# Thinking and Learning in the Anthropocene: The New Three Rs

J. Michael Spector (mike.spector@unt.edu)

Learning Technologies, University of North Texas, Denton, TX

## ABSTRACT

The earlier emphasis on the so-called three Rs (reading, writing and arithmetic) reflected an emphasis on knowledge and skills thought important for productivity and earnings. Recently, a number of governments have emphasized what are called 21st century skills, which include critical thinking, communication, collaboration, and creativity – the four Cs. While the academic foundation for the four Cs seems both innovative and convincing, there is little emphasis of that new framework being adopted on a large, systemic and sustainable scale. Moreover, the justification for the new skills seems to reflect the familiar logic of improving productivity and maintaining a competitive edge in a global market and workplace. Meanwhile, the classical emphasis on education as inherently valuable apart from advancing one's career or gaining global advantages seems diminished. These remarks are intended as a reminder that education should be valued as a life-long human enterprise which requires early emphasis on a developmental approach to inquiry learning and critical reasoning that is not necessarily aimed at a career or discipline; rather, the aim of the new three Rs (re-examining, reasoning, and reflecting) should be understanding who we are becoming and what is likely to become of what we are doing.

## KEYWORDS

Critical thinking; developmental reasoning; inquiry learning; twenty-first century skills

## INTRODUCTION

I have been thinking about issues being addressed in this session and the efforts of Jan Visser for some time. I have come to the conclusion that rather than offer a traditional academic article that I might offer my views that are beginning to become clear at the end of my career. Rather than research references, I am offering a limited bibliography and set of possibly relevant resources for those who might wish to pursue these issues further. While I intend to be brief and

write informally, I do hope others might find some of the things herein of interest and worth pursuing.

I regret not being able to participate in person, but family obligations took higher priority. I have appreciated previous gatherings that Jan has arranged due to their highly interdisciplinary nature and high-level treatment of important issues. I have gained far more than I have contributed to those sessions, and I had looked forward to another mind-expanding session.

What I have to offer this time comes in the form of what am calling three new Rs – namely, re-examining, reasoning, and reflecting (3 Rs). I am using these as shorthand for a refinement of the 21st century skills (see http://www.p21.org/) which involve the 4 Cs: critical thinking, communication, collaboration and creativity. Many people around the world are embracing the 21st century skills, and some are beginning to talk about them in teacher preparation programs. There are in some schools and colleges some small steps to integrate some of the skills and associated principles into curricula at different levels. However, what seems overlooked in these various principles and efforts are three significant things: (1) developing inquiry skills and critical thinking (what I shall call the 3 Rs) is a process that takes years to establish and more years to maintain and refine; (2) successful efforts to promote the development of the 3 Rs require high-level support at the social and governmental level as well as at the state, local and school level; and (3) successful outcomes depend on individual goals and ongoing formative feedback in support of individual goals.

## LESSONS LEARNED BY COINCIDENCE

My formal education was in philosophy – primarily epistemology. My interest in philosophy began as a cadet at the United States Air Force Academy, primarily due to the instructors who seemed the wisest to me. I won the philosophy award the year I graduated and eventually went to the University of Texas in pursuit of my one academic love. I was an early fan of Socrates, although I have written critically of the so-called Socratic method. What I admired in Socrates, as represented in Plato's earlier dialogues, is Socrates' willingness to revisit issues previously discussed. This is the basis for the first of the three Rs – re-examination – and it is apparent in many Platonic dialogues, but particularly evident in the *Crito* (see http://classics.mit.edu/Plato/crito.html). Socrates has been found guilty of corrupting the youth of Athens and sentenced to death. While in prison, Socrates is visited by his friend, Crito, who has

made arrangements for his escape. Crito tries to convince Socrates to escape, but Socrates wishes to first re-consider the nature of right and wrong and whether the good thing to do is escape, even though his accusers misrepresented many things at his trial. Upon re-examining the nature of the good and his own belief in what is right, Socrates declines the offer.

However, others have represented the Socratic method of questioning (a.k.a., the *elenchus*) differently. That methodology is based on later Platonic dialogues. When one examines those later dialogues, the elunchus seems to involve someone asking a question (most often about the nature of virtue), someone taking a position that is popular, and Socrates then engaging that person in a series of questions that lead the person holding the popular position (e.g., might makes right) to a contradiction, thereby forcing that person to give up the simple-minded and unfounded definition. In that process, Socrates seems to have a notion what the acceptable answer is and persists in relentless questioning until that answer becomes evident to the interlocutor. The notion of pre-defined correct answers is consistent with Plato's metaphysics and theory of forms. However, few people these days accept the notion of immutable forms as the target of knowledge and understanding. Even in mathematics and formal logic one can find alternative axioms that lead to different theories and perspectives. For example, the law of the excluded middle (either X or else not-X but not both) that one might regard as essential in logic and univocity can be challenged [and it seems to be irrelevant in politics altogether].

The first lesson I learned by coincidence while at the Air Force Academy is that one should be willing to re-examine evidence and re-evaluate one's beliefs. A simple-minded cadet just wanted to fly airplanes. A less simple-minded person wants to understand who he is and who he might become. In graduate school, my interests shifted from Socrates to Wittgenstein, especially to the *Tractatus Logico-Philosophicus* (see https://www.gutenberg.org/files/5740/5740-pdf.pdf). In that volume, Wittgenstein says that it is not how the world is that is mystical or mysterious – rather, what is mysterious is that the world exists (see Remark 6.44; I still think about that simple remark some 45 years later). Wittgenstein also presents a complete version of two-valued logic in a footnote in that short volume. I value that work because it is a remarkable example of reasoning at work at a very high level addressing quite complex issues. The *Tractatus* consists of seven major numbered statements along with numbered sub-statements of elaboration. The first statement is that the world is everything that is the case – namely, the totality of facts. Given that beginning, it becomes important to understand

the nature of facts. The books ends with remark #7 – "what we cannot speak about we must pass over in silence" – I suppose Wittgenstein meant that what we cannot speak about clearly and in terms of facts that we should pass over in silence [if only politicians would do so].

My fascination with Wittgenstein grew while still a student. In the *Tractatus*, Wittgenstein notices that we picture facts to ourselves, which I interpret to mean that we develop internal representations to make sense of the things we experience. This, of course, is the keystone of a constructivist epistemology. Wittgenstein fails to note that some people sometimes develop internal representations of things that are not factual. The rhetoricians whom Socrates challenged surely did so, as do many people these days [Normally I insert a fill in the blank quiz at this point to engage readers and listeners, but my attorney has advised that I stop doing so as a certain occasional resident of the District of Columbia kept coming up as an example]. As Bob Dylan noted in "Talking World War III Blues," "Half of the people can be part right all of the time, some of the people can be all right part of the time, but all of the people can't be all right all of the time" (see https://www.bobdylan.com/songs/talkin-world-war-iii-blues/). Returning to Wittgenstein, people have the remarkable ability to internally represent what they experience – people are meaning makers, even when some are making mean. A second remarkable ability that people in general possess is to engage in language games about those internal representations. This latter ability is developed in Wittgenstein's *Philosophical Investigations*, published after his death (see https://static1.squarespace.com/static/54889e73e4b0a2c1f9891289/t/564b61a4e4b04eca59c4d232/1447780772744/Ludwig.Wittgenstein.-.Philosophical.Investigations.pdf).

I suppose that the second R is becoming evident at this point, in spite of my meandering and roaming – the second R, for those taking notes, is reasoning. I was trained in formal logic and taught logic for many years before defecting from philosophy to computer science and then to educational technology. The way that I typically represent reasoning is in the form of argumentation as represented in the diagram below (See Figure 1). An argument consists of one or more statements (the premises) offered in support of another (a conclusion). Within an argumentation framework, one is led to ask (a) if the premises offer sufficient support for the conclusion, (b) whether there is adequate evidence to support each of the premises, (c) what assumptions have been made, (d) what alternative explanations exits, and (e) what else follows if one accepts the conclusion. One can find re-examining as well as reasoning in this framework.

One can also map many of Plato's arguments onto this framework. Moreover, the notion of identifying assumptions implies considering alternative perspectives as does examining implications. These higher level aspects of reasoning correspond to the third R – namely, reflection.

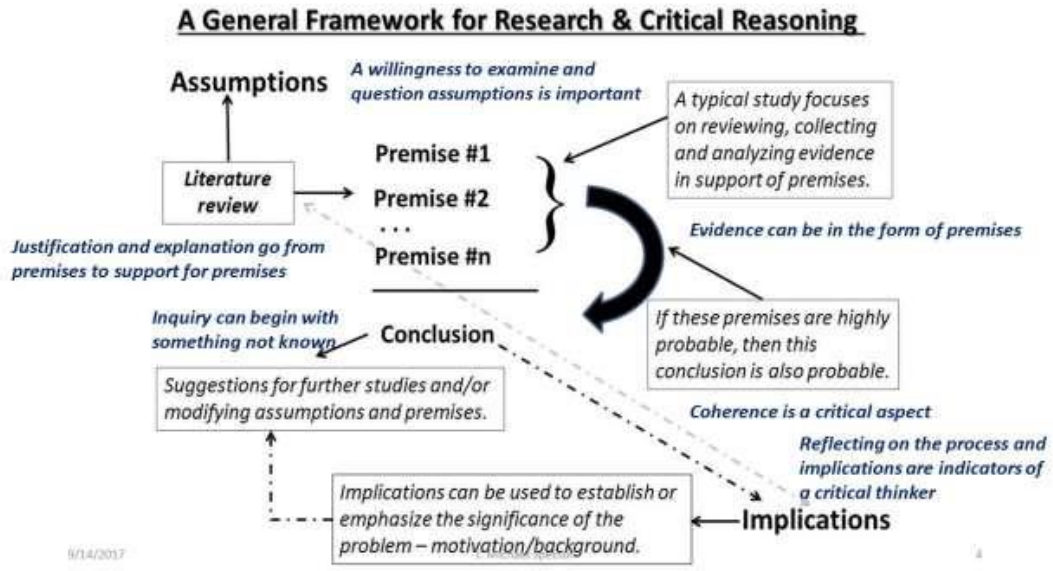


*Figure 1*: Argumentation and reasoning.

I was led to the third R – reflection – reluctantly. An early step in that direction came when Dave Merrill visited our research group at the University of Bergen where we (Pål Davidsen, Erling Moxnes, myself and others) were designing and implementing system dynamics-based learning environments in support of learning to solve complex and ill-structured problems. Merrill asked us an obvious question – namely, "how do you know students are learning anything?" Our simple tests of knowledge were inadequate for determining the progressive development of abilities in solving complex and ill-structured problems. That simple question caused serious reflection on our work and led to a new research effort aimed at developing and validating a way to measure progress of learning in complex and ill-structured problem solving domains. That methodology is called DEEP and formed the work of an NSF grant led by Spector and Koszalka at Syracuse University and was integrated in HIMATT along

with the work of Norbert Seel and two of his doctoral students, Pablo Pirnay-Dummer and Dirk Ifenthaler.

That small reflective step led to redirecting attention to assessment and especially formative feedback. This might be called broadening one's perspective. A second larger step occurred in conjunction with a five-year effort in Indonesia as part of the distributed basic education effort there. I have written and talked about that experience in *TechTrends* in 2017. After a visit to a very rural multi-grade school in West Java, I came to realize that what matters most in promoting education is not technology (useful but might not be necessary), nor a good teacher (most useful and probably necessary), but also the community's value placed on education and the subsequent support for education (critically needed, especially in places where teachers are not valued and there is very little financial support for education for all).

Given that nearly everyone has the two remarkable abilities treated by Wittgenstein – the ability to create internal representations of things experienced and the ability to talk about those representations – then why should those abilities not be primary targets of education and well-supported by any society that values education? If a society says it supports 21st century skills, then that support should be reflected in curricula and learning activities from pre-school to post-graduate and ongoing education. How might such support be made more evident, become systemic, and scaled up and sustained? What follows is a baby step in response to that question.

## THE 3 RS FRAMEWORK

The following indicators of critical thinking are inspired by John Dewey's (1910) *How We Think* (https://www.gutenberg.org/files/37423/37423-h/37423-h.htm) and are derived from what researchers suggest are fundamental to critical thinking. It is worth noting that many of these researchers regard critical thinking as primarily a cognitive and domain-specific skill that is mediated by language. The notion adopted herein is that there are attitudes and habits involved as well. Because this effort is aimed primarily at children between the ages of 7 and 13, the notion is that a habit of inquiry and seeking evidence and explanation can and should be developed early so as to foster critical thinking skills in a domain-general or multi-disciplinary context. In addition, an attitude of respect for those with alternative perspectives and a willingness to be wrong are also part of becoming a critical thinker. These principles are guiding an effort to develop critical thinking skills in young learners.

1. **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.
2. **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, 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?
3. **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 or low tides (about 12 hours and 25 minutes). A second one concerns when high and low tides are happening on the opposite side of the earth.

4. **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 hours and 25minutes 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.
5. **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.
6. **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 – name, 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.
7. **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).
8. **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.

9. **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.

One way to quickly summarize this framework is in the form three Rs: re-examination (principles 1, 2, And 3), reasoning (principles 4, 5, and 6), and reflection (principles 7, 8, and 9).

I am currently working with scholars at the University of North Texas, East China Normal University, Beijing Normal University, and Netdragon on a series of games to help children develop a mindset that is oriented to inquiry and critical thinking. Table 1 shows how the nine principles might be integrated in a series of games that target specific competencies.

Table 1. Principles and associated competencies.

| Principles/Development Phase | Example Competencies |
|---|---|
| Inquiry, observation and puzzlement | Observe oddities; answer questions about oddities; ask about oddities |
| Exploration and hypothesis formation | Identify relevant factors; create an initial explanation |
| Evidence and hypothesis testing | Find relevant factors; predict an outcome of a test |
| Influence and causality | Explain correlation, probability and causality |
| Explanation, communication and collaboration | Explain likely causes and reasoning to others |
| Coherence and consistency | Identify inconsistencies, contradictions and tautologies |
| Assumptions and biases | Recognize unstated assumptions; identify possible biases |
| Perspectives and alternatives | Identify and consider multiple points of view |
| Reflection, refinement and self-regulation | Monitor one's own progress; adjust ot new |

| | |
|---|---|
| | evidence or a different perspective |

To implement this framework, the approach we are taking is based on the notion that the skills associated with inquiry and critical thinking are developed over time, and they build on one another. As a consequence, we want to implement a *thinking companion* – that is to say, a conversational application that starts with initial information about the learner (e.g., age, location, interests, etc.) and grows with the learner as competence and confidence in critical thinking are developed and interests evolve. The ways that growing competence and confidence are recognized are through a series of badges (e.g., detective, senior detective, investigator, chief investigator, wizard) that correspond to having mastered a couple of the principles (e.g., after mastering principles 1 and 2, the learner is recognized as a detective; after then mastering principles 3 and 4, the learner becomes a senior detective; after principles 5 and 6, there is the level of investigator; after principles 7 and 8, chief investigator, and after principle 9, wizard). The level determines the kind of scaffolding and support the application offers the learner.

In addition to having levels, the application is aimed at maximizing learner and teacher control of what to investigate; this means that the application will be extensible and domain neutral. As a consequence, the conversational aspects of the application will be somewhat generic (not unlike the early AI application called Eliza – see http://psych.fullerton.edu/mbirnbaum/psych101/Eliza.htm). The difference is that the application will know some things about the learner including the learner's level and local context. That knowledge can be used to customize conversations with the learner so as to maximize learner engagement and encourage further inquiry and deeper learning. Netdragon is in the process of implementing the first game aimed at observation, inquiry and puzzlement for children who are about 7 or 8 years of age. Scholars at East China Normal University have already developed a game to measure progress in developing associated skills; the game is based on a critical thinking scale validated with middle school children in Taiwan. The basis for that measurement games is the Cornel Critical Thinking Test developed by Robert Ennis (see http://faculty.education.illinois.edu/rhennis/cornellclassreas.pdf).

Additional considerations that inform this approach include:

- Critical thinking is typically associated with concepts and language, which accounts for the emphasis on argumentation shown below. However, it is not realistic to only consider

cognition within a conceptual and language-based approach or in an analysis of critical thinking skills. A more holistic approach that includes biases, dispositions, moods, preferences and other factors is likely to be more insightful and provide both teachers and learners with useful feedback to improve critical thinking skills over time and changing interests and levels of critical thinking competence. In other words, it is perhaps best to consider critical thinking as a situated skill that involves both cognitive and non-cognitive factors.

- Critical thinking is often discussed and analyzed along with problem solving and decision making. This seems natural in that critical thinking skills are often required and found useful in solving challenging problems and in making difficult decisions. However, problem-solving and decision-making skills are more domain specific than are the broader inquiry and critical thinking skills which can be developed in many domains and are probably best developed in a maturing mind (i.e., early adolescence) that is not so engaged in highly domain-specific learning activities. The templates within this framework are intended to be domain neutral or domain general. Assessment will be initially explored using a gamified version of Rober Ennis's Critical Thinking Test, Level X (see file:///C:/Users/jms/Downloads/critical%20thinking%20assessment.pdf),
- Critical thinking is also often discussed and analyzed along with creativity, which is perhaps even broader and more difficult to define and operationalize than critical thinking. This is also somewhat natural because challenging problems and difficult decisions often require an innovative approach that goes beyond one's previous experience, training and learning. In one sense, nearly everyone is creative in that as a person acquires a native language that person begins to use words and phrases in ways that have not entered that person's prior experience. Moreover, people naturally create internal representations (sometimes called mental models) to make sense of the things they experience. Since everyone is creating mental representations to make sense of and react to their experiences (according to mainstream cognitive psychology), then everyone could be considered creative. On the other hand, a different account of creativity involves an ability not merely to create something not previously experienced or in one's cognitive repertoire but the ability to change the problem solving space in a way that the originator of the problem did not envision. In any case, creativity, like critical thinking, arguably spans multiple domains although it might be especially in only a few of the enterprises in which a person engages.

The notion of creating an extensible framework that can be adapted to each teacher's situation and to each child's interests should add to the scalability of the effort. The notion of starting early and applying the framework across multiple domains should contribute to the development of a critical thinking mindset, which seems in need if we are to survive in the anthropocene (not to mention ongoing political and social and economic conflicts).

## CONCLUDING REMARK

I have tried to argue for helping children develop habits of mind that include strong emphasis on inquiry and critical thinking. I have no evidence of success to offer. I only have

faint ideas and some hope for the future which lies in the hands, hearts and minds of our children.

**BIBLIOGRAPHY**


Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.) (2000). *How people learn: Brain, mind, experience and school* (expanded edition). Washington DC: National Research Council. Retrieved from https://www.nap.edu/read/9853/chapter/1

Brian Hull – critical thinking in the classroom paper on the Internet – see http://www.ibo.org/contentassets/b53fa69a03d643b1a739d30543ca8d65/brianhullcriticalthinkingmadrid.pdf

Butler, H. A., Pentoney, C., & Bong, M. P. (2017). Predicting real-world outcomes: Critical thinking ability is a better predictor of life decisions than intelligence. *Thinking Skills and Creativity*, *25*, 38-46.

Dewey, J. (1938). *Experience and education*. New York: Kappa Delta Pi.

Dwyer, C. P., Hogan, M. J., & Stewart, I. (2014). An integrated critical thinking framework for the 21st century. *Thinking Skills and Creativity*, *12*, 43-52. doi https://doi.org/10.1016/j.tsc.2013.12.004

Dwyer, C. P., Hogan, M. J., & Stewart, I. (2014). An integrated critical thinking framework for the 21st century. *Thinking Skills and Creativity*, *12*, 43-52.

Gagné, R. M. (1985). *The conditions of learning* (4th ed.). New York: Holt, Rinehart, and Winston.

Gagné. R. M., & Merrill, M. D. (1990). Integrative goals for instructional design. *Educational Technology Research & Development, 38*(1) 23-30. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.503.6800&rep=rep1&type=pdf

Halpern, D. F. (2014). *Critical thinking across the curriculum: A brief edition of thought & knowledge*. Routledge.

Heijltjes, A., Van Gog, T., Leppink, J., & Paas, F. (2014). Improving critical thinking: Effects of dispositions and instructions on economics students' reasoning skills. *Learning and Instruction*, *29*, 31-42.

Huber, C. R., & Kuncel, N. R. (2016). Does college teach critical thinking? A meta-analysis. *Review of Educational Research*, *86*(2), 431-468.

Ku, K. Y. L., Ho, I. T., Hau, K. T., & Lai, C. M. (2014). Integrating direct and inquiry-based instruction in the teaching of critical thinking: An intervention study. *Instructional Science, 42(2),* 251-269.

McPeck, J. E. (2016). *Critical thinking and education*. Routledge.

Merrill, M. D. (2002). First principles of instruction. *Educational Technology Research & Development, 50*(3), 1042-1629.

Merrill, M. D. (2013). *First principles of instruction: Identifying and designing effective, efficient and engaging instruction*. San Francisco, CA: Pfeiffer.

Milrad, M., Spector, J. M., & Davidsen, P. I. (2003). Model facilitated learning. In S. Naidu (Ed.), *Learning and teaching with technology: Principles and practices* (pp. 13-27). London: Kogan Page.

Paul, R., & Elder, L. (2010). *The miniature guide to critical thinking: concepts and tools.* Dillon Beach: Foundation for Critical Thinking Press. Retrieved from https://www.criticalthinking.org/files/Concepts_Tools.pdf [See also [http://louisville.edu/ideastoaction/about/criticalthinking/framework and the critical thinking foundation located at https://www.criticalthinking.org/]

Pithers, R. T., & Soden, R. (2000). Critical thinking in education: A review. *Educational research, 42*(3), 237-249.

Spector, J. M. (2017). Optimism vs. realisim with regard to educational technologies. *TechTrends, 61*(6), 4`10-511.

Spector, J. M., & Koszalka, T. A. (2004). *The DEEP methodology for assessing learning in complex domains* (Final report to the National Science Foundation Evaluative Research and Evaluation Capacity Building). Syracuse, NY: Syracuse University.

Tiruneh, D. T., de Cock, M., Spector, J. M., Gu, X., & Elen, J. (2017). Toward a systematic and model-based approach to design learning environments for critical thinking. In J. M. Spector, B. B.; Lockee, & M. D. Childress (Eds.), Learning, design, and technology: An international compendium of theory, research, practice, and policy. New York: Springer.

**Resources for the new 3Rs**

- Assessing Critical Thinking in STEM and Beyond (designed mainly for college students) – see https://www.tntech.edu/files/cat/reports/Innovationschapter.pdf
- Baron article on measuring critical thinking skills on a large scale – see http://www.ascd.org/ASCD/pdf/journals/ed_lead/el_198510_sternberg.pdf
- Bensley, D. A., Rainey, C., Murtagh, M. P., Flinn, J. A., Maschiocchi, C., Bernhardt, P. C., & Kuehne, S. (2016). Closing the assessment loop on critical thinking: The challenges

of multidimensional testing and low test-taking motivation. *Thinking Skills and Creativity*, *21*, 158-168.

- Bloom's Taxonomy: Critical Thinking Skills for Kids - https://www.exquisite-minds.com/idea-of-the-week/blooms-taxonomy-critical-thinking-skills/ (Exquisite Minds Website)
- Critical Thinking Activities - https://www.pinterest.com/explore/critical-thinking-activities/ (Pinterest Website)
- Critical Thinking Worksheets - http://www.jumpstart.com/parents/worksheets/critical-thinking-worksheets (Jumpstart Website)
- Critical Thinking: Grades 3-5 - http://www.educationworld.com/a_lesson/worksheets/critical_thinking/3-5/ (Education World Website)
- Educate-Insight tools for grades 3-5: it involves measurements of analysis, evaluation, inference, deduction, induction and numeracy (could be used to validate and add confidence to the stealth assessments in the ECNU tool being developed) – see https://www.insightassessment.com/Products/Products-Summary/Critical-Thinking-Skills-Tests/EDUCATE-INSIGHT-Reasoning-Skills-3-5 Robert Sternberg and Joan
- Ennis, R. H. (1993). Critical thinking assessment. *Theory into Practice, 32*(3), 179–186.
- How to Develop a Critical Thinking Mindset in Elementary Students - https://globaldigitalcitizen.org/critical-thinking-mindset-elementary-students (Global Digital Citizen Foundation)
- How to Teach Critical Thinking - https://www.wikihow.com/Teach-Critical-Thinking (WikiHow Website)
- Ku, K. Y. L. (2009). Assessing students' critical thinking performance: Urging for measurements using multi-response format. *Thinking Skills and Creativity, 4*, 70-76.
- Teaching Children to Think - https://www.psychologytoday.com/blog/memory-medic/201110/teaching-children-think (Psychology Today Website)
- Teaching Critical Thinking: An Evidence-Based Guide - http://www.parentingscience.com/teaching-critical-thinking.html (Parenting Science Website)
- The Critical Thinking Community Website for Testing and Assessment – see http://www.criticalthinking.org/pages/critical-thinking-testing-and-assessment/594
- Think About It: Critical Thinking - http://www.scholastic.com/parents/resources/article/thinking-skills-learning-styles/think-about-it-critical-thinking (Scholastic Website)
- Thinking Puzzles - https://www.superteacherworksheets.com/full-puzzles.html (Super Teacher Website)