Inculcating Metacognition and Critical Thinking: Pedagogical Infrastructures Employing Virtual Humans

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ABSTRACT

This paper reviews the need of and opportunities for improving metacognition and critical thinking in today's DoD personnel. It identifies some current constraints on effectively addressing those issues, and reports on advances in virtual human interfaces that can enhance efforts to augment current educational approaches. The paper asserts that these new techniques would be beneficial to Warfighters and it presents the case that instantiating these pedagogical approaches would be best served by the use of emerging, but prenascent, proactive conversational computer agents using Natural Language Processing (NLP). The paper opens with a view of the need for both metacognition and critical thinking skills in today's defense environment and a reports on the number of leaders, analysts, and staff who decry the current state of those abilities. The capability and need to begin this educational process early with the Warfighters is advanced. Then, a review of the recognized pedagogical approaches to improving these proficiencies is countered by an explication of the many personal, organizational, and social hurdles to implementing these approaches. The last major section is a description of recent advances in the modeling and simulation community leading to the availability of conversationally facile virtual humans and other computer agent avatars with the capability of counteracting the obstacles currently hampering the education required. Some of the obstacles addressed are classroom scheduling, operational schedule overloads, geographic isolations, and personal characteristics of both educator and student. Recent research outcomes are offered as examples of current capabilities and future research efforts are outlined, offering design concepts and previewing some capabilities of new tools that will soon be available to the professionals in this discipline. These capabilities are described with sufficient detail to allow the reader to see if these programs might be applicable in their own work, either now or in the years to come.

ABOUT THE AUTHORS

Dan M. Davis, J.D., is active as a consultant at the Institute for Creative Technologies, University of Southern California (USC), focusing on large-scale DoD simulations and avatar uses. Prior to retirement, he was the Director of the JESPP project at USC for a decade. As the Assistant Director of Advanced Computing Research at Caltech, he ran Synthetic Forces Express, bringing HPC to DoD simulations. He also served as a Director at the Maui High Performance Computing Center and in computer research roles at the Jet Propulsion Laboratory and Martin Marietta. He was the Chairman of the Coalition of Academic Supercomputing Centers and has taught at the undergraduate and graduate levels. As early as 1971, Dan was writing programs in FORTRAN on one of Seymour Cray's CDC 6500's. While in the Marine Corps, he saw duty in Vietnam as a Cryptologist and retired in 2002 as a Commander, U.S.N. He received B.A. and J.D. degrees from the University of Colorado in Boulder.

Frederica J. Stassi. Ed.D. is a Science Education Analyst, working in the Central Coast of California. Her background includes research for the National Science Foundation in which she was funded to study pedagogies and efficacies in U.S. Science museums. This research involved museums from the East Coast to Oʻahu in Hawaiʻi. Her doctoral research was conducted with the advice of Professor William McComas and focused on the development of science standards for the State of California. She received a B.A. degree from Tabor college Hillsboro, Kansas as well as an M.A. Degree and an Ed.D., both from the University of Southern California in Los Angeles.

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INTRODUCTION

The major thesis of this paper is that technologies are emerging that will enable expansion of critical thinking and metacognition skills so that innate intellectual capabilities can better be made manifest. This approach is vital to the optimal pursuit of defense organizational goals. There are constraints that hinder inculcating such skills in DoD personnel and these constraints are not easily ameliorated. The paper opens with a background discussion of the need for enhanced command sophistication in defense organizations. Then, there is an introduction to the concepts of metacognition and critical thinking, followed by research into the definition and use of these terms in education and defense communities. An effort to define the term critical thinking is presented, along with the results of an informal small ethnographic survey.

Then there is a report on the recent advances in Virtual Human (VH) technologies as potential responses to the hurdles identified earlier. There is a short review of common applicable pedagogies to assist those less familiar with them. This paper will use the term "pedagogy" as meaning the art and science of teaching, inclusive of the less familiar, but perhaps more DoD-germane term for teaching adults: "andragogy." Then there is a section on applying these capabilities to the issue at hand, along with a discussion of metrics. That process is discussed and conclusions are advanced, along with issues to be addressed in the future.

Background

Prior to discussing the technical advances that lie at the heart of this paper's major thesis, it may be beneficial to consider the context in which such advances may be made practical and their utility made valuable. It's being impractical to cover here so large a body of experience, insight and lore, a few germane anecdotes will be adduced to set the stage.

Populations have been at war with each other for at least as long as there was a system of recording conflicts. Combat presents an unforgiving environment for those who did not think rationally. Early on the Greeks developed the concept of massing a dense body of fighters into an almost irresistible weapon to shatter the enemy lines. Henry the Fifth's long bowmen at Agincourt gave a person pause to consider if that was still true, but 400 years later at Waterloo, Wellington's troops still formed shoulder-to-shoulder to face an enemy with muskets that were perhaps less accurate than Welsh long bows (Keegan, 1993). A scant fifty years after that, the US would pay in blood for not recognizing that the Civil War rifle had gotten more accurate and longer ranged (Murray, 2016). The American marksmen had grown up with firearms in their hands. Toward the end of that war, a critical thinker developed and advocated a more dispersed and agile style of attack in response to these technologies (Randolph, 1905). But all was forgotten during the American Indian Wars and the British Colonial Wars, and that oversight led to the incredible losses in WW I (Scales, 1976). German Maxims did not honor the bravery of men walking in orderly fashion toward their trenches. In fact, an extension of those inclinations to form an "iron fist" of men may have found its expression in the case of Torpedo Eight in WW II's battle of Midway, in which every plane of that unit was shot down without a landing a single blow against the Japanese Imperial Navy (Mrazek, 2008). A dearth of critical thinking missed the fact that the concentrated planes of Torpedo Eight did not provide the Americans with an iron fist; it provided the Japanese with a single target upon which the entire fleet could concentrate their defenses. A fifth of the names on the Wall at the Vietnam Memorial did not die at the hands of the foe (National Archives, 2020) and it is unknown how many of the other four-fifths were lost due to lack of real-time critical thinking. If the nation were to be able to engage the emerging powers of virtual reality and virtual humans to improve both selection and training to reduce such errors, good work will have been done for the defense personnel who are in harm's way.

The delegation of command authority further and further down the chain of command means that even junior Non Commissioned Officers (NCOs) now have operational distance from higher command oversight and counsel, so they must exercise independent judgment in combat operations (Hogan, 2003). Ironically, the locus of higher-level

control has flowed from the front line Roman Centurion to the Army headquarters of World War II to the halls of Washington during the Vietnam War. Indeed, many casualties inflicted on radical Islamists came by recent decisions made by drone operators sitting in communication centers located on a different continent.

Critical Thinking

One of the major issues is that of recognizing the essential capabilities and the kind of analytical reasoning needed by today's warfighters. Good g-factor tests can measure intellectual capabilities and these tests have been extant in one form or another for millennia, having been in place at least as early as 165 BC (Fu, 1993). Courage can be tested to some degree by challenging candidates with daunting tasks in Officer Candidate programs. However, testing for the subtle and multi-faceted characteristic that is labeled "critical thinking" is much more problematic and much in need of an independent study to characterize the concept and quantify its magnitude and potential. These capabilities are susceptible to stress and fatigue, the two major characteristics of the combat environment. An earlier paper discussed how emerging technologies may speak to these psychometric problems as well (Shaw, 2019).

While the term may be relatively recent (Dewey 1910), consideration of the concept has been extant since the time of the pre-Christian Greek Philosophers. (Visser, 2019). Critical Thinking was not emphasized during the imperial age of the Roman Empire nor the European dark period that followed, but its tradition remained alive in the Asia. Later, it was a major focus in the Age of Enlightenment, as shown by names ranging from Bacon through Jefferson (Withers, 2008). With the age of industry upon the world, the need for critical thinking increased even more. This need was evidencing itself within the defense structures of every nation, as weapons went from tools that can be forged at home to sophisticated machines that required elevated technical expertise to even operate. (Keegan, 2011)

Metacognition

One of the issues that has arisen is how critical thinking is developed and sustained. One method according to Philip Tetlock of Princeton is for the analyst to consider their own method of cognition (Tetlock & Gardner, 2016). Metacognition could be defined in a phrase, "thinking about how one thinks," and it may be one of the most human of the personal characteristics. The term metacognition is of recent advent compared to critical thinking; it was first advanced by Flavell late in the 20th Century. He stated that metacognition refers to knowledge and to cognition about cognitive phenomena and broke that down further into subsets of metacognitive knowledge and experience (Flavell, 1976). This section will concentrate on relating the warfighters' self examination experience and how that should and could impact their metacognitive knowledge, and therefore, their ability to command. *cf.* The fictional, but insightfully rendered, Shakespearean characters Fluellen and Gower (Shakespeare, 1599) in Henry the Fifth exhibit some of the paralyzing self-reflections that are more craven than creative. Some critical thinking is put to good purpose by theorists drive to advance the cause of their nation and minimize bloodshed of their countrymen, *e.g*. Clausewitz (1832), Mahan (1890), Hart (Danchev, 1998), and Scales. (Scales, 1976). Today, junior officers have gone from being enforcers of the General's battle orders, to now being entrusted to make decisions of global significance and respond to situations with sophistication.

While metacognition has garnered a lot of academic interest and a plethora of professional papers, the warfighters may wonder what applicability it has for them. There have been some studies, albeit more anecdotal than statistically pure, that have shown a high correlation between metacognitive activity and performance in intellectual fields (Romainville, 1994). But, not all uses of metacognition are universally seen as beneficial. The thrust of many of these arguments seem to be that sometimes focusing on understanding the process by which one learns, is more a distraction than an aid, *e.g* one cannot learn to ride a bicycle by thinking about it. History is replete with examples of battles being lost because the leader was paralyzed by indecision and examples of battles won by a leader's just "picking up the flag and saying follow me" (Tolstoy, 2008). There has been significant discussion about times when metacognition is not productive (Mathematics Educator, 2020). Being alerted to such issues, the authors maintain it is a vital skill for the warfighter, based on operational defense experience and on significant scholarly study.

Natural Language Processing

Another discipline, more associated with artificial intelligence than cognition analysis, Natural Language Processing (NLP) composes "an area of research and application that explores how computers can be used to understand and manipulate natural language (text or speech) to do useful things" (Chowdhury, 2003).Using this definition within the context of virtual environments, NLP tools use computer technology to recognize voice input, analyze voice tone, provide lifelike conversation, retrieve information, and many other applications, in combination with machine

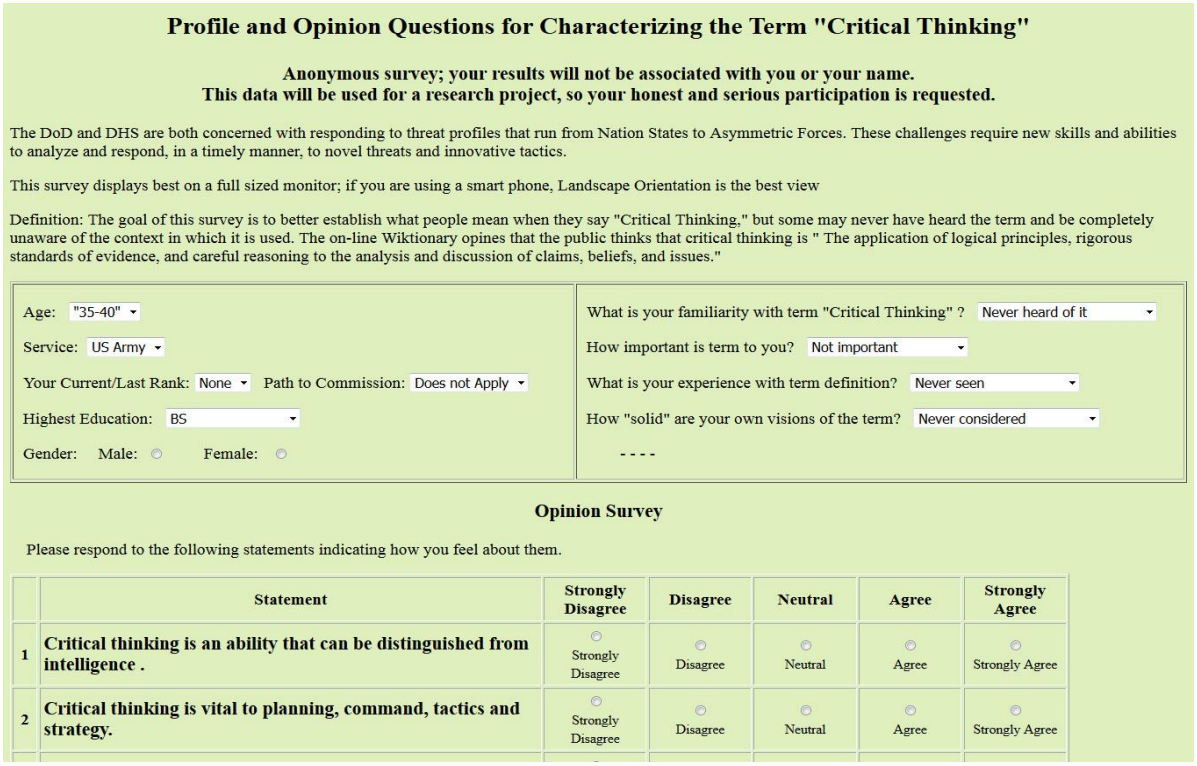
learning. Recent developments in NLP allow "a single convolutional neural network architecture that, given a sentence, outputs a host of language processing predictions: part-of-speech tags, chunks, named entity tags, semantic roles, semantically similar words and the likelihood that the sentence makes sense (grammatically and semantically) using a language model" (Collobert & Weston, 2008). This is central to cognition studies presented below.

CONSIDERATIONS AND ASSUMPTIONS

Definitions

"Critical Thinking" is a term for which many people have significant experience, but little need or opportunity to consider the precise definition of the term. A search has not found definitive evidence of either the recent advent of the concept or an identifiable originator as champion or of the term to whom one could turn to define it. A straight forward approach may be to rely on reference sources. Critical thinking is: "The application of logical principles, rigorous standards of evidence, and careful reasoning to the analysis and discussion of claims, beliefs, and issues." (Wiktionary, 2020). Critical thinking may be one of those concepts that is better understood in the abstract. When considering a different term, Justice Potter Stewart opined: "… I know it when I see it …" (Stewart, 1964). To find a more contextually satisfying definition; counsel was sought from a few close academic and military brethren.

It was decided to survey a more wide-spread and diverse group of military personnel. As no funding was available for a carefully circumscribed and statistically sophisticated study, value was still to be realized from conducting an ethnographic study of a small number (n=<100) of veterans. An instrument was designed to seek input on the definition of the term "critical thinking," observable indicia of it, and its relative value in military service. A group of 38 military veterans for whom eMail addresses were known were invited to participate in the survey. The invitees included pay grades from E-5 through O-8. The participants were further asked to forward their own invitation to veterans and civilians they knew that would be likely to have opinions on the topic. This technique is often called "snowball sampling"; many feel these surveys have both limitations and legitimate uses (Noy, 2008). The survey consisted of a brief introduction, collection of some demographic data, four questions on familiarity and use of the term and a 13-item Likert-style evaluation survey of the indicia of critical thinking. That was followed by text boxes to add to the issues under consideration. This was created using HTML forms for the survey page and PHP code for the data processing, storage and analytic functions. The top of the survey instrument appears in Figure 1.



Profile and Opinion Questions for Characterizing the Term "Critical Thinking"

Anonymous survey; your results will not be associated with you or your name.
This data will be used for a research project, so your honest and serious participation is requested.

The DoD and DHS are both concerned with responding to threat profiles that run from Nation States to Asymmetric Forces. These challenges require new skills and abilities to analyze and respond, in a timely manner, to novel threats and innovative tactics.

This survey displays best on a full sized monitor; if you are using a smart phone, Landscape Orientation is the best view

Definition: The goal of this survey is to better establish what people mean when they say "Critical Thinking," but some may never have heard the term and be completely unaware of the context in which it is used. The on-line Wiktionary opines that the public thinks that critical thinking is " The application of logical principles, rigorous standards of evidence, and careful reasoning to the analysis and discussion of claims, beliefs, and issues."

Age: "35-40" | What is your familiarity with term "Critical Thinking" ? Never heard of it
Service: US Army | How important is term to you? Not important
Your Current/Last Rank: None | Path to Commission: Does not Apply | What is your experience with term definition? Never seen
Highest Education: BS | How "solid" are your own visions of the term? Never considered
Gender: Male: Female: | - - - -

Opinion Survey

Please respond to the following statements indicating how you feel about them.

	Statement	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	**Critical thinking is an ability that can be distinguished from intelligence .**	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
2	**Critical thinking is vital to planning, command, tactics and strategy.**	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Figure 1. Ethnographic Survey on Critical Thinking

This instrument was in no way intended or designed to be statistically compelling evidence in support of an articulated thesis. It was instead a working document to aid the researchers in their work. The instrument remains on-line and the researchers continue to value and to seek input on the issues covered therein. The reader is invited to contribute to this work by participating in the survey. The time required is about five minutes is most conveniently taken on a large screen device rather than a smart phone. The URL address for the survey is: http://www.hpc-educ.org/Danz/CrtThnkSurvRedirect.html

The data management program first checks for completion and then evaluates the Likert data for non-compliance (*e.g*. no answers or all Likert answers the same value. Discrepancies are noted and the participant is invited to go back one page and complete the form. While there is no rigorous security to prevent specious data being maliciously submitted, the program has a function, disabled during this test phase, that checks to see if the previous input internet address is the same as the current one, in which case a diagnostic window advises the participant to contact the *webmeister* to resolve the matter.

The data submitted, along with the text, was forwarded via eMail to the team for consideration and analysis. This function also had the benefit of providing a back up of the data, retained on the eMail server, should something go awry and the data files themselves be lost for any reason. Of the 38 invitees, no one reported technical issues pertaining to or complaints about the survey. Several asked to see the response summaries when completed. As data is still being collected, updated data will be provided at the paper's presentation in early December and available from the research team after the conference.

The users' answers were then reflected to the user as is shown in Figure 2. This page ended with an expression of the researchers' thanks and a reminder for the participant to contact other potential participants for their submission.

Your Data:
Age = 35-40
Service Branch = USA
Current Rank = None
If commissioned, your path: None
Education Level = BS
Gender = Male
Your familiarity with term 'Critcal Thinking' = Never heard the word used
The importance of Critical Thinking was listed as: = Not Important
Your sense of how well defined the term was: = Never Seen
Your own vision of the term was: = Never Considered
Likert Scale Responses:
1. Critical Thinking different from Intelligence - Strongly Disagree
2. Critical Thinking is vital - Disagree
3. Should be factor in advancement - Neutral
4. No Emotionality - Neutral
5. Disciplined Analysis - Disagree
6. Follows hunches - Neutral
7. Recursive Analysis - Disagree
8. Open to Novel Ideas - Neutral
9. Rejects Social Pressure - Disagree
10. Relies on Intuition - Neutral
11. Inclined to Quantify - Neutral
12. Avoids Disruption - Disagree
13. Considers Context - Neutral
Issues comment =
Examples of Critical Thinking =
Commnents =
Submited at 10.57:2 on 05/10/20.

Figure 2. Responses as shown to user

Most of these early responses submitted did not include any input in the three closing text boxes. The reason for this is not certain, but many of the participants had sent the researchers personal eMails and two even made phone calls. As the snowball effect takes hold, more responses in the text boxes may occur. In order to facilitate the more direct method of response, more contact data was added to the user response confirmation page.

The PHP data management program stored the raw data, with the exception of the suggestions additions and examples from the closing three text boxes. It was determined that there was no need for an elaborate relational data base. The content from the three text boxes, were requests for Other Characteristics, Examples of critical thinking or the lack thereof, and Suggestions, were eMailed directly to the authors. This reflected a main goal: hearing what a broader group thought rather than just relying on the team. The effort did not seek to show any proof of a particular thesis or any characterization of an entire defense community. The demographics and Likert data were kept in a comma separated values (CSV) flat file as is shown in Figure 3 below.

```
1  $timestamp, $date, $time, $user, $Age, $Service, $CurRnk, $PathCom, $CurGrade, $Gender, $Term, $TermImport, $Difinitions, $OwnVision,
    $CritThink_Survey[1], $CritThink_Survey[2], $CritThink_Survey[3], $CritThink_Survey[4], $CritThink_Survey[5], $CritThink_Survey[6],
   $CritThink_Survey[7], $CritThink_Survey[8], $CritThink_Survey[9], $CritThink_Survey[10], $CritThink_Survey[11],
   $CritThink_Survey[12], $CritThink_Survey[13]
2
3  1588843331, 05/07/20, 2.22:2, 71.80.185.84, 71+, USN, O-5, Direct, JD, Male, 3, 4, 3, 4, 1, 0, 1, 0, 0, 3, 0, 1, 1, 4, 0, 3, 2
4
5  1588844043, 05/07/20, 2.34:2, 65.191.98.183, 61-70, USN, O-4, ROTC, PhD, Male, 5, 4, 4, 4, 0, 0, 2, 4, 0, 2, 0, 0, 0, 3, 0, 4, 0
6
```

Figure 3 - Flat CSV file showing data from survey

The issue of whether the need for critical thinking and enthusiasm about this issue is worthy of further study is being analyzed. A more sophisticated instrument, a better focused set of questions and a new look at project goals may result in ascertaining a wider mandate to pursue augmented training or a focused education initiative. One of the participants did report an effort in the US Army to address this issue and contact with that effort will be initiated.

The next issue was how to make sense of the data. As already noted, the first insight was a confirmation and quantification of how important this issue is to the American warfighters. But the target issues themselves required some more detailed consideration. In this paper, the analysis is not the main thrust of the paper, so only the raw data amalgamations will be reported. The data and the more informal insights to be drawn therefrom are left to the reader alone to evaluate and internalize. The team felt well-served by this bolstering of their own impressions and that of the previous scholars who had addressed these issues. Term familiarity responses are set forth in Table 1.

Table 1. Participant's Familiarity With and their Use of the Term (N=60)

Familiar with term:	Term Importance:	Definition experience:	Own vision of term:
4 Never heard the word used	11 Not Important	10 Never Seen	4 Never Considered
4 Have heard others use it	0 Interesting	4 No Consensus	2 Nebulous
16 Have used it a little	24 Useful Concept	19 Competing Definitions	23 Open to new
20 Used it and am interested	0 Important to Others	27 Mine Evolving	11 Will Adopt Others
6 Deeply Involved	15 Important to me	0 Well defined consensus	20 Comfortable with mine
10 Participated in Discussion	10 Vital to all	0 Universal Term	0 Committed to mine

In analyzing the survey respondents' evaluation of the characteristics offered, it was noted, somewhat to the surprise of the authors, that there were a significant number of respondents who were open to accepting intuition and willing to follow hunches as valid critical thinking processes. This had not been foreseen by either the officers or educators.

Some other early impressions were confirmed by the Likert data from the survey which appears below in Table 2.

Table 2. Likert Survey Responses (N=60)

Characteristics	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Critical Thinking different from Intelligence	31%	49%	17%	3%	0%
Critical Thinking is vital	74%	26%	0%	0%	0%
Should be factor in advancement	34%	40%	26%	0%	0%
No Emotionality	6%	46%	20%	14%	14%
Disciplined Analysis	49%	49%	3%	0%	0%
Willing to follow hunches	11%	40%	34%	14%	0%
Recursive Analysis	37%	51%	11%	0%	0%
Open to Novel Ideas	40%	43%	3%	14%	0%
Rejects Social Pressure	29%	54%	14%	0%	3%
Relies on Intuition	6%	40%	17%	29%	9%
Inclined to Quantify	31%	51%	11%	6%	0%
Avoids Disruption	11%	17%	26%	37%	9%
Considers Context	40%	34%	26%	0%	0%

Current Pedagogies

There are three recognized pedagogies that have shown promise in inculcating both metacognition and critical thinking. For want of a better set of terms, this paper will discuss these three as: Didactic, Socratic and Constructivist. These terms are commonly used, but just as commonly are disputed as to what they mean and how they should be used. However, for this paper to proceed, it is necessary to have an understanding about the terms that are to be employed here. For that reason, the following comments are offered, not to resolve the competing issues, but to define how the terms will be applied in this paper. In an artificially plain-language format, the Didactic method will be taken to mean that situation in which a "knowing entity" has information needed by an "unknowing group" and resolves that issue by telling the "unknowing group" the needed information. This approach is intuitive and is commonly available in the classroom and is often called the "lecture method" (Paul, *et al*., 2019). Socrates found this method fell short of creating the future ability for the student to learn and unduly make the student reliant on the teacher. His Socratic method was based on propounding a series of challenges to the "unknowing entity", thereby forcing them to learn the truth on their own. This allowed them to be better able to learn things they do not know now, but will need to know in the future. This approach has many benefits, but is difficult to use and is not facile in subjects such as teaching calculus, which is significantly more complex and abstract than is learning how to be a Greek citizen in 400 BC. The last method we shall address is Constructivism. That term will be used to identify the approach that has the "knowing entity" creating a series of tasks or challenges designed to cause the "unknowing

entity" to have to master the needed skills in order to achieve the identified goal. This method can be understood to use the goal-driven activities in a germane environment in the place of the incisive questions of the Socratic master (Ng'ambi & Johnston, 2006). All three methods have their strengths, weaknesses and hazards.

There are recognized approaches to using all three of the pedagogies mentioned above to inculcate both critical thinking and metacognition. The Didactic approach works by training the student to memorize and then invoke a set of rules. These rules are on the order of: establish the situation, identify the challenge, consider a solution, review supporting facts for this solution, consider opposing facts, implement the solution, test, evaluate, and repeat the cycle. There is some supporting evidence that this track is not only effective, it has been shown to be durable (Heijltjes *et al*., 2014). The Socratic Method naturally and profoundly establishes critical thinking and metacognitive skills to provide the student a defense against the incessant grilling by the Socratic mentor (Edwards, 2019). The adherents of the Constructivist approach would endeavor to attain the same result, suggesting that getting to the same place by putting the student into a situation more like that they would face outside of the walls of academe (Matthews, 1998). This result may be even more likely to find applicability in the high stress combat environment.

If these approaches are known, one may ask why they are not being implemented. There are hurdles that have to be overcome for them to work. These hurdles may be manifold, but they must be overcome. Without presuming to establish them in an exhaustive way, the following is intended to identify some major impediments to each of the three previously listed pedagogies. Taking them in the order mentioned above, one of the major weaknesses of the Didactic method is its focus on the Didacts themselves and the isolation of the students from the life that awaits them. A common complaint comes from iconoclastic educators like John Taylor Gatto. They have long held that any education system that is singularly centered on the students' satisfying their teachers will fail in imparting any sense of applicability of mastery of the subject (Gatto, 2002). This also may doom any sense of motivational immediacy in the students. The manifest failure of the Writing Across the Curriculum movement in the US is strong evidence that that teaching a skill detached from a real-life goal may not obtain after the school bell rings. The Socratic Method avoids many of those pitfalls, but every top Law School in the country will attest to the difficulty of finding effective Socratic professors. The other issue is the small class size required to adequately implement this method, especially difficult in the DoD, with its hectic operations schedules and geographic dispersions. Constructivism also speaks to some of these issues, but also has trouble with the need for hero teachers, small instructional cohorts, and creative instructional-environment creators. Staffing, scheduling, sustaining, and assessing any new approach will potentially be facilitated by the emerging technologies of the computational sciences, as discussed below.

Another approach that would also be enhanced by the implementation of virtual human teachers, tutors, and testers is the reawakened interest in the multidisciplinary and multipedagogy approach known at the Trivium and Quadrivium (Hepner, 2015). Based on the curricula of classical education, the Trivium consists of the liberal arts study of grammar, logic (or dialectic) and rhetoric followed by the more advanced study in the Quadrivium of arithmetic, geometry, astronomy and music (Littlejohn & Evans, 2006). The Trivium seems particularly well suited to enhancing both critical thinking and metacognition. The interest in this resurgence of a more classical approach to inculcating critical thinking was championed in the early 20th Century by Charlotte Mason and has a growing number of adherents (Anderson *et al*., 2004), especially in private schools. The Trivium/Quadrivium approach focuses on the students' development of a generalized metacognitive and disciplined approach to analysis in a real-world exploration paradigm. It includes a recognition of the benefits of the discipline of the memorization of classical literature segments and the appreciation of the fine arts, especially the benefits of the connection of the study of music with the mastery of the mathematical skills (Barroso *et al*., 2019). The implementation of the Trivium/Quadrivium multi-pedagogy requires the unique ability to switch rapidly from Didactic to Socratic, a capability that may be more effective if provided by computer agents than by many classroom instructors.

COMPUTER AGENTS AND VIRTUAL HUMANS

State of the Art

There is a large and growing capability in simulation, virtual humans, global communication, and computer agents. All of these are highly probable as detours around the hurdles and liberty from the constraints mentioned above. Before the paper examines how it would be appropriate to outline some of these technologies, both in terms of where they are and where they are going. The above survey of impediments to the more effective inculcation of critical thinking and metacognition seem to fall into three basic categories: lack of ability to provide individualized

germane and motivating educational learning environments, lack of availability of individual attention 24 x 7, and paucity of dynamic, charismatic mentors, tutors and instructors.

Current research is being driven by expanding technologies. A seemingly unfettered stampede of new technologies replace and make obsolete technologies that the public hardly had a chance to adopt (Christensen, 2013). There have been advances in the responsiveness of virtual humans, the two-way transmissions of data and images with reduced latencies, increased data transmission bandwidths, Natural Language Processing accuracy, Artificial Intelligence (A/I) usefulness and neural net training efficiency. On the hardware side, General Purpose Graphics Processing Units (GPGPU's) have provided computational headroom for increasingly human-like behavior.

There are applications of these technologies in everyday use in the civilian world. In many ways this has led the development of capabilities that the DoD can exploit in real-time. Anyone who has served in the military can tell of occasions in which the civilian world had better, more durable, cheaper and more useable products than the military. Establishing the need for implementing these capabilities to address the current DoD issues is the first step in future advances in national security. The technologies which are being addressed here are not just abstract visions for the future, *e.g*. NLP allows for the hands free oral-speech access to virtually any factoid in the world with latencies of just a few seconds. High resolution images and videos are available at any time via networking infrastructures.

Emerging Technologies

Many of the looming hurdles to advancing these new technologies seem to be beyond the reach of current technologies, both in hardware capabilities and software sophistication. (Yao *et al*., 2018). The advent of promising emerging technologies and approaches is worthy of consideration here. To have defense utility, training a "virtual human" should be orders of magnitude faster than that necessary to develop and field live human instructors. The major impediment here is the long neural net training times for so complex a set of behaviors. The amount of material to be input and then recursively looped through a training algorithm presents a daunting obstacle for sophisticated behaviors like graceful conversation initiation.

A new software approach to data analysis is Deep learning, which uses layers of computational units to learn data representations at multiple levels of abstraction. This may emerge as the leading methodology for developing NLP applications (Young *et al.*, 2018, Pouyanfar *et al.*, 2018). The reader not familiar with the terminology in this discipline may benefit from a short introduction into terms and methods. One of the basic concepts in this field is that of Convolutional Neural Network (CNN). Word vector representation or word embeddings learned using neural networks capture the meaning of words by embedding similar words closer to each other in vector space (Mikolov, 2013). Distance and relative direction of words can capture semantic meaning. The word for *queen* can be approximated using vector arithmetic: *queen = king – man + women*. These word embeddings form the basis for input to deep CNN networks for a variety of NLP applications, including topic classification and sentiment analysis. In question answering (QA) applications CNN's are used to select semantically similar answers from an existing knowledge base. CNN processes sequential data, such as sentences, by using windowing, but the window size is fixed at training time. Word context outside the window is ignored. Recurrent Neural Networks (RNNs) are designed to processes sequence data. RNN adds feedback loops into the neural network, which enables it to retain state information and process variable length of input sentences. A popular recurrent network is Long Short-Term Memory (LSTM), which introduced the notion of input, output and forget gates to regulate the flow of information (Hochreiter, 1997). This ability to remember long distance information enables LSTM to perform well in applications like natural language translation and in facilitating dialogue systems.

Digital computing has many physical limitations that have, as yet, not been overcome. One of the alternatives frequently offered is Quantum computing. It has been seen as an improvement to digital computing since the Nobel Laureate Richard Feynman published his seminal paper in 1982. In that paper he held that: "… with a suitable class of quantum machines you could imitate any quantum system, including the physical world." (Feynman, 1982). Quantum Computers do not use binary bits; they use qubits, which can represent multiple values simultaneously. This gives an almost unimaginable power in certain areas, but yields only probabilistic results. There is one operational design on the market: while not a general purpose quantum computer, this machine requires extremely cold temperatures (15 milliKelvin) to create a useable quantum effect (Lucas *et al*., 2013).

At the quantum computing center in Marina del Rey California there is a D-Wave open-system adiabatic quantum annealer that is capable of sampling from Boltzmann machine network with loops, specifically chimera graphs. Although the current machine has a limited number of qubits (~2,000) and intralayer connections (6), it has been

shown that the extra representational power afforded by these extra edges can decrease the training time and improve learning (Yao *et al.,* 2018). This advance should enable more realistic and "human" virtual computer agents, especially when the number of qubits and interconnection pathways increases. These advances are significantly interesting and have attracted inquiries for various agencies of the government, many of whom ask about size, which is indicated in Figure 4.

Figure 4. D-Wave size image

Widely used generative networks include auto-encoders, deep belief network (DBN), Deep Boltzmann Machines (DBM) and Generative Adversarial Networks (GAN) (Goodfellow *et al.,* 2014). GANs can generate photo realistic faces (Karras *et al.,* 2019), as well as novel paintings (Elgammal *et al.,* 2017,) and could also effectively enhance virtual humans. Please review the cited work for more detailed explication of these advances.

Extensibility

Experience has shown that, not only are there a range of military situations, technologies (Burmaogla & Saritas, 2017), and organizational hierarchies, but these are becoming more dynamic, more complex and more transitory (Kott & Perconti, 2018). In response to this unremitting flow of new technologies over the course of a career, it seems most important to focus analyses on successful approaches, more than specific platforms and units. The insights from a system, proffered to facilitate a Squad Leader's optimal control over a heterogeneous unit made up of human and non-human combat entities, may also illuminate how to best approach the control of an Unmanned Aerial Vehicle (UAV) pilot over a flight of Unmanned Aerial System (UAS) aircraft. Interoperability may not be universally feasible, but experience dictates a cautionary admonition not to become too insular, but remains open to other services' advances in the human/non-human interfaces (Gong *et al*., 2001).

Another dimension of extensibility is the dual-use interest held by DoD research organizations. Clearly the issues discussed in this paper would be immediately extensible into civilian first responder contexts, but that may only be the beginning, Providing a more human-like interface, critical in high stress situations, may have similar benefits in other important functions. One of these functions could be that of counseling, such as demonstrated in the SimCoach project (Rizzo *et al*., 2016), another may be that of assessment (Shaw *et al*., 2019) and yet another may be that of instructional environments, (Elstad & Davis, 2017). Additional implementations will no doubt occur to the reader. This paper asserts that it is incumbent upon the researchers to abstract, identify, define and communicate their insights and approaches in this field, avoiding the tendency to focus solely on the task before them.

Ongoing Research

One useful emerging, technology is that of Virtual Humans. As that term is used in this paper, a wide range of virtuality is accepted, including using computer-selected video clips of a live human. A VH is a creation in virtual reality portrayed by an avatar which attempts to recreate the appearance, voice, feel, and interaction that a live human would produce. Using the advances in several new technologies, including but not limited to natural language processing (NLP), virtual reality (VR), computer-generated imagery (CGI), machine learning, and virtual learning, live teachers can be presented. The uses, as well as the limits, of these tools are becoming evident. Researchers have developed programs that have been shown to be effective, *e.g.* SimCoach, New Dimensions in Testimony (NDT), PAL3, and others (ICT, 2019). These are generalized under learning sciences, medical VR, mixed reality, narrative, social stimulation, virtual humans, and vision and graphics. The field of knowledge available here is immense, and countless resources and expertise are now becoming available in this promising field. The user interface can take many forms, as noted in other papers (Davis *et al*. 2020).

Preliminary Results

The SimCoach saw really gratifying advances in an automated computer agent. The SimCoach kept veterans on the phone longer for therapeutic sessions than did live counselors. PTSD patients talked longer and about more sensitive topics. In New Dimensions in Testimony, the two-way conversation in a museum were so life-like that the museum patrons started treating the electronic image like a human, weeping at the survivors tales of the death camps and even apologizing to the "survivor," which was actually and obviously a recorded holographic image. Mentor Pal was a different, 2D approach and the students who were counseled by the virtual mentors gave the program very high marks for the computer agents' "conversationality."

Despite these successes, the question may be raised as whether this technology could be implemented to achieve the announced sophisticated goals of this paper. Most of the issues considered here have been analyzed and there is confidence that today's technology could easily be adapted to new uses such as training and counseling. Experience in such programs as PAL_3 AI has revealed no issues that might preclude implementation.

PARADIGM FOR INCULCATING METACOGNITION AND CRITICAL THINKING

Addressing Constraints

Naturally, there is always the unexpected, but considering the issues faced in other programs, the researchers can see no real issues in the way of extending the existing capabilities over into a critical thinking/metacognition trainer or mentor. Time, staffing and effort are needed, but there are no apparent constraints to a full implementation by any competent organization. This is not to ignore the challenges to be met. Whether using a video-clip approach or an animated avatar approach, the success cannot be guaranteed until the prototype is demonstrated.

One issue is the need for hero teachers to be models or actors to create the data-base of potential answers. Assessing and presenting on-screen "presence" has always been a gamble, but the tried and true methods of the entertainment industry can be applied these efforts. It has been learned that vivacious and attractive people in person-to-person meetings typically translate well into on-screen personalities. The investment in creating an entire corpus of an instructor's answers is not so large as to preclude not fielding an instructor who did not exude the requisite charisma.

One challenge is developing sensors and sensitive software that can detect a "teachable moment" with the facility with which experienced teachers can recognize such an opportunity. Creating a video record, appropriately annotated in a way that alerted the computer that this was a teachable moment, would be a lengthy and daunting task. If such data were to be found or created, A/I techniques could eventually isolate the meaningful characteristics.

The research team has found Table 1 useful in analyzing the best way to proceed. It rates the three pedagogical approaches versus the constraints outlined above. The Trivium/Quadrivium approach merges all three pedagogies.

Table 3. Pedagogy/Hurdle Matrix with emerging technology impacts

	Individualization	24 X 7 Access	Teacher Charisma
Didactic	Classroom Size of 1; self paced	Open class scheduling	1 hero teacher, but scalable to all
Socratic	Focus questions on 1; others not idled	Mentor available globally	Private forum for challenge
Constructivist	Different environment for each student	Pause button on situation	Different levels of coach's support

Selecting the Optimal Pedagogy

In selecting the best pedagogical approach, one of the issues to be addressed is the retention of the educational impact in the future by the subject. Would refreshers courses be necessary? How resilient would the behavior be in combat? Would these techniques be susceptible to subsequent peer pressures? Careful attention to metrics and input from professional pedagogists would be more than useful; it would be mandatory. This caveat is made with the concomitant assertion that many researchers have seen these issues before and have successfully met them. As mentioned before, one of the important metrics would be assuring the beneficial retention of and utilization of the critical thinking and metacognitive skills. To truly measure that metric, longitudinal studies would be required. One technique that has been used in the past is visiting the students some period of time after their training. This was done once under the thin artifice of just wanting to know if new issues had arisen in their environment for which it was thought his new training should now succeed. Then the research team members were pleased to observe that the students implemented effective critical thinking approaches in resolving their current issues.

Yet another problem may need to be addressed. The research team has witnessed, both during research and on active duty, that there is a tendency to resist any required program that interferes with either "down time" or the "real job." That has been known to dramatically reduce the commitment to utilization of the training objectives. This result is similar to the high-school students' not uncommon view of education as having no real meaningful impact on them, merely being a way that the system beleaguers them for no apparent reason and leading to their often observed goal of finishing the required courses with as little effort and as little impact on their day-to-day lives as possible. The

technologies and approaches described above may allow recursive evaluation of the ability to "tailor" programs to meet each student's individual motivation foci. A/I programs are envisioned that can monitor and enhance response to individual sensitivities throughout the service members' career, driven by performance evaluation insights.

Metrics

A major issue in this area is the lack of metrics. Without metrics, it is difficult, if not impossible, to recognize whether innovative steps are having any impact. This is an extension of the lack of consensus as to what critical thinking means. There are organizations that specialize in creating standards and psychometricians can develop tools, once they are given a set of parameters on which to evaluate their instruments. A concerted effort is required to pierce the interdisciplinary barriers still found in the military and on the campuses. Some of the emerging technologies discussed below may enable analyses that will facilitate this process.

Implementing a Practicable Methodology

Experience has shown that this approach would require a significant amount of planning and forethought. The magnitude and difficulty of the design effort would depend on what was held out by the DoD program manager as required capabilities. Then there would need to be a significant Validation, Verification and Test effort. The technologies cited above are workable today and the emerging technologies may make significant enhancements in both the "humanness" of the computer agents and the efficacy of the implemented pedagogical approaches.

DISCUSSION

Benefits of Approach

There is a real and unmet need for critical thinking training and metacognition skills. Many of the remedial programs used in society today have devolved into bureaucratic burdens, where all too often the only metric of success is class attendance. As has been suggested above, emerging technologies may better address all of these issues and in a scalable way. The DoD environment imposes a most challenging training situation with its unpredictable operations schedule, 24-hour duty cycle and globally dispersed personnel. The global network and the computer agents' scalability, individualization, pedagogy adherence, and efficacy may well prove enabling. The path forward holds the promise of an entirely new paradigm for leveraging the best, most compelling and diverse set of instruction to prepare the warfighter by maximizing their use of intelligence, in both of the senses of that word.

The emerging capabilities can be foreseen today as enablers of an even more powerful set of A/I programs to deliver a sagacious, sensitive and personable mentor, tutor and instructor 24 by 7, anywhere there is network connectivity. The data adduced above indicates that such a capability has the real potential to improve battlefield performance, reduce combat losses, regularize policy instruction and individualize training, mentoring and education. The technical feasibility of these programs has been shown already, but two issues need to be resolved before they can optimally be implemented: an acceptance by the command structures that such a program has value and the implementation of the emerging capabilities of quantum computing, deep learning, A/I programs, NLP interfaces, and high-production value videotaping of charismatic and engaging virtual conversation computer agents.

All of these will require a new willingness to make individual advances available to all communities in the defense realm and a new commitment to breaking down the walls of the "silos" to foster more cross-disciplinary research. All of these can combine to finally shed the oft cited aphorism that the warfighters' commanders are always fighting the last war. As shown above, the technology is there; all must avail themselves of it. Many members of the I/ITSEC community can no doubt see where these approaches might become applicable in their own disciplines.

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