Critical Thinking:
A Modern Practitioner's Journey of Discovery

The author describes how he discovered, adopted and eventually began teaching critical thinking skills as the foundation for a complex problem-solving methodology currently in use at the US National Laboratories and the Nuclear Weapons Complex. He also posits that educational institutions have not evolved their pedagogy to meet increasing demand for higher order thinkers in the age of Artificial Intelligence.

By: Rob De La Espriella

July 12, 2020

Critical Thinking and Complex Problem Solving are two of the most valuable human skills that will help us thrive in the age of Artificial Intelligence.

INTRODUCTION

According to a report published by the World Economic Forum in 2016[1], the top two skills that will help humans thrive in the fourth industrial revolution (i.e. the age of Machine Learning and Artificial Intelligence), are "Critical Thinking" and "Complex Problem Solving."

In this paper, the author describes his journey towards becoming a stronger critical thinker and problem-solver and the discoveries, observations and lessons that he learned along the way. This journey spans nearly four decades and four careers: the US Navy, commercial nuclear power, the Nuclear Regulatory Commission and consulting for the Federal Government. Along this journey, he was fortunate to gain a vast amount of experience in solving complex problems through the teachings of Deming, Juran and others. But it was not until he understood critical thinking that he was able to develop a truly effective complex problem-solving methodology.

Critical thinking became the foundation for the author's methodology for solving complex, human-centric problems. The author's methodology is now being taught and used at commercial nuclear plants, Department of Energy National Laboratories, the Nuclear Weapons Complex and other Department of Defense installations.

One of the more significant discoveries the author made along the way was that there is a whole universe of problems that cannot be solved by math and science alone, and more importantly, that his engineering degree and post-graduate studies did not properly prepare him to face complex, "human-centric" problems that require higher order thinking skills that are not often emphasized in traditional educational curricula.

In some of the author's client organizations, as much as 30% or more of their resources are being spent on non-mission-critical tasks, including recurring human-centric problems.

Mastering how to investigate complex, human-centric problems could help solve a vast number of the problems that are costing organizations time and money and keeping them from their mission critical tasks.

Another revelation is that there is a continuous debate by experts in the field on whether critical thinking is a skill or a set of skills that can be learned, or whether it is a developmental process; something we strive for. The author is in the first camp, noting that to maximize the effectiveness and retention of critical thinking and problem-solving skills, we need concepts and methods that can be understood, implemented, and practiced. After three decades of studying and applying many approaches to solving human-centric problems, the author was able to break down applicable critical thinking concepts to their teachable fundamentals so they could be learned, practiced and even mastered, within the context of solving complex, human-centric problems.

The most significant of discoveries from these past four decades is perhaps the following paradox; our education systems are not keeping up with the demand for critical thinking and problem-solving skills, and the gap grows larger as the industry reaches for the golden ring of Artificial Intelligence. According to some studies, the lack of graduates who are equipped with critical thinking skills is on the rise and there is a critical need for updating our schools with curricula that translates critical thinking concepts into practical skills that can be taught and practiced so that students can reach a level of proficiency by the time they enter the workforce.

The author proposes that educational institutions must strengthen their critical thinking curricula. If formal critical thinking and problem-solving skills are not developed by the time a student enters the workforce, their chances of developing those skills greatly diminish. In his final thoughts, the author asks us to imagine:

If each year, a cadre of students entered the workforce with 16 or more years of education and experience on the practical application of critical thinking and problem-solving…what a different world this would be.

[1] World Economic Forum, 2016

THE DECADE OF THE 1980s

THE INITIAL DISCOVERY OF GAPS IN OUR EDUCATION SYSTEM

My journey began in the 80s, probably the most intense years of my life. Learning occurred at an incredible pace and major life changes were taking place just about every year. As a young man in my 20s, I obtained an engineering degree, joined the US Navy where I learned to operate nuclear reactors and command nuclear warships, and I met and married the love of my life, a feisty Irish girl by the name of Kathleen Irene. But the 80s posed a major challenge; my formal education and training did not prepare me for the kind of problems that I was to face the minute I entered the workforce. And in spite of my formal education, any knowledge and understanding of critical thinking was merely accidental.

My journey towards becoming a more critical thinker actually began the minute I set foot onboard a ballistic missile submarine. In 1981, I entered the US Navy's Nuclear Power Officer Candidate Program, and after receiving my degree, I immediately embarked on nearly two additional years of education that included Masters' level courses in Nuclear Engineering and hands-on training on nuclear reactors. We were trained on the science and math behind nuclear fission, as well as the construction, operation and maintenance of the Navy's reactors.

I arrived at my first submarine, the USS Simon Bolivar (SSBN 641), in 1984. The Bolivar was a magnificent example of innovation and the will of one person to put a nuclear reactor inside of a submarine. That was the brainchild of Admiral Hyman Rickover, known as "the father of the nuclear navy." By the time I left the Navy, I had trained onboard three ballistic missile submarines; a nuclear submarine makes for an excellent classroom!

After six years of training and hands-on experience, I left the Navy with the first of many discoveries:

There is a whole universe of problems that cannot be solved by math and science alone, and our education did not properly prepare us to face those problems.

Often, the problems we faced were very different than the ones that could be solved using Nuclear Physics, Thermodynamics and Fluid Mechanics. Finding solutions to these problems required skills we did not have.

In 1988, I went to work as a System Engineering Supervisor at Florida Power & Light's (FP&L) Turkey Point Nuclear Plant, near my hometown of Miami, FL. And the next few years of my journey forever altered the course of my career.

When I arrived at Turkey Point, I did not know that it had been on the Nuclear Regulatory Commission's (NRC) watchlist of the worst performing plants in the United States for three years in a row. To work their way out of the NRC watchlist, FP&L had launched a major initiative to win the Deming Prize, awarded annually by the Japanese Union of Scientists and Engineers (JUCE) to organizations that demonstrated the highest standards of Total Quality Management (TQM). It was at this point that my journey to becoming a better critical thinker and complex problem solver actually began.

My role during FP&L's quest for the Deming Prize was a small one. As a Supervisor in the Engineering organization, I was formally trained on a methodology called Root Cause Analysis (RCA), which allowed us to systematically find the deepest-seated causes of significant events. Once trained, I was tasked with presenting a case study on how we solved a recurring problem with our air compressors using RCA. In 1989, FP&L became the first company outside Japan to ever win the Deming Prize. The Deming Medal we received commemorates the event with the inscription "1st Overseas Prize."

Being a part of the effort that won the Deming Prize was a milestone in my career because of the knowledge I gained about TQM and RCA. Armed with new problem-solving skills, I became the Event Response Team Coordinator for Turkey Point, leading teams that were addressing serious equipment failures and human performance events.

However, just as I had noted during my time in the Navy, a large number of the problems we faced in the commercial nuclear industry had very little to do with math or science. I discovered that these kinds of problems had a key variable in common: a variable that added a layer of complexity and created a multitude of possible outcomes. That variable was human behavior, and I call these problems "human-centric problems.

"Human-centric" problems are driven by human behavior, and these problems require higher order thinking skills, skills that are not given nearly as much emphasis in academia as math and science.

When we insert humans into the mix, it changes everything. The way we humans interact with each other and across organizations, how we use tools, materials and equipment, how well we abide by laws, rules and regulations, and in general, how we engage with the world around us, is highly unpredictable and nearly impossible to model using formulas or equations.

However, it was not clear to me what those higher order thinking skills were. In researching papers from that timeframe, thought leaders of the 80s noted that: "Critical thinking is a learned skill and one of the important life skills,"[2] I had no idea the concept even existed because it had not come up in all my years of formal education.

By the end of the 80s, I had performed a few hundred causal analyses and performance assessments and developed a better understanding of complex, human-centric problems, which included:

Human Behavior/Performance:
Many problems are caused by human error. This category defines the pursuit of why humans behave the way they do, particularly their "at-risk" behaviors. In complex problem-solving, we have to find the reasons why the person behaved the way they did, leading up to the mistake or the at-risk-behavior. In too many cases we simply blame the person and believe that by coaching them, these problems or mistakes will not recur. This is largely not true. Through Socratic Questioning, we can begin to understand why they behaved a certain way. What makes it difficult is that the same person can behave differently on different days, so there are other environmental factors that have to be considered under a complex problem-solving model.

Equipment Failures:
This category includes tools, materials and equipment that humans routinely interface in problem scenarios. These components are designed, manufactured, installed, operated and maintained by humans. How humans interact with these tools, materials and equipment must be evaluated under our complex problem-solving methodology to determine how or if they are contributing to the problems. In the case of an equipment failure, it is not enough to determine the failure modes; we must also investigate why those failure modes existed, which often brings us back to a human interface.

Organizational and Programmatic Breakdowns:
We are governed by many rules and regulations. There are laws we must abide by, and these laws are implemented through policies, programs and procedures at the organizational level. They define the parameters for a civilized society, such as how to drive, how companies should do business, and the social norms for what is considered acceptable behavior. When investigating a complex problem, we must also evaluate the family of requirements that were applicable to the issue, to identify latent weaknesses in those programs, policies and procedures, and to identify "error-likely situations" in our environment where those same rules set us up for failure.

In extreme cases, we encounter "wicked" problems that involve social or cultural issues that are difficult or impossible to solve, such as hunger, homelessness, terrorism and climate change.

Mastering how to approach complex, human-centric problems could help solve a vast number of the problems that are keeping organizations from their mission critical tasks.

[2] Sternberg, 1986; Lipman, 1988; Ennis, 1989

THE DECADE OF THE 1990s

DISCOVERING THE LINK BETWEEN CRITICAL THINKING AND PROBLEM SOLVING

The 90s marked significant milestones along my journey of discovery towards becoming a better critical thinker. Armed with the knowledge that came from participating in the Deming Prize, in this decade I honed my newfound skills as a complex problem-solver at both commercial nuclear plants and at the United States Nuclear Regulatory Commission (NRC).

My challenge during this period was that, without formal schooling or training, I had to uncover through trial and error the skills that were needed to evaluate this other universe of human-centric problems. By the end of this decade, my knowledge of critical thinking was still marginal, at best.

When I was certified by FP&L as an RCA instructor in 1991, I was well equipped to find the root causes for significant events. As the new Event Response Team (ERT) Coordinator for Turkey Point, I re-wrote their root cause analysis procedures and led their most significant event investigations.

One of the first lessons in my young professional career involved leading a root cause team for a reactor scram with many complications. Our disciplined method for gathering and organizing available data helped us to analyze and solve the problems in five weeks. But it was a tense reactor startup: my heart rate did not slow down until the reactor reached 100% power because I had been told by the Plant Manager that my career depended on it!

In 1992, I joined the Nuclear Regulatory Commission (NRC) and was certified as a Resident Inspector, overseeing the Millstone Nuclear Power Station in Connecticut during a difficult time in their history. During my four years at the NRC, I was called on to solve complex problems at the Region 1 Office and at Millstone, for which I received three awards in three years.

In 1995, I was recognized as one of the 10 most outstanding NRC inspectors in the United States, which was quite surprising as I worked in one of the most talented Federal Agencies in the US. In my opinion, the one differentiator and the reason I was selected was that I had the skills to solve complex, human-centric problems, and those skills were in short supply.

After four great years at the NRC, I returned to FP&L so my newborn daughter could grow up closer to family. Although my time with the NRC was brief, I added a new skill to my problem-solving abilities: as a member of an oversight organization, I learned how to ask carefully crafted, evidence-based questions to gain insights into the actual problems, and to continue to ask questions until they ran out of answers. I consider my time at the NRC as the next big step towards becoming a better critical thinker. Even with these newfound insights, I was still oblivious to the formal concept of critical thinking and had not read any literature on the subject.

During my research, I found that it was during this decade that leaders began to demand for workers with higher order thinking skills. In 1994, Sormunen and Chalupa wrote: "Leaders in the business world are increasing their demands for the need of highly competitive workers who are critical thinkers with high order thinking skills."[3] In his paper in 1992, G. A. Cabrera wrote: "Teaching critical thinking is a competency that is most wanted in our society."[4] In 1999, Diane Halpern wrote: "For students to be able to solve complex problems, students must be engaged actively in the process of critical thinking."[5]

Even with increased demands for critical thinking skills in the workforce, studies showed that our education system had not met the challenge of graduating students with higher-order thinking skills.

In the 90s, I discovered a close tie between critical thinking and complex problem solving, specifically the skills associated with developing focused, evidence-based questions. But I closed out the decade of the 90s with a little more than a marginal understanding of critical thinking gained from practical experience. Only now, when I look back, do I recognize there was a lack of discussion, literature and perhaps even interest in critical thinking.

[3] Sormunen & Chalupa, 1994
[4] Cabrera, 1992
[5] Halpern, 1999

THE DECADE OF THE NEW MILLENIUM

A CHANGE IN CAREERS CREATED A NEW PROVING GROUND

The new millennium marked the beginning of a new career for me. By 2000, the connection between asking great questions and solving complex problems was solidified in my approach. Now back at FP&L's St. Lucie Nuclear Plant, I found myself in a leadership position, allowing me to put in place policies and procedures that promoted the identification of the deepest-seated causes of our problems. In a few short years, our organization was recognized by industry oversight groups for our ability to get to the root of problems. By the end of this decade, my critical thinking skills had improved. My challenge was, I could not intelligently talk about the tenants or building blocks of critical thinking or teach them to others.

My second time around at FP&L was a great proving ground for my approach to solving problems. In 1999, I was promoted to the position of Site Quality Manager, a position I would hold for the next six years. Admittedly, my first three years as a first-time manager were rocky at best. The three Nuclear Assurance organizations I was managing included talented Operators, Engineers, Mechanics, Radiation Protection Specialists and Chemists. However, our performance was lackluster. Looking back, I struggled those first three years because I could not figure out how to accomplish our oversight mission of Quality Assurance, Quality Control and Performance Assessments, in a way that our customers (the line organizations at the site) actually considered a positive sum gain.

I became a student of Juran, gaining much knowledge from Juran's Quality handbook.[6] After adopting many of Juran's principles for creating breakthroughs in performance, my staff and I turned our attention to improving the value we brought to the site. We mapped out our improvement initiative as a classic business case: the value that our organization brought to the table should result in a net positive sum gain of three-to-five times the value of our combined salaries. However, to ensure we were adding value required new oversight strategies and a new way of thinking.

In 2002, I established policies and procedures that required my staff to do more than "circling the bullet holes" and "drawing a chalk outline around the dead bodies," which were common complaints at the time. Our new goal was to identify value-added issues that the site managers would unequivocally agree had to be solved. Accomplishing this level of oversight required critical thinking and complex problem-solving skills that included asking great questions and analyzing available information so that we could pin-point the deepest-seated problems that needed to be addressed. I also followed "The Greatest Management Principle in the World,"[7] tying my organization's pay to their performance because "the things that get rewarded, get done." It was at this time that I reached a key milestone along this journey: In my six years as a manager of an oversight organization, I learned that:

To maximize the effectiveness and retention of critical thinking and problem-solving skills, they need to be simple to understand, easy to use, and practiced routinely or they quickly fade.

An example was teaching the staff how to conduct a Barrier Analysis in their heads as they conducted oversight activities in the field. This required asking themselves what defenses (requirements) were in place to prevent a particular problem from occurring, and by comparing the requirements to what actually took place, the staff was able generate excellent questions that would lead us to the real issues.

By 2003, the St. Lucie Nuclear Assurance organization was receiving industry recognition. The Institute of Nuclear Power Operations (INPO) listed our organization as one of the stronger groups in its class. In their 2003 peer review of St. Lucie, INPO wrote: "The products of this hybrid Quality Assurance organization are critical, are promptly acted on by plant management, and have resulted in the identification of value-added issues that improved plant performance. Senior management frequently looks to Nuclear Assurance as the first responder to investigate problem areas." We repeated this feat in 2005, when INPO once again highlighted our performance as a strength.

---

[6] Juran, De Feo (1999)

[7] LeBoeuf, 1985

In the summer of 2005, The World Association of Nuclear Operators (WANO) asked me to support improvement initiatives in Slovenia and South Africa after our Site Vice President noted that he had never worked with a more effective Nuclear Assurance organization.

Critical thinking and problem-solving skills vaulted our organization from mediocre to best-in-class in a few short years, catching the attention of INPO and WANO.

Following the industry recognition from INPO and WANO, I took a leap of faith, founding my own consulting practice in 2006.

In 2007, I began a long and productive relationship with the companies that manage and operate sites for the Department of Energy (DOE) within the US Nuclear Weapons Complex and the National Laboratories. Those sites included the nation's high level nuclear waste repository at Yucca Mountain, the nation's Gaseous Diffusion plants where fissionable Uranium is produced, the Depleted Uranium Hexafluoride Conversion Facilities, and sites that design, manufacture, assemble and store the nation's stockpile of nuclear and chemical weapons, such as Pantex, Y-12, and the Los Alamos and Savannah River National Labs. Those sites employ some of the most brilliant scientists and engineers in the world and they are well equipped to solve such problems as how to design and build Hydrogen bombs and small modular reactors. However, the sites are often lacking in personnel with the skills to solve complex, human-centric problems.

As a result, many organizations at these sites experience a steady stream of recurring human-centric events and performance issues that are taking significant time, money and resources away from the scientists and their critical missions.

At some sites, 30% or more of their resources are spent on non-mission-critical tasks due to recurring human-centric problems.

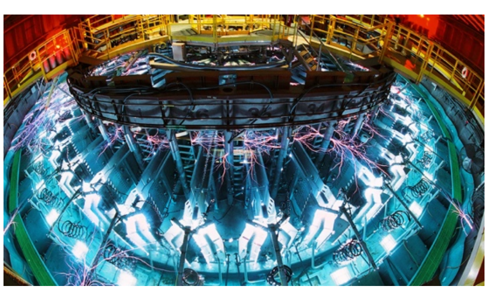
And human-centric problems, as previously noted, cannot be solved by math and science alone.

After spending half of this decade as a Senior Policy Advisor at a few of these sites, I developed a better understanding of the kinds of human-centric problems that are driving poor performance at the sites. For example, many of the issues were caused by latent weaknesses within the organizations' management control systems, the lack of proper flow-down of laws, rules and regulations into implementing policies and procedures, and the inadvertent creation of error-likely-situations that drove at-risk behaviors and set personnel up to fail.

By this time, I had also been trained in different approaches to solving problems, such as: Total Quality Management (TQM), Kempner-Tregoe Problem Solving, Management Oversight Risk Tree (MORT), TapRoot, INPO's Human Performance Evaluation System (HPES), Dr. Corcoran's Phoenix Method, Lean/Six Sigma training, and Kaizen Team Leader certification training.

Each of these methods offered some useful tools or techniques. By using the strengths of the various methods, tools and techniques, I developed a universal and integrated approach for solving complex problems, one that included critical thinking skills at its core. I also learned that it is just as important to understand which problem-solving tools and techniques are too inefficient or cumbersome to be of value.

As the decade came to a close, my knowledge of critical thinking and complex problem-solving slowly continued to grow through the trials and tribulations of helping clients solve their most complex problems.



SANDIA NATIONAL LAB

LAWRENCE LIVERMORE NATIONAL LAB

THE DECADE OF 2010

BLOOM'S TAXONOMY AND THE CREATION OF A NEW METHODOLOGY

The next 10 years were arguably the most professionally rewarding years of my life. During this decade I took my company through the pains of becoming a prime contractor for the US Federal Government, and before the decade was out, recognizing that this was not my calling. This is the decade that I formally began researching critical thinking (realizing how little I knew about the subject) and solidifying my own approach.

After three decades of studying many approaches to solving problems, I crafted a modern, lean and agile critical thinking and complex problem-solving methodology. The challenge was how to break down those concepts to their teachable fundamentals.

It was the Spring of 2012 when my client at a DOE Gaseous Diffusion Plant in Ohio asked if I would teach a select group of their oversight and Safety Department personnel how to investigate their more serious issues and accidents. I completed five root cause analyses and a comprehensive common cause analysis of the most serious issues at that site, and the site's leadership wanted their staff to learn my methodology. That request put me on a new path that was to lead me to my final destination on this journey of discovery; that of a teacher.

Over the next few years, I taught several hundred site personnel how to solve complex problems, which posed a new challenge: the need to better understand the skills required to think more critically, like what it takes to develop questions that allow us to challenge assumptions, examine different perspectives, probe implications and ultimately lead to the deepest-seated causes.

I read my first book on critical thinking in 2014: "Developing Critical Thinkers," by Stephen Brookfield.[8] Brookfield encourages us not to automatically accept a particular set of doctrines; to challenge the tenants and assumptions and assertions made by philosophers, psychologists and scientists, and especially the news media. He proposed that to think more critically means unearthing new assumptions and creating new insights, proposing new perspectives and alternatives.

Brookfield also proposed that "challenge is central to helping people think critically." And that notion resonated with me because, in my line of work, I was constantly challenged to solve the most complex human-centric problems that my clients could not solve, and do it quickly and accurately.

Brookfield's thoughts on *Critical Questioning* and *Criteria Analysis* were of particular interest to me. Critical Questioning led me to incorporate Socratic Questioning into my curriculum as the fundamental skill behind Cause & Effect Analysis. Socratic Questioning drives us to: seek clarification; challenge assumptions; probe the evidence; examine viewpoints and perspectives (empathy); and, probe implications and consequences. Criteria Analysis was something I was already familiar with and had been teaching for some time: how to examine and evaluate the defenses or requirements that establish governance within organizations, to determine their effectiveness and uncover any incorrect assumptions or interpretations that personnel had formed regarding these criteria, preventing their proper implementation.

As I began to delve into critical thinking papers, studies and books, I noted that its growth in popularity was fueled by our entry into the 4th Industrial Revolution: the age of Artificial Intelligence and Machine Learning.

In 2016, global leaders from the World Economic Forum (WEF) identified "the 10 skills you need to thrive in the 4th Industrial Revolution."[9] At the top of the list were: #2, critical thinking; and, #1, complex problem solving.

Dr. Alex Jones, Professor of Leadership College of Business Administration American University in the United Arab Emirates, arrived at a similar conclusion. In his paper on critical thinking published in the International Journal of Management in 2020, Dr. Jones wrote: "Critical thinking is considered one of the critical skills that are required to meet the demands of the complex world we live in, especially in the age of

[8] Brookfield, 1987

[9] World Economic Forum, 2016

artificial intelligence."[10] To bring these statements into context, Artificial Intelligence (AI) and Machine Learning are going to change the landscape of jobs in the very near future, generating millions of new jobs.

Mining data from more than 50 million job postings, ZipRecruiter found that Artificial Intelligence created three times as many jobs as it destroyed in 2018. The fastest growing jobs included Senior Data Scientist, with an annual growth of 340%, Mobile Application Developer (186%) and SEO Specialist (180%).

However, AI and Machine Learning are also expected to eliminate many of the jobs currently being done by humans. The notable exceptions were jobs that relied on the skills that were highlighted in the WEF's list of top 10 (human) skills we will need to thrive in the age of AI. And what is at the top of the list…?

WEF Top 10:

1. Complex Problem Solving
2. Critical Thinking
3. Creativity
4. People Management
5. Coordinating w/ Others
6. Emotional Intelligence
7. Judgement & Decision-making
8. Service Orientation
9. Negotiation
10. Cognitive Flexibility

With the advent of AI, there will be an ever-increasing need for workers with the ability to think critically and solve complex problems. And by "complex problem solving," the WEF is not only referring to problems that can be solved by computers and algorithms.

As I continued my research into the skills that one needed to practice and even master in order to become a stronger critical thinker, I was pulled in different directions. The white papers, articles, dissertations and media on critical thinking offered as many theories, opinions and approaches on this topic as there are people studying the field. One study concluded: "Findings show that each researcher has defined critical thinking according to their own ideas so it can be mentioned that the number of critical thinking definitions are nearly equal to the number of scholars in this field."[11] But I noted that many of the approaches fell primarily into two schools of thought.

One school of thought is that critical thinking is an ethereal and unattainable state of being that we could never fully reach in just one lifetime. It propels philosophers and PhDs to develop new theories and paradigms on how to think critically, which continue to stimulate discussions on the topic and generate research that will continue to advance our understanding of the subject. The more we study their theories, the more we recognize how far we are from mastering the unattainable state of being a truly critical thinker.

A second school of thought is that of the practitioners. They are attempting to define critical thinking in ways that allow others to grasp the concepts and apply them to their day to day problems. This includes defining a set of skills that can be learned and practiced, and tools that enhance our ability to think more critically. Dr. Jones highlights this conundrum in his 2020 paper:

"There is a continuous debate by experts in the field whether critical thinking is a skill or set of skills that can be learned or whether it is a developmental process."[12]

It does not matter which side of the fence you are on, as both are worthy pursuits. As a practitioner, I am in the latter camp.

By the end of 2014, I was committed to teaching critical thinking and complex problem solving and began researching the best way to go about it. My research led me to Bloom's Taxonomy[13], a framework that has been around since 1956 (and modernized in 2001). Bloom's Taxonomy is a framework for educational achievement in which each level depends on the one that precedes it. It's often depicted in the form of a pyramid, similar to Maslow's hierarchy of needs.

Bloom's Taxonomy was important to me because, not only did I readily identify with the hierarchy, it also clearly defined my own path to achieving the highest levels of education on the topic of human-centric complex problem solving. I could now define my journey of discovery by putting a year next to when I

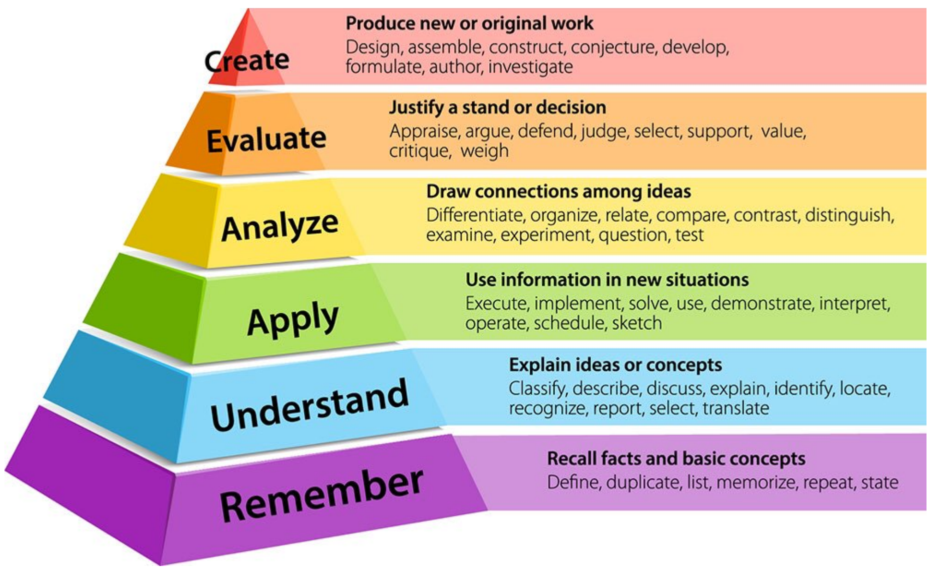
[10] Jones, 2020
[11] Atabaki, Keshtiaray & Yarmohammadian, 2015
[12] Jones, 2020
[13] Forehand, 2005

mastered each of the six stages of Bloom's Taxonomy, from 1989 to 2015.

I reached the final level of Bloom's Taxonomy in 2015: "to create a new or original work after developing a comprehensive understanding of the topic." That is the year I created the hyper-integrated causal analysis methodology for solving complex, human-centric problems under the trademarked name of BlueDragon®.

Robert H. Ennis, whose entire career revolved around critical thinking and philosophy, wrote: "Critical thinking is represented in the three upper levels of Bloom's Taxonomy (i.e. Analyze, Evaluate, Create). At the end of the learning process, the goal with Bloom's taxonomy is that a student has honed a new skill, level of knowledge, and/or developed a different attitude towards the subject."[14]

Figure 1 – Bloom's Taxonomy



The marriage of critical thinking skills, tools and techniques with a modern complex problem-solving framework proved to be most effective in addressing human-centric problems (i.e. human error, at-risk behaviors, equipment failures, and organizational and programmatic breakdowns).

This marriage of critical thinking and complex problem solving has achieved amazing results: most complex problems can now be solved in one to two weeks. My own average is five days.

Only in the most difficult of cases have my investigations taken up to two weeks to complete. Completing a complex investigation in one week is in sharp contrast with industry averages, where similar investigations can take many weeks and months, as they can be done without tying up considerable resources. The savings in time and money are significant; resources that can now be returned to mission critical tasks.

At the Savannah River National Laboratory, my method was adopted by Savannah River Nuclear Solutions (SRNS), the management company for the laboratory. Prior to 2017, Savannah River had experienced recurring problems and partial shutdowns for extended periods. In 2017, SRNS established an initiative to strengthen its Contractor Assurance (CAS) Program, adopting the "BlueDragon Critical Thinking and Complex Problem Solving Method" as its root cause methodology. In October 2019, two years after implementation, the President and CEO of SRNS and the CAS Manager attended one of our workshops and offered the following comments: "The CAS, of which the BlueDragon Causal Analysis process is a significant part, has driven substantial performance improvement throughout our company. In the last two years we have cut our personnel

[14] Ennis, 1993

error events in half, have seen a significant increase in resources available to perform mission critical tasks, and have had an increase in production of 25%."

At about the same time, we discovered that the method could be used proactively to investigate negative trends of lower level events that were indicative of more significant problems. The proactive use of the method was solidified after conducting three investigations:

- *Independent Root Cause Analysis of a Negative Trend of Critical Procurement Issues in the Procurement/Acquisition Program at the Savannah River National Laboratory*
- *Independent Root Cause Analysis of a Negative Trend of Dropped Objects From Great Heights at the Uranium Processing Facility Project in Oak Ridge, TN*
- *Independent Root Cause Analysis of a Longstanding Negative Trend of Untimely Completion of Condition Report Action Items at the Bechtel Infrastructure Global Business Unit*

This meant that we could identify the deepest-seated causes before they could cause a much more serious problem or an event.

The proactive use of this method to evaluate negative trends stands out as a significant advancement in complex problem-solving.

The list of companies and sites that have adopted this methodology has grown steadily and now includes the majority of the US National Laboratories and the Nuclear Weapons Complex. It is gratifying that organizations have recognized the value of a method that relies heavily on critical thinking, and not on applications that purport to solve problems for you.

Another development in the latter half of the decade was my foray into higher education. In 2016, I set out to bring critical thinking and complex problem-solving to colleges and universities as a not-for-profit initiative. I visited a half-dozen colleges including the US Naval Academy and one of the Historically Black Colleges and Universities. And although they grasped the need for developing practical critical thinking and complex problem-solving skills in support of developing higher order thinkers, I found it challenging to get them interested in enhancing their existing curriculum. After many unsuccessful attempts, I began inviting college seniors and graduate students to take my courses at no cost. So far, over 125 college students have been exposed to these critical thinking tools and problem-solving techniques.

One noteworthy exception was Princeton University's Keller Center for Innovation in Engineering Education, Entrepreneurship, and Design Thinking, where they are training students to work with actual clients on solving some of society's "wicked" problems using Design Thinking under a program called the "Tiger Challenge." After speaking with the Director of the Tiger Challenge, we instantly found a natural fit between their Design Thinking curriculum and the critical thinking tools and techniques I was teaching. Since 2016, I have been invited by the Keller Center as a guest lecturer, to teach these critical thinking and problem-solving tools to their Design Thinking teams.[15] The latest training session was held on July 7, 2020, and the training was done entirely online due to the COVID-19 pandemic.

15 https://kellercenter.princeton.edu/stories/critical-thinking-tools

TEACHING CRITICAL THINKING

SKILLS AND TOOLS TO STRENGTHEN OUR ABILITY TO SOLVE PROBLEMS

As previously mentioned, my school of thought falls in line with other practitioners that are seeking tangible, teachable critical thinking tools and techniques that can be applied in a particular field of study.

I was comforted to find notable scholars that shared this school of thought. In 1990, Joseph Halpern (PhD in mathematics from Harvard and currently a professor of computer science at Cornell) wrote: "Critical thinking is not just a concept, but it is a process that involves solving problems through which decision can be reached."[16] Over the years, a number of other scholars have published similar conclusions. In summation: "The focus should be on the active use of critical thinking, learning methods of addressing and practicing it, and exercising rational thinking through active engagements using the cognitive skills that bring thoughtful questioning methodologies."[17]

To teach critical thinking in the context of supporting the investigation of complex problems, meant that its concepts had to be crystalized in a way that could be readily taught, grasped, remembered, understood, and applied (i.e. the first three levels of Bloom's Taxonomy).

The first challenge was to develop a practical definition of critical thinking that would be simple enough to understand the skills required to engage in the problem-solving process.

In 2015, I crafted a teachable definition of critical thinking that my students have been able to readily translate into action.

Critical thinking is: "the intellectually disciplined process of gathering, organizing and analyzing information, so we can make the best decisions or take the best course of action."

The definition does not stray far from the definition provided by the U.S. National Council for Excellence in Critical Thinking in 1987, but it provided a construct that could be broken down and taught, using concrete and repeatable examples of how to think more critically throughout the process. And through the use of case studies, students are able to quickly progress through the first three stages of Bloom's Taxonomy (Remember, Understand, Apply) and develop a baseline level of proficiency.

Each part of the definition is defined in the context of how the skills are used within the complex problem-solving framework.

"**Intellectually**" infers that the process of critical thinking does not rely on Artificial Intelligence or software. Rather, we must rely on our own ability to critically evaluate the situation and all available information, formulate the best possible questions, and interact with other subject matter experts to solve the problems. It is here that we make the point that:

Artificial Intelligence is for answers; humans still have to ask the critical questions.

"**Disciplined process**" denotes that we are going to follow a rubric. It took years to develop an effective framework that has proven to be accurate and efficient. Many clients that struggle with finding the causes of their recurring problems are using non-disciplined processes such as brainstorming and intuition, identifying the low hanging fruit and often placing blame on an

16 Halpern, 1990

17 McPeck, 1981; Beyer, 1985; Halpern, 1998; Reid, 2009

individual. These organizations are looking for a way to solve their problem as quickly as possible and move on to the next one, but they only address the symptoms.

"**Gathering information**" is a concept that can be readily taught, understood and applied. Before starting an investigation into a problem, we can obtain documents, procedures, operating logs, emails, witness statements and other information that can be readily gathered for our review. With enough information and evidence, we can develop focused and evidence-based lines of inquiry that will lead us to the deepest-seated causes.

"**Organizing information**" refers to the use of any number of tools that allow us to capture and evaluate the information we have gathered. The more organized our information, the better we can develop insights that we can use during our analysis. Some of the more powerful tools I routinely use for organizing and analyzing information include simple tables, Pareto charts, fault trees, affinity diagrams, process maps, KT-decision making matrix and the T-matrix.

"**Analyzing information**" refers to a broad range of methods we use to analyze the information we have gathered and organized, the most fundamental of which is Cause & Effect Analysis. The drive to develop faster, more accurate and more cost-effective means to get to the deepest-seated causes drove me to develop a framework that integrates many of those methods into one seamless approach (i.e. hyper-integrated causal analysis).

The Causal Analysis tools and techniques that are seamlessly integrated into the complex problem-solving framework shown on Figure 2, include:

- Barrier Analysis
- Task & Change Analysis
- Comparative Timeline Analysis
- Human Performance Evaluations
- The Anatomy of an Event
- 5-Why's and Cause Trees
- Cause & Effect Analysis
- Socratic Questioning
- Common Cause Analysis
- Ishikawa (the Fishbone)
- Events & Causal Factors Charting

The overall framework and the individual tools and techniques that go into the methodology can be taught, learned and mastered with enough practice.

"**Make the best decisions or take the best course of action**" is the ultimate outcome of thinking critically and solving problems. The end result of gathering, organizing and analyzing available information is the knowledge and insights needed to decide what actions to take or to help us make the best decision possible. For my clients, identifying the deepest causes of their problems allows them to put in place corrective actions that will prevent recurrence, saving time and resources that can be better spent on mission critical tasks.

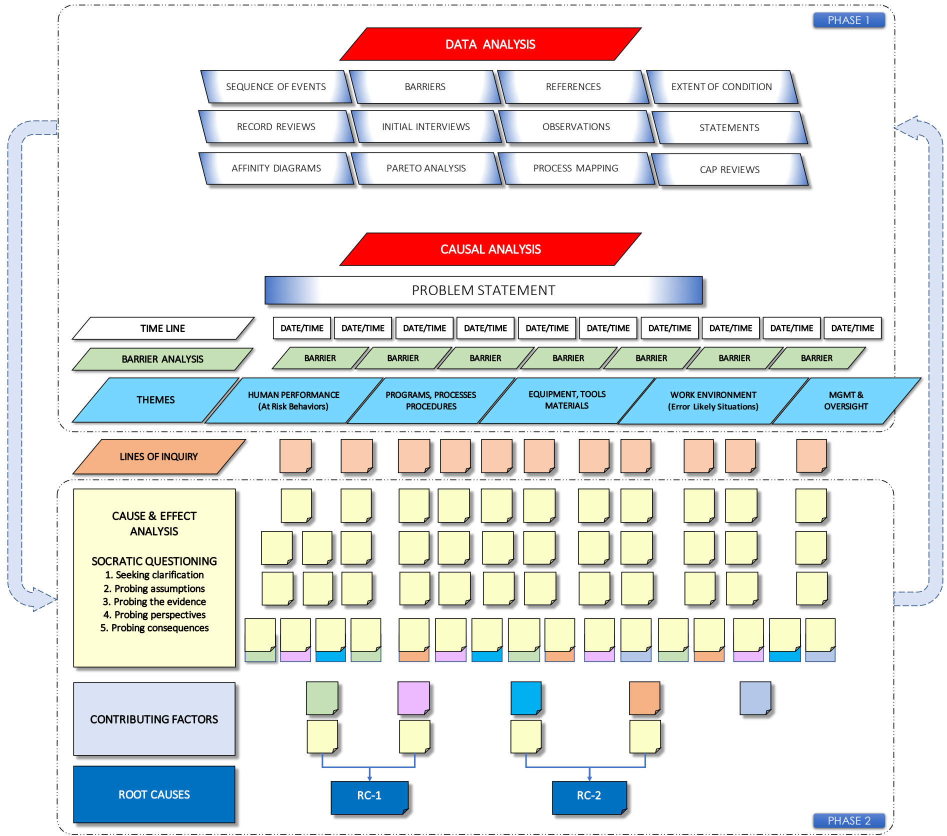
Critical thinking (and not a software application) has become the fundamental concept that drives every aspect of this complex problem-solving methodology.

We gather and critically evaluate every piece of available information to draw insights used in our analysis

We develop great questions to seek clarification, evaluate different perspectives, challenge assumptions, probe the evidence and evaluate implications

We follow a disciplined framework that allows us to harness the intellect of others and identify the deepest-seated causes of our most complex problems

Figure 2 – The Human-Centric Complex Problem-Solving Framework

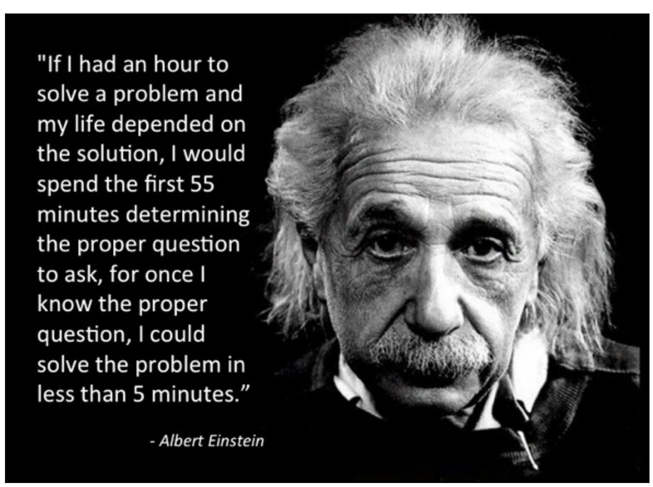


The marriage of critical thinking and problem-solving is effective because students are taught to develop the best possible questions using every bit of available information and insights from the critical review of data before starting cause & effect analysis (i.e. before starting to ask questions). Figure 2 shows the process is divided into two phases: data analysis and causal analysis. The whole purpose of our research and data analysis is to be able to generate the best evidence-based lines of inquiry possible, as that is the key to a successful outcome.

Einstein is famously quoted for stating that determining the proper questions to ask is of paramount importance in solving any problem.

It is the development of great questions that will determine whether our efforts will succeed.

Once we develop lines of inquiry that are based on the evidence, on available information, and with the goal of challenging assumptions, probing the evidence and implications, we increase the effectiveness of our investigations.



As in the study of any methodology, it takes much practice before a student can achieve the level of proficiency needed to solve the most complex of problems.

But any student can climb the first three rungs of Bloom's Taxonomy after initial training and a bit of practice (i.e. remembering, understanding, applying).

And one does not have to aspire to reach the top of Bloom's Taxonomy in order to be proficient at critical thinking and complex problem solving. With enough training and practice, many can become proficient at applying these skills.

THE CRITICAL THINKING PARADOX

ARTIFICIAL INTELLIGENCE HAS HIGHLIGHTED A GAP IN OUR EDUCATION SYSTEM

We are in the 4^{th} Industrial Revolution, the age of AI and Machine Learning, which is going to reshape our jobs and our education system. It would seem sensible that teaching the human skills that will not likely be replaced by AI (i.e. the WEF's list of top 10 skills) would receive much more emphasis in education systems. However, studies show that higher education institutions have not evolved their pedagogy to meet the increasing demand for higher order thinkers in the age of AI. (and I would add to that: complex problem-solving). It is paradoxical that, as world leaders ask for universities to produce higher order thinkers and highlight the human skills that will become even more essential in this new age of AI and machine learning, mainstream academia has not pivoted to meet these demands.

As we approach the golden age of AI, we find ourselves in a paradox: the more we race towards advances in artificial intelligence and machine learning, the more we seem to be distancing ourselves from our ability to think critically and solve our most complex problems.

Even though he wrote this in 1990, Joseph Halpern hit the nail on the head: "Technology advancement has also increased the demands for more critical thinkers. There are more demands than ever to teach critical thinking skills in higher education institutions. Teaching students the skills to think critically without real-life applications is not that useful."[18]

The best study I found on this point comes from research conducted by Dr. Richard Paul, Dr. Linda Elder and Dr. Ted Bartell. Although it is from 1997, I would assert that it holds true today. In their study of 38 public universities and 28 private universities [in California] to determine faculty emphasis on critical thinking in instruction, they concluded: "Careful analysis of the interviews indicates that the central problem is that most faculty have not carefully thought through any concept of critical thinking, have no sense of intellectual standards they can put into words, and are, therefore, by any reasonable interpretation, in no position to foster critical thinking in their own students or to help them to foster it in their future students-except to inculcate into their students the same vague views that they have."[19]

Since 2017, I have asked a small sample of several hundred college graduates whether their curriculum included the practical application of critical thinking and (human-centric) complex problem-solving skills. The results were a resounding no: most of the students had not taken any courses on the practical application of critical thinking and complex problem-solving, with one exception: the Design Thinking programs at a few universities.

The vast majority of students are no better prepared or more skilled to think more critically or solve complex, human-centric problems than I was when I entered the work force nearly four decades ago. I was able to strengthen my own critical thinking skills because they are integral to a major part of my life's work.

If formal critical thinking and problem-solving skills are not developed by the time a student completes their formal education, their chances of developing those skills diminish as they fall into the slipstream of their professional life.

Most college graduates will not have the opportunity to hone those skills on their own. We are also in a communication crisis in this country, providing an even

[18] Halpern, 1990

[19] Paul, Elder, Bartell (1997)

more compelling reason for enhancing our education system with practical critical thinking skills. The communication crisis stems from the amount of misinformation put out by the mainstream media; conclusions that are unsupported and go unchallenged because we don't ask our own questions and draw our own conclusions.

Halpern was almost clairvoyant in describing this issue in 1990, and it has become a more pressing problem in recent years: "Education leaders should teach students the skills of checking the credibility and reliability of sources obtained in different ways to be able to make a sound judgment. These skills are increasingly becoming an integral part of teaching critical thinking."[20] In her paper published in 2020, Alison King took a similar position: "Critical thinkers investigate things around them and ask good questions every time they come across things that are not satisfactory to them."[21]

Higher education institutions have continued to fall behind in meeting the demands for higher order critical thinkers as the world advances towards AI, with noteworthy exceptions such as universities that are teaching Design Thinking (Stanford, Princeton and others). With the world jumping on the AI bandwagon, we are establishing a deep dependence on all things digital; instant access to information and blazing fast computations. We are also developing a false sense that the almighty microchip can think for us and solve our problems.

Congruent to the AI Paradox, there is empirical evidence that universities have a long tradition of focusing more on the philosophical aspects of critical thinking. Case in point: try asking your local colleges whether they have a course on how to solve problems using critical thinking (i.e. a course on par with calculus or thermodynamics).

> The scales of academia are tipped heavily in the direction of the theoretical and philosophical studies of critical thinking and not on its practical application.

There does not seem to be equal interest in developing courses that teach the more practical applications of critical thinking and solving problems that cannot be solved by math or science. Not only should there be a world-wide awakening as to the importance of teaching the practical application of critical thinking skills, but the concepts and skills should be taught from the time a student enters Kindergarten and continue through post-graduate studies.

Figure 3 – The Author Teaching Critical Thinking and Complex Problem Solving

[20] Halpern, 1990

[21] King, 2020

CONCLUSION

HIGHER EDUCATION NEEDS A CALL TO ACTION WHEN IT COMES TO CRITICAL THINKING

After a professional career spanning nearly four decades, I can readily admit that the more I learn about critical thinking, the more I recognize that it is a vast ocean from which I have only drawn a cup. Although I am not satisfied with the limited knowledge I've managed to take out of that ocean thus far, I did manage to apply that small bit of knowledge to create my own small oasis from which I could draw from and move forward in my area of expertise. If I had to choose what was my biggest lesson learned along this journey, it is this:

There is a critical need for updating our education systems with curricula that include critical thinking and problem solving. Specifically, critical thinking concepts should be translated into practical skills that can be taught and practiced so that students can reach a level of proficiency by the time they enter the workforce.

Academia is focused largely on problems that can be solved with math and science and paying far less attention at training us how to solve this whole other universe of complex, human-centric problems. We have waves of graduates that are largely unprepared to solve the problems that they will face as soon as they enter the workforce.

Two recent studies bring this point home. They concluded that nearly half of millennials get an 'F' in critical thinking."[22],[23] The lack of critical thinking skills in that sample group highlights the continuing need for educational systems to evolve their pedagogy to meet the demand for higher order thinkers, with added emphasis on critical thinking and problem solving.

In the study of public and private universities in California mentioned on page 16, the authors offered four interventions as a requisite for substantive change to occur in academia: (1) Disseminate the information faculty needs to change their perceptions; (2) Provide for faculty skill-building through appropriate professional development; (3) Establish a mandate to systematically teach critical thinking (and how to teach for it) in all programs of teacher education: and (4) Develop an exit examination in critical thinking for all prospective teachers. That report was published 23 years ago, and although improvements were made at certain institutions, empirical evidence shows that universities and colleges have not been able to pivot and meet the ever-increasing demands for higher order thinkers.

The closer we get to Artificial Intelligence, the faster we are leaving critical thinking in the rear-view mirror. Therefore, in addition to the four interventions listed in the 1997 research (which I heartily endorse), I would add this call to action: Rather than waiting for our education system to catch up, we should challenge those who have studied and are proficient in critical thinking and problem solving, to find ways to intervene, to make a difference, no matter how small. We should teach our peers, students, protégés and our children the basic critical thinking skills that they will need to thrive in the age of AI (their future). This challenge is especially aimed at those that have the opportunity to teach at the lower grade levels. This call to action also reinforces the need for organizations such as The Foundation for Critical Thinking, which I only discovered in 2018, to continue to expand their reach.

Mary Halton, a science journalist and ideas editor at TED writes: "We need to give students an opportunity to grapple with questions that don't necessarily have one correct answer. This is more realistic of the types of situations that they're likely to face when they get outside the classroom. How can we encourage kids to think critically from an early age? Through an activity that every child is already an expert at — asking questions!"[24]

Imagine for a second if, each year, a cadre of students entered the workforce with 16 or more years of education and experience on the practical application of critical thinking and problem-solving…what a different world this would be.

---

[22] Williams, 2020
[23] MindEdge Online Survey, 2020
[24] Halton, 2019

REFERENCES

1. Dr. Alex Jones, Conceptual Analysis of Critical Thinking in the 1990s, International Journal of Management (IJM), 11 (3), 2020, pp. 278–286. http://www.iaeme.com/IJM/issues.asp?JType=IJM&VType=11&IType=3

2. World Economic Forum (2016): The 10 skills you need to thrive in the Fourth Industrial Revolution. https://www.youtube.com/watch?v=TZRyCrTX9oQ

3. Cooper, K. (2020). "Wicked" problems: What are they, and why are they of interest to NNSI researchers?

4. Sternberg, R. J. (1986). Handbook of intelligence. New York: Cambridge University Press.

5. Lipman, M. (1988). Critical thinking: What can it be? Educational Leadership, 46(1) , 38-43.;

6. Ennis, R. H. (1989). Critical thinking and subject specificity: Clarification and needed research. Educational Researcher, 18(3), 4-10.;

7. Cabrera, G. A. (1992). A framework for evaluating the teaching of critical thinking. Education, 113(1), 59-63.

8. Sormunen, C., & Chalupa, M. (1994). Critical thinking skills research: Developing evaluation techniques. Journal of Education For Business, 69(3), 172.

9. Halpern, D. F. (1999). Teaching for critical thinking: Helping college students develop the skills and dispositions of a critical thinker. New Directions for Teaching & Learning, 80, 69–74.

10. Joseph Juran and Joseph A. De Feo (1988). Juran's Quality Handbook; The Complete Guide to Performance Excellence."

11. LeBoeuf, Michael (1985). The Greatest Management Principle in the World: For Anyone That Needs to Get Anything Done. Berkley Books, New York, N.Y.

12. A. Siahi Atabaki, N. Keshtiaray & M. Yarmohammadian (2015). Scrutiny of Critical Thinking Concept. Published by Canadian Center of Science and Education.

13. Brookfield, Stephen D. (1987). Developing Critical Thinkers. Josey-Bass, San Francisco, CA.

14. Forehand, Mary (2005). Bloom's Taxonomy – Emerging Perspectives on Learning, Teaching and Technology. Retrieved from: https://cft.vanderbilt.edu/wp-content/uploads/sites/59/BloomsTaxonomy-mary-forehand.pdf.

15. Ennis, R. H. (1993). Critical thinking assessment. Theory Into Practice, 32(3), 179.

16. King, A. (1995). Inquiring minds really do want to know: Using questioning to teach critical thinking. Teaching of Psychology, 22(1), 13–17.

17. McPeck, J. E. (1981). Critical thinking and education. New York: St. Martins Press.

18. Beyer, B. K. (1985). Critical thinking: What is it. Social education, 49(4), 270-276.

19. Halpern, D. F. (1998). Teaching critical thinking for transfer across domains: Disposition, skills, structure training, and metacognitive monitoring. American Psychologist, 53(4), 449.

20. Reid, J. (2009). Can critical thinking be learned. Mid-West Regional Educational Research Association.

21. Halpern, J. Y. (1990). An analysis of first-order logics of probability. Artificial intelligence, 46(3), 311-350.

22. Williams, T. (2020). "Study: Nearly Half of Millennials Get an 'F' In Critical Thinking."

23. MindEdge (2020). "Dig Deeper: Critical Thinking in the Digital Age," an Online Survey of Critical Thinking Skills. (MindEdge is a company founded in 1998 by Harvard and MIT educators).

24. Halton, M. (2019). Critical thinking is a 21st-century essential — here's how to help kids learn it.

25. Case, R. (2005). Bringing critical thinking to the main stage. Education Canada, 45(2), 45–46.;

26. Giancarlo, C. A., Blohm, S. W., & Urdan, T. (2004). Assessing secondary students' disposition toward critical thinking: Development of the California measure of mental motivation. Educational and Psychological Measurement, 64, 347–364.

27. Paul, R., Elder, L., & Bartell, T. (1997). Study of 38 public universities and 28 private universities [in California] to determine faculty emphasis on critical thinking in instruction. Retrieved from http://www.criticalthinking.org/pages/center-for-critical-thinking/401