Developing Critical Thinking: A Review of Past Efforts as a Framework for a New Approach for Childhood Learning

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Abstract

The purpose of this chapter is to establish a theoretically grounded and research-based framework to support the development of inquiry and critical thinking skills in children. As a first step in developing the framework, a review of the research literature on critical thinking and inquiry learning was conducted. Noteworthy efforts were found primarily in science domains, such as "The Adventures of Jasper Woodbury" and WISE (Web-based Inquiry Science Environment). Earlier attempts to use the Internet to promote inquiry and critical thinking involved such methodologies as *webquests* and computer-supported intentional learning environments (e.g., CSILE). One approach not involving modern technologies was the effort of Matthew Lipman to teach logic to young children (e.g., *Harry Stottlemeier's Discovery*). Given a growing emphasis on twenty-first-century skills (e.g., communication, collaboration, critical thinking, and creativity), and the evidence from prior work that it is possible to support inquiry learning and critical thinking with and without advanced technologies, an effort was made to see how curricula were changing to embrace those skills, especially at a middle school level when abstract reasoning and habits of mind are developing. We found very few examples of systemic or large-scale changes in curricula, although some organizations (e.g., The Critical Thinking Company) offer support materials. Very little empirical research has been done with young children or with the use of interactive technologies across multiple subject areas. Further, we found no efforts to create a sustained developmental path for the relevant skills and subskills, which are clearly emphasized in the literature on twenty-first-century skills, although rarely implemented on a sustained basic across multiple subjects and school years. As a consequence, we decided that it would be worthwhile to consolidate our findings in the form of a theoretically grounded and research-based framework that could be used to guide efforts to support the early development of inquiry and critical thinking skills in young children.

Keywords

Argumentation · Critical thinking · Developmental approach · Habits of mind · Inquiry learning · Logical reasoning

A number of developments are coming together that make it possible to seriously reform how young children are prepared for life. More specifically, there have been significant advances in learning theory, pedagogy, instructional research, educational technology, and workplace and lifelong learning skills. In spite of many promising efforts in those areas, little has changed in how young children are being educated with regard to inquiry and critical thinking. This chapter presents a framework intended to remedy that deficit. The framework is called DeFACTIL (Developmental Framework for Advancing Critical Thinking and Inquiry Learning). DeFACTIL is intended to help educators, instructional designers, school leaders, and educational software vendors start making substantial and sustained progress in properly preparing all children for a meaningful and productive life in the twenty-first century. In this chapter, the underlying theory, research, and technology advances supporting the framework are presented prior to describing the theory and ongoing research being conducted using the framework.

A great deal of what has been learned about learning theory and pedagogy is reflected in Bransford, Brown, and Cocking's (2000) *How People Learn*. The subtitle of that important volume indicates four relevant areas, namely, brain, mind, experience, and school. While the work that resulted in *How People Learn* is now almost 20 years old, the contents are as relevant now as when the work was first published. We now know more about the brain than was known 20 years ago, and there is a great deal more to know about the brain. Nonetheless, broad notions about how the brain functions and manages to organize, retrieve, and modify information remain intact. Neuroscientists are exploring what happens when a learner makes a mistake and how understanding develops in terms of mindsets (Schroder et al., 2017). The existence of a field called cognitive neuroscience reflects one important advance in terms of our understanding of learning and instruction – namely, the significance of interdisciplinarity beyond past interdisciplinary efforts that were typically limited to psychology, subject matter, and instructional design.

It has long been established that thinking undergoes progressive development (see, e.g., Inhelder & Piaget, 1958). One phase of a developmental process is emphasized at the beginning of *How People Learn* – namely, there often occurs a movement from speculation (what may first strike one as an obvious explanation) to further investigation and a consideration of evidence (i.e., a kind of early scientific reasoning). In short, sometimes there is a movement from inquiry to investigation and then to reasoning about evidence in support of a conclusion (i.e., argumentation).

That process depends on a great extent on two important related factors: (a) motivation and (b) experience. These two factors are logically and chronologically related. If a child is not curious and has no interest in understanding something, then no inquiry and investigation occur, and there is no experience that can contribute to the growth of understanding. However, if a child becomes curious and decides to devote some time and effort to understanding or exploring something, then the second factor of experience becomes highly relevant. This has been known for centuries and is well documented in John Dewey's (1938) *Experience and Education*. Dewey argues that understanding occurs through experience, and, as a consequence, effective learning requires interaction. In addition, Dewey argues for a holistic understanding of the individual learner and for a reasonably open approach that fosters experience and growth of understanding, which Dewey finds missing in many schools.

In many places, today's schools are not much different from those about which Dewey wrote in 1938. Some even take place in the same buildings. Teachers are prepared in much the same way, although one now finds many technologies in schools and in teacher preparation programs, along with a modest emphasis on the effective integration of technology into teaching and learning (see, e.g., Herring, Koehler, & Mishra, 2016).

What then is lacking in helping children develop skills believed to be important in the twenty-first century? The relevant skills include critical thinking along with communication, collaboration, and creativity (see http://www.p21.org/our-work/p21-framework). The focus hereafter is on critical thinking, which we define broadly as a developmental process that proceeds from experience (e.g., observation and interaction) to inquiry, investigation, examination of evidence, exploration of alternatives, argumentation, testing conclusions, rethinking assumptions, and reflecting on the entire process. Experience is ongoing throughout the process and proceeds from relatively simple experiences (such as observation) to more complex interactions (e.g., manipulation of an actual or virtual artifact). In short, critical thinking is not one thing, nor is it limited to one domain. Rather, critical thinking, broadly understood, includes the ability to communicate and collaborate effectively with others and to be creative as well as contemplative when challenges and difficulties arise (Spector, 2018). In short, schools still need transforming as Dewey argued long ago, from the old three Rs (reading, writing, and arithmetic) to the new three Rs (reexamining, reasoning, and reflecting) (Spector, 2018). Along the way to presenting the detailed framework, research and developments in the critical area of critical thinking are next described.

Critical Thinking

In this section, definitions of critical thinking are reviewed along with approaches and general interventions, interventions for children (our focus), and ways to assess the progressive development of inquiry and critical thinking skills.

Definitions

As this chapter is likely to be read by people with different backgrounds and from different countries, the first thing to clarify is that the word "critical" in the phrase "critical thinking" does not imply that one must criticize something to be thinking critically. Quite the contrary, the usage in this chapter involves the widely held view of psychologists, philosophers, and educators that what "critical" implies in "critical thinking" is an openness to and an exploration and analysis of alternative explanations of something puzzling, controversial, or otherwise not obvious or well understood (see, e.g., http://www.criticalthinking.org/pages/our-conception-of-critical-thinking/411). In *Critical Thinking in Psychology* (Sternberg, Roediger, & Halpern, 2007), critical thinking is roughly defined as a set of cognitive skills and strategies that are purposeful and goal directed that enable someone to be likely to achieve a desired outcome. Critical thinking, in that volume, involves effective problem-solving, the formulation and evaluation of inferences, and reflecting on the efficacy of those processes. Such a definition of critical thinking is broad and multifaceted and widely adopted by many other psychologists, philosophers, and educators. Ennis (1993) offered a simpler albeit compatible definition of critical thinking as reasonable reflective thinking that is focused on deciding what to believe or do. A broad definition of critical thinking addresses inquiry, exploration, explanation, communication, collaboration, creativity, metacognition, and self-reflection (i.e., broad coverage of the cognitive domain).

Two things are worth noting when accepting a broad cognitive definition to which we ascribe: (1) while a broad definition is widely accepted and shows up in the aforementioned twenty-first-century skills (see http://www.p21.org/our-work/p21-framework), it is barely visible in curricula, especially those provided for children; and (2) while the definition is primarily cognitive in nature addressing reasoning skills, an even broader view adds non-cognitive components to the ability to be an effective critical thinking (e.g., emotions, culture, habits, and values).

It is clear that a person may have the capacity to consider and evaluate alternative explanations, but may not do so as a result of being upset or moody. The alternatives one might consider may also be constrained by one's culture or values. A robust account of critical thinking ought to proceed with the belief that a person is more than a thinking machine. People have biases, habits, moods, and many other things that influence what they do and how they think. As Wittgenstein (1922) noted in the *Tractatus Logico-Philosophicus* at remark #6.43, the world of the happy person is not the same as that of the unhappy person. Moreover, the world waxes and wanes as a whole in part depending on one's moods and dispositions. This is similar to Quine and Ullian's (1978) notion in *The Web of Belief* that beliefs are interconnected, and when one belief is challenged there is an effect on other beliefs, implying some resistance to changing beliefs (i.e., critical thinking is inherently effortful as Halpern (2014) noted), while also implying that multiple beliefs tend to change together.

Like others, our framework embraces a primarily cognitive perspective of critical thinking, but we acknowledge that other factors often need to be taken into account, as many teachers realize on a daily basis.

If one adopts a cognitive orientation to critical thinking, one might then be inclined to identify relevant skills and subskills and devise strategies to promote critical thinking. Halpern (2014; see also https://louisville.edu/ideastoaction/-/files/featured/halpern/critical-thinking.pdf) presents the following high-level critical thinking skills: (1) verbal reasoning, (2) argument analysis, (3) hypothesis testing, (4) managing probability and uncertainty, and (5) decision-making and problem-solving. Each of these has associated subskills, and they generally build on each other; for example, to analyze an argument, one must already possess requisite verbal reasoning skills. Halpern's pedagogical model has four general parts: (a) explicitly teach the above critical thinking skills, (b) develop dispositions for effortful thinking and learning, (c) support trans-contextual transfer, and (d) make metacognitive monitoring overt and explicit. Such a model adds important skills – namely, metacognition and self-regulation. In addition, the model implicitly recognizes non-cognitive aspects of critical thinking, for example, in the form of perseverance. In addition, the model recognizes that critical thinking skills can and do apply across multiple contexts and subject domains, although many of the applications reviewed below do not address issues of far transfer. Ironically, while Marzano's (1998) research showed that teaching critical thinking skills in high school had a very large effect on learning outcomes, such teaching remains quite rare at the high school level and is barely visible at the middle school level.

Approaches and Interventions

Halpern's (2014) approach had already been mentioned. It involves a direct instructional approach (e.g., explicitly teach the skills and subskills) coupled with supportive formative feedback and an emphasis on a developmental approach. Her approach is largely consistent with Marzano's (1998) findings that suggest that teachers should identify and target the relevant knowledge and skills, identify and deploy specific instructional techniques appropriate for specific critical thinking goals, and address a variety of contexts and instructional goals.

Ennis (1989) classified critical thinking instructional interventions into four types: (a) general (e.g., stand-alone courses not specific to a subject domain), (b) infusion (specific to a subject domain with explicit critical thinking objectives in that domain), (c) immersion (domain specific but without explicit critical thinking objectives), and (d) mixed (a general approach combined with either an infusion or immersion approaches). These instructional intervention types go beyond what Halpern (2014) and Marzano (1998) recommended, which raises interesting research opportunities (e.g., determining which interventions work well with different learners and learning goals). Some philosophers who teach informal logic courses at college level might be inclined to the general approach as that approach focuses on logic and argumentation apart from specific subject matter content, although examples are required to illustrate principles. Others prefer to present the relevant skills and subskills in the context of a specific knowledge domain. Still others argue for an exploratory approach that immerses learners in complex problem-solving situations. Some have argued for what amounts to a combination of all types at some point in a learning progress (see, e.g., Milrad, Spector, & Davidsen, 2003).

A meta-analysis of 117 empirical studies conducted by Abrami et al. (2008) adopted Ennis' typology and found that these all types of interventions, in general, had a positive impact, with a mean effect size of 0.34. In addition, mixed instructional approaches that combine both content and critical thinking instruction significantly outperformed the general approach that is domain neutral. However, it should be noted that the Abrami meta-analysis did not focus on applications for children nor did it differentiate among domains studied (Lai 2011). Our conclusion going forward with a focus on children is that domain-specific examples are important but that the skills should be taught to young children across multiple domains so as to promote far transfer as suggested by Halpern (2014). Moreover, our notion is that one should resist the temptation to limit critical thinking skills to the sciences, which is where one finds many applications. Given the centrality of critical thinking in the context of twenty-first-century skills, our inclination is to target the development of those skills in children once their verbal reasoning skills have reached a basic level – at least the concrete operational level around age 7 (Inhelder & Piaget, 1958).

Information and communications technologies have evolved significantly since Ennis' (1989) taxonomy of critical thinking instructional intervention types. New technologies include interactive simulations, social networking, and augmented realities, for example. In addition, pedagogical approaches have also evolved, in part thanks to new technologies that allow learning from and with others in simulated realities and through games (Lee et al., 2016). Technologies, which can support a variety of critical thinking interventions, include digital journals, role-playing exercises, simulations, storytelling, collaborative and cooperative learning, inquiry-driven and problem-solving strategies, and more. Moreover, information and communications technologies are flexible and adaptable and can be combined. For example, Hee-Ok and Insook (2016) combined simulations with problem-based learning for improving the critical thinking skills of nurse-trainees. Research has shown that, particularly in higher education, using problem-solving and group learning opportunities tends to increase student involvement in learning (Bowen, 2000). Many critical thinking studies have been conducted in the medical field. In this field, approaches like simulation and role-play are more popular (e.g., Harris, Schuster, Kay, & Kibble, 2016; Hee-Ok & Insook, 2016; Kim, 2018; Mai, Pilcher, & Frommelt-Kuhle, 2018). A review conducted by Carvalho et al. (2017) found that problem-based learning approach is widely used in the field of nursing. The prevalence of critical thinking approaches in the medical domain is a natural extension of problem-based learning which originated in that field (Barrows & Tamblyn, 1980).

Generally, inquiry-driven approaches such as problem-solving and problem-based learning have been the most popular ones (Asyari, Al Muhdhar, Susilo, & Ibrohim, 2016; Hadi, Susantini, & Agustini, 2018; Jariyah, 2017; Kanirawati, 2017; Negrete, Hanna, & García, 2017; Reza, Ibrahim, & Rahayu, 2018; Ulger, 2018; Weaver, Samoshin, Lewis, & Gainer, 2016). A systematic review and metadata analysis of empirical studies on improving critical thinking through problem-based learning conducted by Kong, Qin, Zhou, Mou, and Gao (2014) suggested that, compared to traditional lectures, problem-based learning has a significant impact on enhancing critical thinking skills ($p < 0.001$). A similar result ($p < 0.01$) was observed by Gholami et al. (2016).

Technologies are increasingly being used to support critical thinking. Compared with traditional paper and pencil approaches, interactive simulations and other technologies are more effective in support of critical thinking (Eftekhari, Sotoudehnama, & Marandi, 2016). The technologies used for critical thinking promotion include simple or easy-to-use technologies and advanced technologies. Examples of simple or easy-to-use technologies are flow charts, diagrams, sketch notes, social media, online group discussions and assessments, and advanced technologies like concept maps, digital games, virtual realities, and more. Given the number and types of technologies, the issue is which one to select given a particular learner, learning goal, and learning situation. Concept mapping is popular for building up conceptual understanding. Technology-supported methods like games and gamification are popular to spark interest and to engage learners in problem-solving activities (Qian & Clark, 2016). A review by Qian and Clark (2016) suggested that game-based learning might be more effective than traditional class, because it could motivate learners and provide them with opportunities to explore and acquire new knowledge and skills. Many researchers explored using game-related methods to improve critical thinking across domains. For example, Hooshyar et al. (2016) applied an online game-based formative assessment in a flowchart-based tutoring system for encouraging critical thinking skills. The study suggested that the system can be more effective on facilitating problem-solving skills acquisition. Sipiyaruk, Gallagher, Hatzipanagos, and Reynolds (2017) demonstrated and evaluated a serious game used for improving critical thinking in undergraduate dental students; the overall feedback is positive. For enhancing journalism students' critical thinking, Huang and Yeh (2018) employed gamification too. The logic in such cases was elaborated by Spector (2016) as follows: (1) time-on-task, timely and informative feedback, and prior knowledge have been shown to enhance learning; (2) games can spark interest and encourage learners to spend more time on learning tasks as well as provide timely and informative feedback on decisions and actions; therefore, (3) when used appropriately, game-based approaches can improve thinking skills and learning outcomes.

Given the small sample on critical thinking applications mentioned above, it appears that most are with adult learners and focus on problem-solving, decision-making, and higher-order reasoning tasks. As a consequence of the theories promoted by psychologists, philosophers, and educators, researchers are still trying to develop a general model for the development of critical thinking skills (e.g., Darmawan, Zubaidah, Susilo, & Suwono, 2016; Duron, Limbach, & Waugh, 2006; Hadi et al., 2018; Jatmiko & Supardi, 2017; Setiawan, Malik, Suhandi, & Permanasari, 2018). According to Tiruneh, De Cock, Spector, Gu, and Elen (▶ Chap. 38, "Toward a Systematic and Model-Based Approach to Design Learning Environments for Critical Thinking"), systematic design of learning environments in accordance with theoretically sound and empirically valid instructional design principles can be an effective approach to stimulate the development of inquiry and critical thinking. Moreover, as Halpern (2014) recommended, a systematic and explicit critical thinking instruction has shown promise (Tiruneh, Gu, De Cock, & Elen, 2018).

Among the existing frameworks, there are a few that are theoretically sound and based on research (e.g., Duron et al., 2006). Duron and colleagues proposed a domain-neutral critical thinking framework with five steps: (1) determine learning objectives; (2) teach through questioning; (3) practice before assessing; (4) review, refine, and improve; and (5) provide feedback and assessment of learning. This framework is basically consistent with most instructional design models (see http://www.instructionaldesign.org/models/); it has been adopted and validated by Reed and Kromrey (2001) and Naber and Wyatt (2014) in support of teaching critical thinking skills. A domain neutral assessment framework was developed by Spector and Koszalka (2004) that involved eliciting how a problem-solving was thinking about a complex problem, transforming the response into an annotated graph and comparing that graph with others, including highly experienced problem-solvers.

Paul and Elder's (2006) critical thinking model focuses on three aspects of thinking (see http://louisville.edu/ideastoaction/about/criticalthinking/framework): (a) the elements of thought or reasoning, (b) intellectual standards, and (c) intellectual traits. These aspects are interrelated. The standards should be applied to the elements in order to develop intellectual traits. The intellectual standards include clarity, accuracy, depth, significance, fairness, precision, relevance, breadth, and logic. The traits include intellectual humility, intellectual perseverance, intellectual empathy, intellectual fairmindedness, intellectual courage, intellectual autonomy, intellectual integrity, and confidence in reason. The process of critical thinking becomes to first formulate a question or problem and then proceed using the elements of thought. Dwyer, Hogan, and Stewart (2014) proposed an integrative critical thinking framework for the twenty-first century that places memory, knowledge, and comprehension as foundational processes necessary for the successful application of critical thinking which involves analysis, evaluation, and inference. The Dwyer, Hogan, and Steward model also includes reflective judgment, as well as self-regulation and metacognition which were mentioned in an earlier section and which are part of the framework proposed herein.

Catchings (2015) developed a model known as Coaching for Critical Thinking Skill and Leadership Development(C/CTSLD). It starts with oral and written critical self-reflection on each of the critical thinking skill area (*interpretation*, *analysis*, *inference*, *evaluation*, *explanation*, *self-regulation*), followed by critical self-assessment and self-correction. It is a continuous process model, which results in the formation of *habits of mind*, which are also mentioned in Spector (2018). Tiruneh et al. (2018) demonstrated a systematic design of domain-specific instruction on near and far transfer of critical thinking skills. Tiruneh and colleagues used *The First Principles of Instruction* model (Merrill, 2013) to guide the intervention design. The design process includes three stages, (1) identifying critical thinking skills that needed to be targeted in a unit of instruction, (2) formulating the competencies for each of the targeted skills, and (3) designing and developing the instructional activities for each of the immersion- and infusion-based interventions (since the skills are typically applied in a specific domain and might be supported by either direct instruction or inquiry approaches, both of which require ongoing support and feedback.).

Critical Thinking Applications for Children

Similar to the critical thinking applications for college students, a slight difference is that most critical thinking applications promote children's critical thinking through simple strategies and easy-to-use technologies. For children, the most often adopted approaches are cooperative or collaborative learning, problem-solving, and inquiry-based-related approaches. Many studies were conducted by combining the above strategies with different methods and interventions such as interactive games; increasing attention has been given to game-based interventions or gamification. For example, McDonald (2017) employed a problem-solving game to improve secondary students' critical thinking skills. Lee et al. (2016) adopted a mobile learning game designed with cooperative reciprocity to encourage children's critical thinking skills. Mixed reality resources were used to lead the players through a realistic scenario, providing them with physical, cognitive, and collaborative challenges. Collaborative learning was believed to be more effective for encouraging critical thinking.

Few efforts have been done on the systematic interventions, though a lot of development has been done for the improvement of children's critical thinking, and some attempts were conducted with the intention of systematically developing critical thinking for high school adolescents (e.g., Fuad, Zubaidah, Mahanal, & Suarsini, 2017; Jatmiko & Supardi, 2017; Yazidah, Irawan, & Sulandra, 2017).

Based on the review of these efforts, most of the studies target senior or junior high school students typically in science subject areas; very few studies concern children's critical thinking in ages 7 and younger. However, there is a growing shift that people are tending to give more attention to children's critical thinking in their earlier developmental stages. For example, Sundararajan, Adesope, and Cavagnetto (2018) implemented Collaborative Concept Mapping in Kindergarten, which was supported by mentorship discussion and real-life scenarios.

In summary, current critical thinking studies mostly focus on higher education level, high school comes second, and very few studies were conducted for primary level (Zuriguel Pérez et al., 2015). More studies on children, especially at their earlier developmental stage, need to be conducted. Additionally, the experimental duration of interventions reported in various studies usually ranges from few weeks to few semesters. There are rare reports about longer-term effects of interventions on critical thinking (Carter, Creedy, & Sidebotham, 2016). No matter simply applying pedagogical strategies or integrating technologies for promoting critical thinking development, most of the interventions and approaches might easily fall into short-term effect.

Though numerous studies and explorations have been conducted, many questions remain unanswered on how to systematically develop learners' critical thinking. Clearly, there is a lack of systematic and enduring guide for developing critical thinking in children (Qian & Clark, 2016). Although critical thinking might be best initially developed in an educational setting, critical thinking utilization and development should not be restricted to such settings and can easily be extended to nonformal settings such as interactive games and puzzles used outside school and not linked to a specific subject area (Butler, Dwyer, Hogan, Franco, & Almeida, 2012; Dwyer et al., 2014; Ku & Ho, 2010).

Critical Thinking Assessment

Attention to critical thinking skills assessment has increased considerably since the 1990s. Multiple formats of critical thinking tests have been created, such as multiple-choice tests, short answer, essay, performance test, etc. (e.g. Ennis, 1993; Liu, Frankel, & Roohr, 2014). For standardized tests, examples are the most well-known tests like Watson-Glaser Critical Thinking Appraisal (WGCTA; Watson & Glaser, 1980), the Cornell Critical Thinking Test (CCTT; Ennis, Millman, & Tomko, 1985), the California Critical Thinking Skills Test (CCTST; Facione & Facione 2008), and the International Critical Thinking Essay Test (Paul & Elder, 2013). For non-standardized tests, examples are those measuring critical thinking in action (Daly, 2001; Jones, 2008; Morey, 2012) or measuring critical thinking through reading and writing (Shaaban, 2014). There are also some recent critical thinking assessments developed such as "a chemistry critical thinking test" (Danczak, Thompson, & Overton, 2017), Carter Assessment of Critical Thinking in Midwifery (CACTiM) – student version (Carter, Creedy, & Sidebotham, 2017), a graphic novel critical thinking assessment (Gelerstein, del Río, Nussbaum, Chiuminatto, & López, 2016), "Use Your Brainz" (Shute, Wang, Greiff, Zhao, & Moore, 2016), and the HEIghten™ critical thinking assessment (Liu, Mao, Frankel, & Xu, 2016). For details, see Table 1, which was *adapted from* Ennis (1993) and Liu et al. (2014).

The aforementioned critical thinking tests, especially the standardized tests such as WGCTA, CCTT, and CCTST, have been proven to be valid and implemented by many researchers (e.g., Liu et al., 2014). For avoiding unnecessary repetition, this review will focus on the newly developed critical thinking assessment tools. The latest innovative instruments, such as stealth assessment and game-based assessments as psychometric tests tools, have been examined in terms of validity and reliability in a variety of ways. For example, Shute et al. (2016) validated "Use Your Brainz," a game-based assessment for measuring problem-solving, by examining the performance on game with the results of two external measures. The results indicate that the problem-solving estimates derived from the game significantly correlated with both external measures (Raven, MircorDYN), Raven's ($r = 0.40$, $p < 0.01$) and MicroDYN ($r = 0.41$, $p < 0.01$). The Carter Assessment of Critical Thinking in Midwifery (CACTiM) – student version, a domain-specific critical thinking assessment tool, has a high content validity index score of 0.97 through expert review and good internal reliability with a Cronbach's alpha coefficient of 0.92, and its concurrent validity with the MSLQ subscale was 0.35 ($p < 0.001$) which indicates that it's a valid measure.

Recently, there has been a discourse about domain-general versus domain-specific examination of critical thinking (Liu et al., 2014; ▶ Chap. 38, "Toward a Systematic and Model-Based Approach to Design Learning Environments for Critical Thinking"). Many researchers (e.g., Carter, Creedy, & Sidebotham, 2015; Jacob, Duffield, & Jacob, 2017) called for domain-specific critical thinking assessment tools, especially those from specific areas such as nursing, pharmacy, etc. Carter et al. (2015) conducted a systematic review examining 34 studies of critical thinking in nursing and midwifery, which revealed that there was a need for domain-specific critical thinking assessment tools, as limited reliability reported using different tools in various studies and inconsistent reliability and validity was reported using the same measure in midwifery and nursing areas. However, domain-specific critical thinking assessment seems not to be well validated. Against such a background, few domain-specific critical thinking measures have been developed (e.g., Carter et al., 2017; James, Hartzler, & Chen, 2016;

Table 1 Existing critical thinking assessments

Domain	Instruments	Authors	Populations	Format	Delivery	Facets
Domain-specific	A chemistry critical thinking test	Danczak et al. (2017)	College students	Multiple-choice (MC)	Online or paper/pencil	Making assumptions, assessing arguments, making hypotheses, testing hypotheses, and drawing conclusions
Domain-specific	Carter Assessment of Critical Thinking in Midwifery (CACTiM) – student version	Carter et al. (2017)	College students	Selected-response (Likert scale)	Online or paper/pencil	Seek information, reflect on practice, facilitate shared decision-making, and evaluate practice
Domain-specific	Critical Thinking in Midwifery (Reflection) (CACTiM-Reflection)	Carter et al. (2017)	College students	Reflective writing	Paper/pencil	Analyze context, reasoned inquiry, and self-evaluation
Domain-general	A graphic novel critical thinking assessment	Gelerstein et al. (2016)	Primary students, grades 3–4	Scenarios and open-ended	Paper/pencil	Interpretation, analysis, evaluation, inference, and reasoning or explanation
Domain-general	"Use Your Brainz"	Shute et al. (2016)	Middle school students	Bayes nets	Digital game	Problem-solving skills (a) analyzing givens and constraints, (b) planning a solution pathway, (c) using tools and resources effectively and efficiently, and (d) monitoring and evaluating progress
Domain-general	The HEIghten™ critical thinking assessment	The Educational Testing Service (ETS; Liu et al., 2014)	College students	Selected-response	Online	Analytical skills (a) analyzing argument structure and (b) evaluating argument structure) and synthetic skills (a) developing valid (structurally strong) or sound (evidentially strong) arguments and (b)demonstrating understanding of the implications of information and argumentation

Domain-specific	Progressive, 3-item rubrics for measuring critical thinking	James et al. (2016)	College students	Assignments, Likert-type	Online or paper/pencil	Considering context, problem-solving, and innovative thinking
Domain-specific	California Measure of Mental Motivation (CM3)	Insight assessment (2013)	Secondary school students	Selected-response	Online or paper/pencil	Learning orientation, problem-solving, cognitive integrity, scholarly rigor and technological orientation
Domain-general	Collegiate Learning Assessment+ (CLA+)	Zahner (2013)	College students	Performance task and MC	Online	The CLA+ PTs measure higher-order skills including analysis and problem-solving, writing effectiveness, writing mechanics. The MC items assess scientific and quantitative reasoning, critical reading and evaluation, critiquing an argument
Domain-general	The Critical Thinking VALUE Rubrics	Finley (2019)	College students	Assignments, Likert-type	Paper/pencil	Explanation of issues, evidence, influence of context and assumptions, student's position, and conclusion/related outcomes
Domain-general	Collegiate Assessment of Academic Proficiency (CAAP) Critical Thinking	CAAP Program Management (2011–2012)	College students	MC	Paper/pencil	Argument analysis, argument evaluation, and argument extension
Domain-general	Halpern Critical Thinking Assessment (HCTA)	Halpern (2010)	College students	Forced choice and open-ended	Computer based	(a) Verbal reasoning skills, (b) argument analysis skills, (c) skills in thinking as hypothesis testing, (d) using likelihood and uncertainty, and (e) decision-making and problem-solving skills

(continued)

Table 1 (continued)

Domain	Instruments	Authors	Populations	Format	Delivery	Facets
Domain-general	The CAT© instrument	Stein, Haynes, Redding, Ennis, and Cecil (2007)	College students	Essay	Online	Inference, interpretation, identification argument, connection, hypothesis, conclusions, problem-solving, analyzing and integration, communication
Domain-general	Educate Insight Reasoning Skills Grades 3–5 (https://www.insightassessment.com/Products)	Insight Assessment (n.d.)	Grades 3–5	MC	Online or paper/pencil	Analysis, evaluation, inference, induction, and deduction
Domain-general	The International Critical Thinking Basic Concepts and Understandings Test	Elder, Paul, and Cosgrove (2007)	Grade 10 and above	MC	Online	The necessary understandings for thinking critically

▶ Chap.38, "Toward a Systematic and Model-Based Approach to Design Learning Environments for Critical Thinking"). Lately, such a debate is ending with the following growing consensus that (a) no matter in which domain, a set of critical thinking that can be taught and learned across domains exists; (b) specific subject knowledge is a necessary condition to competently engage in critical thinking tasks. Currently, the main concern over critical thinking is shifting from this debate to a focus on development of both domain-general and domain-specific critical thinking skills (▶ Chap.38, "Toward a Systematic and Model-Based Approach to Design Learning Environments for Critical Thinking").

Most of the existing measurements used multiple-choice type, with Likert type or essay type questions, but those single measures of critical thinking are not comprehensive (Ennis, 1993; Halpern, 2010; Ku, 2009; Norris, 2003). What are needed are more sophisticated measures of more complex and multifaceted critical thinking (Liu et al., 2014, 2016). In reference to lack of comprehensiveness, Ku (2009) believed that adopting multi-response critical thinking measures can solve such a problem. Besides, the researcher believes a comprehensive critical thinking assessment tool should include the measurement of dispositional and cognitive components. However, critical thinking is multidimensional and complex; it involves specific skills and abilities such as reasoning, interpretation, analyzing, decision-making, and problem-solving. Measuring critical thinking comprehensively is not an easy job (Bensley et al., 2016; Ku, 2009). Simply using multi-responses may not be able to solve the problems and challenges that critical thinking assessments face including low test-taking motivation and test anxiety (Bensley et al., 2016). Test-taking motivation is significantly correlated with the scores of critical thinking test (Hawthorne, Bol, Pribesh, & Suh, 2015; Liu et al., 2016; Liu, Bridgeman, & Adler, 2012; Nair & Stamler, 2013). Many researchers (e.g., Bensley et al., 2016; Hawthorne et al., 2015; Liu et al., 2016) ask for more attention to relevant research on low-test motivation, especially for the low-stakes tests. If there are no incentives or personalized consequences, test-takers may not perform to their best, and the results might not represent valid indicators of the impact of interventions. Regarding this issue, Hawthorne et al. (2015) suggested that including personalized motivational prompts in critical thinking assessments can increase test-takers' performance. Bensley et al. (2016) tried to apply an instructional intervention for raising test-taking motivation, though the results showed that the intervention had no significant effect on enhancing test-taking motivation.

Emerging Assessment Technologies

Along with the emergence of technologies, technologies are believed to support assessments, especially for the ones that cannot be assessed by a conventional testing format. On the other hand, technologies can bring opportunities to enable assessment tools to be more effective and engaging (U.S. Department of Education, 2010). Rosen and Tager (2013) utilized an evidence-centered concept map (EECCM) as a thinking tool to optimize students' critical thinking processes: the critical thinking scores indicated that students who were assessed in EECCM outperformed students who were assessed in notepad. Formative assessment can be enhanced by technologies (Spector 2016). Lookadoo et al. (2017) suggested that using instructional video games either for formative assessment or for summative assessment can increase learning. The advanced assessment technologies are playing an increasingly important role in psychometric testing such as problem-solving and social emotion skills (Bhagat & Spector, 2017; DeRosier & Thomas, 2018). Gameplay is believed to reduce test anxiety, which in turn decreases assessment bias and subjectivity (Mavridis & Tsiatsos, 2017; Kiili & Ketamo, 2018; Isbister, Karlesky, Frye, & Rao, 2012); it provides a more positive test-taking experience and externally helps test-takers achieve a better performance (Lehman, Hebert, Jackson, & Grace, 2017; Mavridis & Tsiatsos, 2017; Sundre & Wise, 2003). According to Shute (2011), assessment works best when it is stealthy or embedded into the game, because the test-takers can remain engaged during gameplaying. Hooshyar et al. (2016) developed an online game-based formative assessment named “tic-tac-toe quiz” for single players (TRIS-Q-SP); they integrate TRIS-Q-SP in an intelligent tutoring system (ITS) to teach computer programming. The results show that it can improve students’ problem-solving skills. In another study, another game-based assessment for measuring problem-solving skills, named “Use Your Brainz,” was developed by Shute et al. (2016); it embeds stealth assessment in the gaming environment. Validity was established by comparing the performance on game with two external problem-solving measures. In the field of psychometrics, some other skills and abilities are measured through game-based assessment. For example, DeRosier and Thomas (2018) developed a game-based assessment for measuring social emotion skills (SE), called “zoo U,” which also can engage children in social problem-solving and critical thinking for performance-based assessment of SE skills. Its acceptability, usability, and feasibility were established in elementary school settings (Craig, Brown, Upright, & DeRosier, 2016).

In sum, the emerging technologies such as game-based assessment and stealth assessment provide promising methods of measuring critical thinking, also an opportunity for realizing a comprehensive, more effective test for critical thinking while addressing the problems that low-stakes tests are facing – such as low test-taking motivation and test anxiety. Additionally, most of the current critical thinking assessment studies focus on college level, and few critical thinking assessments are created for young children, although there is already a consensus that the early stage of childhood (i.e., the first years of primary school) is believed to be the precious period for developing critical thinking for twenty-first-century roles (Ennis, 1987). Currently, artificial intelligence (AI) has grown very well, but as to human intelligence (HI), there is little progress. For the sake of future generation, we argue that more attention should be given to children’s critical thinking development. A more comprehensive, valid, and effective critical thinking measurement for children is demanding.

For ensuring a continuous process of critical thinking development and its mastery, apart from systematic and operational interventions, the interventions should be inserted with some incentives that motivate students to be self-determined learning in improving their critical thinking skills. Moreover, those interventions should play a role as a scaffold of fostering learners' critical thinking; the ultimate purpose should be developing critical thinking as an inner part of human beings.

Summary of Findings

While this review of the research on critical thinking for children has not been completely exhaustive, it has covered developments in the area of cognitive science, curricula, instructional technology, and learning psychology. Our findings suggest that few efforts have been sustained aimed at developing inquiry and critical thinking skills in young children although one can easily find many short books, instructional applications, and learning resources. Most efforts have occurred in the domains of science, technology, engineering, and mathematics (STEM) with older children and young adults. Most of those efforts have been domain specific with a few efforts aimed at developing skills that cut across domains (e.g., those in logic, mathematics, and philosophy).

The lack of emphasis on the development of inquiry and critical thinking skills in young children in spite of emphasis at the national and international level suggests that there is a need for more research and development. The goal should be aimed at developing large-scale and sustained efforts if one expects progress to occur. In order to achieve large-scale and sustained efforts, there is a need for a reliable, theoretically and empirically grounded design and development framework which is presented next.

A Framework for Developing Critical Thinking

Table 2 below represents the core notions of the framework (Spector, 2018).

Table 2 Principles and associated competencies

Development phase/principles	Example competencies
1. Inquiry, observation, and puzzlement	Observe oddities; answer questions about oddities; ask about oddities
2. Exploration and hypothesis formation	Identify relevant factors; create an initial explanation
3. Evidence and hypothesis testing	Find relevant factors; predict an outcome of a test
4. Influence and causality	Explain correlation, probability, and causality
5. Explanation, communication, and collaboration	Explain likely causes and reasoning to others
6. Coherence and consistency	Identify inconsistencies, contradictions, and tautologies
7. Assumptions and biases	Recognize unstated assumptions; identify possible biases
8. Perspectives and alternatives	Identify and consider multiple points of view
9. Reflection, refinement, and self-regulation	Monitor one's own progress; adjust to new evidence or a different perspective

This framework was first presented in a talking paper at the 2018 International Big History Conference (Spector, 2018) and includes the following nine principles:

Inquiry, Observation, and Puzzlement. A critical thinker is basically inquisitive. A critical thinking process often starts with the individual observing and identifying something puzzling or unknown or perhaps simply something about which that person would like to learn more; that point of departure can be put into an argumentation framework in a subsequent phase as the conclusion of an argument to be established based on evidence and explanation. An overarching goal of helping learners develop their critical thinking skills is to enable them to form productive inquiry and reasoning habits and perhaps learn to love learning about many different kinds of things. For example, suppose the point of departure involves a compass that uses a magnet to indicate the general direction of north. A person might wonder why a compass always seems to point north – this question could come from the learner without any guidance or it could be posed to the learner as a challenge.

Exploration and Hypothesis Formation. A critical thinker is an investigator; once a point of inquiry is identified, an exploration can be undertaken to resolve the initial question or solve the initial puzzle or problem. An exploration can result in forming a hypothesis to resolve the question. The transition from #1 (inquiry – asking) to #2 is the difference between *asking* a question and *having* a question. To have a question means that one is willing to investigate or explore – that is to say, to invest time and effort in finding an answer or solving the puzzle or problem. Aspects of exploration include identifying the kind of thing that is the target or focus and then identifying related things in that category or in a related category. Exploration involves finding out more about the target in question. With regard to the compass example, the exploration can easily extend to what it is that is pointing north. The person may or may not know that it is a piece of metal that is magnetized. Additional questions can be posed either by the learner or the person or system prompting or supporting the learner. Sample questions might include the following: (a) Which kinds of things typically have magnetic properties? (b) Are all metals naturally magnetic? (c) If one breaks a magnetic strip in half, will the two halves behave like the original piece, with each half still point north if suspended as in a compass? (d) Why do suspended magnets point north? (e) When did people discover that a compass could be used for navigation? (f) What happens when two magnetic strips are brought close together? (g) Does a compass always point north? (h) Suppose you are standing somewhere on earth and you are holding a compass, and it indicates that you are facing south (opposite of north); suppose you then make a quarter turn to your right and the compass still indicates you are facing south; you again make a quarter turn to your right but the compass still indicates you are facing south; you make still another quarter turn to your right and find the compass still showing that you are facing south. Where on earth are you standing?

Evidence and Hypothesis Testing. A critical thinker seeks evidence and follows where the evidence leads. Suppose the learner has indicated a desire to learn more about ocean tides. An exploration has led the learner to find out that the tides seem to be more dramatic during a full moon. The learner might want to gather evidence to support the notion of a strong high or low tide occurring during a full moon. What kinds of evidence might be relevant? What evidence might the learner find to warrant a modification of the hypothesis of a full moon being correlated with very high or low tides? The learner could be guided to gather evidence about the days corresponding to phases of the moon and also times and dates about high and low tides. Based on that evidence, the learner could be asked to formulate a new or refined hypothesis about the moon's influence on the tides. Two kinds of evidence might be relevant to supporting learners' development of a new or refined hypothesis. One concerns the time between high and low tides (about 12 h and 25 min). A second one concerns when high and low tides are happening on the opposite side of the earth.

Influence and Causality. A critical thinker can distinguish coincidence, correlation, and causality. Suppose the learner is shown or discovers an exceptionally high tide when there is a new moon. As it happens, on that particular night, in addition to an exceptionally high tide, there is also an observable meteor shower. The learner might be asked if that is a coincidence or if it is related to the high tide (which is not likely). Then the learner might be shown tables of when that meteor shower appears and the phases of the moon at those dates and times. Next, the learner might be shown the tables of high tides and moon location with high tides occurring about 12 h and 25 min apart on a regular basis. The learner could be asked if there is a correlation between tides and moon location with some explanation about causality being a much stronger claim than simple correlation. Simpler examples might be appropriate for younger learners.

Explanation, Communication, and Collaboration. A critical thinker is able to explain how evidence supports a conclusion or resolves a problem or puzzle. Another way to characterize this principle is in terms of argumentation – namely, the ability to identify, construct, and explain valid and sound arguments (see the critical reasoning framework depicted below that is organized around an argument as typically treated in logic – namely, as premises offered in support of a conclusion as explored in previous principles). Once a learner is able to formulate a hypothesis and gather evidence, often accomplished in collaboration with learning peers, it is then necessary to determine the adequacy of the evidence and explain how specific evidence support a particular conclusion.

Coherence and Consistency. A critical thinker's explanations are coherent and free from inconsistencies. This principle expands the notion of argumentation and the adequacy of evidence by focusing on desirable characteristics of a strong argument – namely, coherence – as well as undesirable characteristics of many arguments, namely, inconsistency. From a developmental perspective, it seems reasonable to first develop the ability to identify and distinguish inconsistent arguments from those that are coherent prior to expecting a young learner to develop the skill of formulating coherent patterns of reasoning.

Assumptions and Biases. A critical thinker is able to identify unstated assumptions and examine those assumptions including that person's own assumptions.

A deeper step in the development of critical reasoning involves the ability to recognize bias which often requires the ability to make explicit unstated assumptions in an argument or pattern of reasoning. Some bias is often involved in reasoning about anything complex and that bias is often revealed by making unstated or implicit assumptions explicit. This ability is one that enables a person to consider alternative perspectives (the next principle).

Perspectives and Alternatives. A critical thinker is able to identify alternative perspectives and biases. The underlying notion in this case is that many complex problems and situations lend themselves to multiple interpretations and can be understood from different perspectives. An example of this occurred in the validation study of DEEP (Spector & Koszalka, 2004). One problem case involved the deterioration of a coral reef in the Pacific Ocean. The five expert ocean biologists involved in the study conceptualized the situation quite differently; some saw the primary goal as a need to restore the reef in order to be able to support human life with a viable food supply on a nearby island; others basically viewed the primary goal as one aimed at increasing the biodiversity of the ocean. In spite of such differences, those five experts identified very similar critical factors and relationships to consider in resolving the dying reef. The point of this principle is that recognizing alternative points of view and bias can help improve one's understanding of a problem. In a fundamental way, this principle underlies the notion that a critical reasoner is basically humble – that is to say, willing to admit limitations and the legitimacy of other points of view.

Reflection, Refinement, and Self-Regulation. A critical thinker reflects on a problem-solving process or investigation to gain lessons learned that can guide future inquiry and exploration. This principle is intended to mark the maturation of a critical thinking developmental process. The notion is that critical thinkers are reflective and willing to learn from prior efforts. The ability to reflect on the quality and effectiveness of one's reasoning and to then make refinements is a strong indication of self-efficacy in the domain of critical thinking.

As previously noted, these nine principles can be consolidated in terms of the three new Rs – reexamining, reasoning, and reflecting. This framework is being implemented in a mobile application being developed in collaboration with NetDragon and researchers in China, India, and the USA. Researchers at East China Normal University have developed a game based on a shortened version of the Cornell Critical Thinking Test for children to be used to measure progress of learning (Ennis, 1989, 1991; see https://www.criticalthinking.com/cornell-critical-thinking-test-level-x.html).

Concluding Remarks

What has yet to be done is to test the impact of interventions developed using this framework on the development of inquiry and critical thinking habits of mind in young children. In addition, the assessment game has yet to be validated against the paper-based version of the short Cornell Critical Thinking Test. Once the game has been validated, the assessment can then be conducted in an unobtrusive manner consistent with the recommendations of Shute and others (Shute et al., 2016).

Our hope is that educators will take seriously a commitment to twenty-first-century skills. And there is an associated need to develop habits of mind relevant to inquiry and critical thinking in young children; such a need is a grand challenge for twenty-first-century education.

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