which individuals can more accurately evaluate the plausibility and coherence of assertions and opinions. Content knowledge potentially has a second positive effect on critical thinking in reducing metacognitive illusions, namely the Dunning-Kruger or: “the less you know, the more you overestimate your knowledge” effect. Providing factual and content-adapted knowledge is therefore crucial to critical thinking education – which cannot be reduced to a “general skills education”. It also emerges from our analysis that critical thinking education should include d. metacognitive interventions and scaffolds—e.g., external assessments, self-assessment tools—and other strategies for progressively nourishing explicit

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metacognition. A modicum of knowledge of their cognitive mechanisms and of their limits (another form of metacognition) might be useful in order to motivate learners in adopting the proposed advanced criteria.

But what are the chances that these tools, learned in class, will actually be *used* in daily life? This question reminds us of the interrogation we’ve left open in the introduction of the present paper, about *whether critical thinking can be actually taught*. It seems reasonable to entertain a relative optimism. Even though transfer is the pet peeve of learning, it certainly cannot be said that transfer never occurs. We find ourselves almost constantly confronted with new situations, which at the same time present similarities with those encountered in the past, but also, inevitably, many differences. If we could not transfer our learning and know-how, facing novelty would be impossible. Nonetheless, transfer of knowledge and skills has certain requirements and constraints, which should be duly taken into account in order to enhance the chances of success in critical thinking education (Perkins and Salomon 1989). Among the practical suggestions to facilitate transfer we can cite: i. the multiplication of concrete contexts (Bransford, Brown and Cocking 2000; Gick and Holyoak 1980), ii. relying on decontextualized situations (Salomon and Perkins 1988, 1989), iii. associating concrete examples and exercises with abstract principles (Salomon and Perkins 1988), iv. explaining and making rules explicit (Bransford, Brown and Cocking 2000; Minervino, Olguin and Trench 2016), v. inviting to produce examples (Minervino, Olguin and Trench 2016), vi. engaging in a lot of deliberate practice (Van Gelder 1995), vii. actively engaging metacognition (Bransford, Brown and Cocking 2000; Quigley, Muijs and Stringer 2018; Heyes et al. 2020), and viii. the recourse to argumentative strategies (Kuhn 2005; Trouche, Sander and Mercier. 2014). In the light of these considerations, we propose an approach to critical thinking education that blends embedded and explicit education. By embedding the strategies and criteria that help assess information in content-rich lessons in different disciplines—science, math, history, etc.—critical thinking education can exploit the variety of the curricular contents in order to find occasions for repetition and deliberate practice of criteria in different contexts and in relationship with different contents. The teacher will also draw links with examples of the same criteria applied in daily life, will ask students to produce their own examples and use them as often as possible, e.g. in argumentation. As we learn from studies on transfer that practice and repetition, even if done in various contexts, are not enough, we insist on the explicit formalization of the worked criteria, as well as on their

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verbal expression (e.g. at the end of the lesson, and at the beginning of a new lesson drawing on criteria that have been worked in past lessons). Explicit education also means for the teacher to structure his/her lessons with the objective of developing critical thinking in mind, and to assess the acquisition and use of relevant criteria by students. Our bet is that working on the same criteria and making them explicit during different lessons, in relationship with different contents will help students generalize them to new situations in daily life. Still, the role of content knowledge in both our epistemic vigilance and metacognitive sensitivity sets some limits to our hopes of transfer *without sufficient knowledge*, and implies that critical thinking is not a matter of all or nothing, but of degrees.

We want to address our final words to researchers in the domain of cognitive science. We would like to think that our paper will help encourage translational research in critical thinking education: from the understanding of its cognitive building blocks to the classroom, and back. Up to now, research on epistemic vigilance, epistemic cognition and metacognitive confidence has advanced mostly on separate tracks. As a consequence, fundamental knowledge—notably about the developmental path of critical thinking cognitive building blocks—is still lacking. The development of research on critical thinking education might help unify these tracks and obtain such knowledge.

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